Rotating plane Couette flow: some aspects of its stability and flow structures

P. Henrik Alfredsson*, Takuya Kawata, Alexandre Suryadi

Linné FLOW Centre, KTH Mechanics, Royal Institute of Technology, S-100 44 Stockholm, SWEDEN

Plane Couette flow exists between two planes moving in opposite directions, each with a speed U_w and separated by a distance of $2h$, as shown in Fig. 1a. At the laminar state, a linear shear flow is found between these planes with $u(y) = U_w y/h$ with y as the direction normal to the moving surfaces. The other two directions x and z are the streamwise and spanwise directions, respectively. Without rotation the flow described is linearly stable for all Reynolds numbers ($Re = U_w h/\nu$, ν is the kinematic viscosity) however, in experiments transition to turbulence starts around $Re \approx 350$ [1].

On the other hand does plane Couette flow with system rotation $\mathbf{\Omega} = \Omega_z \hat{e}_z$ (rotating plane Couette flow, RPCF), shows linear instability for anticyclonic rotation with the marginal stability limit

$$Re_c = \Omega + 107\Omega^{-1} \quad (1)$$

where $\Omega = 2\Omega_z h^2/\nu$ is the non-dimensional rotation number. For flow parameters close to, but above the stability line, straight Taylor vortices are observed, see Fig. 1b. For other parameters this flow can reach a number of different instabilities as shown in Ref. [2].

In both pressure-driven turbulent channel flow and plane Couette flow undergoing spanwise system rotation, it has been observed that the absolute vorticity, i.e. the sum of the averaged spanwise flow vorticity and system rotation, tends to zero in the central region of the channel [3, 4] (in RPCF for anti-cyclonic rotation). This observation has so far eluded a convincing theoretical explanation, despite experimental and numerical evidence reported in the literature.

It was recently shown experimentally [5, 6] that the three-dimensional laminar structures observed in RPCF also makes the absolute vorticity tend to zero if the (anti-cyclonic) rotation rate is high enough. Hence the absolute vorticity near zero is not limited to fully-developed turbulent shear flows, but may also occur for laminar flows with three-dimensional flow structures. This means that this effect is a more general feature than previously suggested and is not due to turbulence *per se* but that for laminar flows the three-dimensional structures instead play a similar role in the momentum transfer associated with the distribution of the streamwise velocity across the central part of the channel. We discuss these results in the light of new measurements of the flow field using PIV and also show that zero absolute vorticity is consistent with a Richardson number equal to zero corresponding to a stable stratification of the rotation induced body (Coriolis) force.

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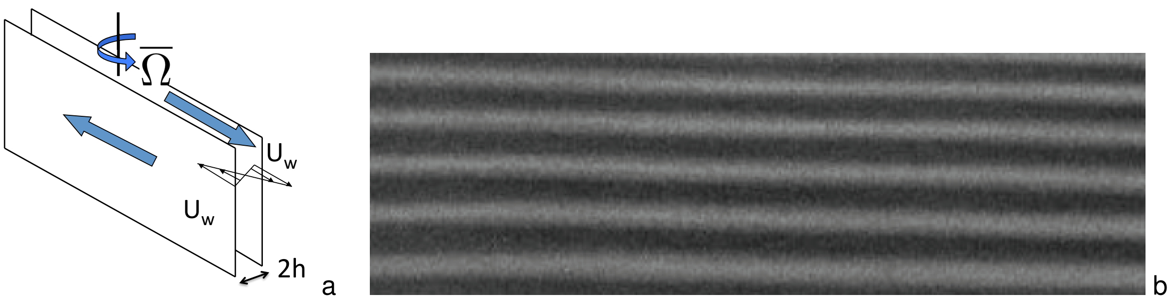

Fig. 1: a) Schematic of RPCF, b) flow visualisation of Taylor cells at $Re = 50, \Omega = 2.6$

References

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*corresponding author: hal@mech.kth.se