Sidewall-induced secondary currents and coherent structures over mobile sediment beds

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Turbulent secondary currents arise in a variety of geophysical flows, with spanwise wavelengths ranging from a few decimetres in small rivers to several kilometres in the atmospheric boundary layer[1]. In hydraulic flows such as rivers or canals, secondary flows are triggered not only by lateral variations of the bottom roughness and topography, but are also driven by the presence of lateral riverbanks or canal sidewalls. In this talk, we study sidewall-induced turbulent secondary currents in open duct flows at low aspect ratio, with an emphasis on their relation to instantaneous coherent structures and relevance for sediment transport. With the aid of an immersed boundary technique[2], a series of particle-resolved direct numerical simulations of turbulent open duct flow over (i) smooth bottom walls, (ii) stationary and (iii) fully-mobile sediment beds at friction Reynolds numbers $Re_\tau \in [200, 500]$ has been performed. The secondary flow pattern over the immobile, hydraulically smooth sediment bed is seen to be more or less unchanged compared to its smooth wall counterpart, so that the relative global mean secondary flow intensity is only weakly affected (cf. figure 1). When sediment grains can be eroded by the turbulent flow, however, streamwise-aligned sediment ridges and troughs evolve along the bed and the turbulent secondary flow activity is seen to increase. The observed secondary flow intensification is arguably a consequence of the increased bottom friction due to the sediment motion: It will be shown that sediment erosion is accompanied by a reorganisation of small-scale quasi-streamwise vortices, which causes a modification of the mean streamwise vorticity field[3]. On the other hand, we analyse how the sediment bed affects the organisation of coherent vortex clusters[4], providing some evidence that the large-scale mean secondary vortices represent their statistical footprint.

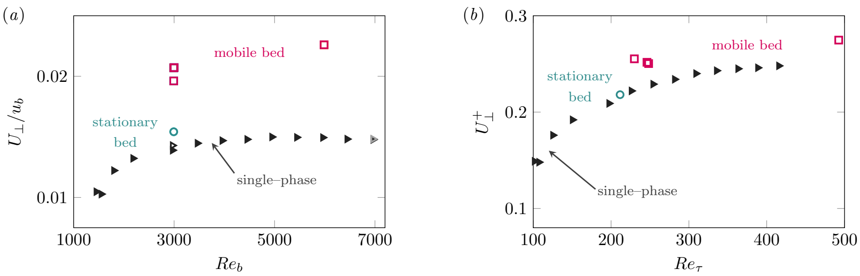

Figure 1: Mean secondary flow intensity $U_\perp \equiv \langle \langle v_f \rangle_{xt}^2 + \langle w_f \rangle_{xt}^2 \rangle_A^{1/2}$ of the streamwise- and time-averaged secondary flow field over smooth walls, stationary and mobile sediment beds, scaled in terms of (a) the bulk velocity u_b and (b) the friction velocity u_τ, respectively. Time averaging intervals are $\mathcal{O}(10^3)$, $\mathcal{O}(10^2)$ and $\mathcal{O}(10)$ bulk time units, respectively. $\langle \bullet \rangle_A$ denotes the cross-sectional averaging operator.

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