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Mechanism of Vorticity Generation in Free-Propagating Surface Waves

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Langmuir circulations, which induce elongated streaks on natural water surfaces, are formed from the interaction between the Lagrangian drift of the surface waves and the mean shear current driven by the wind. The nonlinear interaction mechanism is described by the wave-averaged Craik- Leibovich equation. Yet, elongated surface streaks were also observed on free-propagating (non-breaking) surface waves in the recent laboratory experiments and numerical simulations. It has been a prevalent notion that the flow beneath such waves is essentially irrotational; since there is no wind to impose shear stress on the water surface. But the role of viscosity in producing a second-order Eulerian drift currents in the presence of surface waves has been recognized theoretically by Longuet-Higgins in early 50 even as the characteristic Reynolds number approaches infinity. This was also confirmed recently in numerical simulation of free-propagating surface waves by solving the Navier-Stokes equation subject to the fully nonlinear boundary conditions. It is therefore plausible to reason that the elongated streaks on free-propagating surface waves are also induced by arrays of counter-rotating vortices arising from the same mechanism that forms Langmuir circulations. To confirm this proposition, linear instability analysis of the perturbed Craik-Leibovich equation is conducted. Representing the perturbation by normal-mode expansion and discretizing the differential equation using collocation method result in a linear eigensystem governing the eigenmode of the disturbance. The spanwise wavelength of the least stable disturbance mode is found to be close to the spacing between predominant counter-rotating vortex pairs (an equivalence of streak spacing) observed in the laboratory experiments and numerical simulations, thus confirms the streamwise vortices underneath free-propagating surface waves are excited by Craik-Leibovich instability.
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