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Optimal Taylor-Couette Turbulence

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Strongly turbulent Taylor-Couette flow with independently rotating inner and outer cylinders with a radius ratio of $\eta = 0.716$ is experimentally studied. From global torque measurements, we analyse the dimensionless angular velocity flux $Nu_\omega(Ta, a)$ as a function of the Taylor number Ta and the angular velocity ratio $a = -\omega_o/\omega_i$ in the large-Taylor-number regime $10^{11} \lesssim Ta \lesssim 10^{13}$ and well off the inviscid stability borders (Rayleigh lines) $a = -\eta^2$ for co-rotation and $a = \infty$ for counter-rotation. We analyse the data with the common power-law ansatz for the dimensionless angular velocity transport flux $Nu_\omega(Ta, a) = f(a)Ta^\gamma$, with an amplitude $f(a)$ and an exponent γ. The data are consistent with one effective exponent $\gamma = 0.39 \pm 0.03$ for all a, but we discuss a possible a dependence in the co- and weakly counter-rotating regimes. The amplitude of the angular velocity flux $f(a) \equiv Nu_\omega(Ta, a)/Ta^{0.39}$ is measured to be maximal at slight counter-rotation, namely at an angular velocity ratio of $a_{opt} = 0.33 \pm 0.04$, i.e. along the line $\omega_o = -0.33\omega_i$. This value is theoretically interpreted as the result of a competition between the destabilizing inner cylinder rotation and the stabilizing but shear-enhancing outer cylinder counter-rotation. With the help of laser Doppler anemometry, we provide angular velocity profiles and in particular identify the radial position r_n of the neutral line, defined by $\langle\omega(r_n)\rangle_t = 0$ for fixed height z. For these large Ta values the ratio $a \approx 0.40$, which is close to $a_{opt} = 0.33$, is distinguished by a zero angular velocity gradient $\partial\omega/\partial r = 0$ in the bulk. While for moderate counter-rotation $-0.40\omega_i \lesssim \omega_o < 0$, the neutral line still remains close to the outer cylinder and the probability distribution function of the bulk angular velocity is observed to be monomodal. For stronger counter-rotation the neutral line is pushed inwards towards the inner cylinder; in this regime the probability distribution function of the bulk angular velocity becomes bimodal, reflecting intermittent bursts of turbulent structures beyond the neutral line into the outer flow domain, which otherwise is stabilized by the counter-rotating outer cylinder. Finally, a hypothesis is offered allowing a unifying view and consistent interpretation for all these various results.