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# The effect of streamwise rotation on plane Couette flow

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Previously, we have studied the effect of spanwise system rotation on turbulent heat and momentum transfer in plane Couette flow using DNS[1]. We showed that spanwise rotation can break the Reynolds analogy, and that the heat transfer can be much faster than momentum transfer when the rotation is anti-cyclonic[2].

We now study the effect of **streamwise** system rotation on plane Couette flow (PCF). As a first step, we study the stability of streamwise rotating PCF using linear stability analysis and DNS[3]. We also perform a stability analysis of streamwise rotating plane Poiseuille flow (PPF) for comparison. The linear stability analysis, considering three-dimensional perturbations, reveals in both flow cases a low-$Ro$ and a high-$Ro$ asymptotic regime, where $Ro$ is the non-dimensional rotation rate. In the low-$Ro$ regime, the critical Reynolds $Re_c \propto Ro$, the critical streamwise wavenumber $\alpha_c \propto Ro$ and spanwise wavenumber $\beta_c$ is constant. In the high-$Ro$ regime, when $Ro \to \infty$, $Re_c = 66.45$ and $\beta_c = 2.459$ in streamwise rotating PPF, and $Re_c = 20.66$ and $\beta_c = 1.558$ in streamwise rotating PCF, and $\alpha_c \propto 1/Ro$. The results for streamwise rotating PPF agree with a previous linear stability analysis of the same case[4]. The critical vortices are most oblique to the streamwise direction when $Ro = O(1)$ and increasingly align with the streamwise direction when $Ro \to 0$ and $Ro \to \infty$. Interestingly, $\beta_c$ and $Re_c$ at $Ro \to \infty$ in **streamwise** rotating PPF and PCF are the same as $\beta_c$ and the minimum $Re_c$ in **spanwise** rotating PPF at $Ro = 0.3366$ and PCF at $Ro = 0.5$ reported previously.

To study the flow field near $Re_c$ and to determine whether a subcritical transition can occur, we perform DNS in a range of $Ro$ and $Re$. At low $Ro$ subcritical transition can occur and a transitional regime with large-scale turbulent patterns can emerge in streamwise rotating PPF when $Ro \lesssim 0.034$ and $Re \gtrsim 1000$, and in streamwise rotating PCF when $Ro \lesssim 0.05$ and $Re \gtrsim 340$. At higher $Ro$ no subcritical transition is observed and the flow relaminarizes once $Re < Re_c$. Figure 1 summarizes the observed flow regimes in streamwise rotating PCF. We also find that in a small $Ro$ range, turbulent-laminar patterns can develop under supercritical conditions when $Re > Re_c$. The patterns can then form in the DNS of streamwise rotating PPF and PCF after a linear instability starting from laminar flow with small noise (figure 1).

We are now carrying out DNS of streamwise rotating turbulent PCF with heat transfer in extended domains at $Re = 1500$ and 4000 at low to high $Ro$. We observe very clear oblique large-scale structures that can be up to $5\pi\delta$ wide and a strong secondary flow with a maximum mean spanwise velocity up to $W = 0.18U_w$ at $Ro = O(1)$. Here, $\delta$ is the channel half gap-width and $U_w$ the velocity of the moving walls. At higher $Ro$ the structures become less oblique and the secondary flow becomes weaker.

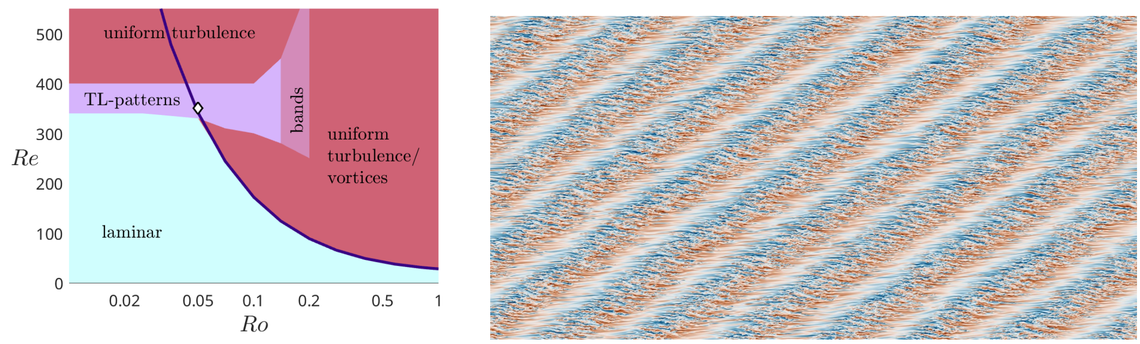


Figure 1: Flow regimes as a function of $Ro$ and $Re$ (left plot) and visualization of the streamwise velocity field in the centre plane at $Ro = 0.1$ and $Re = 350$ (right plot) in streamwise rotating PCF.

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[1] Brethouwer, *J. Fluid Mech* **912**, A31 (2021)
[2] Brethouwer, *Int. J. Heat Mass Transfer* **205**, 123920 (2023)
[3] Brethouwer, *Submitted to J. Fluid Mech.*, (2025)
[4] Masuda et al., *J. Fluid Mech.* **603**, 189–206 (2008)