Interaction between capillary waves and hydrodynamic turbulence in a two-layer oil-water flow

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We use pseudo-spectral Direct Numerical Simulation (DNS), coupled with a Phase Field Method (PFM), to investigate the turbulent Poiseuille flow of two immiscible liquid layers inside a channel. The two liquid layers, which have the same thickness ($h_1 = h_2 = h$), are characterized by the same density ($\rho_1 = \rho_2 = \rho$) but different viscosities ($\eta_1 \neq \eta_2$), so mimicking a stratified oil-water flow. This setting allows for the interplay between inertial, viscous and surface tension forces to be studied in the absence of gravity. We focus on the role of turbulence in initially deforming the interface and on the subsequent growth of capillary waves. Capillary wave propagation and interaction is studied by means of a spatiotemporal spectral analysis and compared with previous theoretical and experimental results. Wave propagation is found in agreement with the theoretical dispersion relation. At wave scales larger than the turbulent forcing range the observed scaling of the one-dimensional wavenumber spectrum suggests an energy equipartition regime, which is predicted by theory and recently has been observed in experiments with capillary wave turbulence in microgravity. At wave scales directly forced by hydrodynamic turbulence an initially mild slope of the wavenumber spectrum is succeeded by a sharp decay of wave energy at larger wavenumbers, with the transition taking place near the Kolmogorov-Hinze critical scale, where surface tension forces and turbulent inertial forces are balanced.

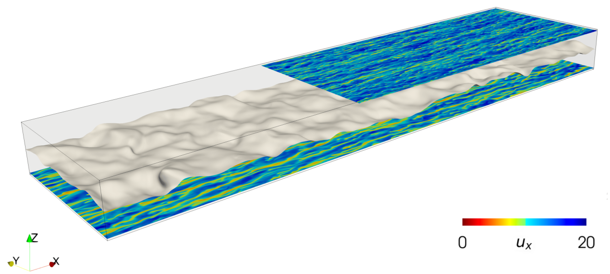

Figure 1: Channel geometry and flow topology of a two-layer turbulent flow simulation. Capillary wave formation can be seen at the interface between the two layers. The fluid in the upper half of the channel has a viscosity that is 50% lower than that of the fluid in the lower half of the channel. This fact is responsible for the difference between top and bottom near-wall turbulence structure, here made visible using the value of the streamwise component of the velocity vector (u_x).

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