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Stability of a shear flow with a free surface

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Stability of shear flows with an upper free surface has important applications in geophysics. Such flows arise at the crest of a spilling breaker, in viscous ship wakes and in wind-drift currents at the ocean surface breaking into turbulent mixing layers. Previous studies of surface shearing currents considered a surface layer of uniform vorticity overlying a stationary layer of infinite depth and showed that the flow is unstable for a limited range of zonal wavenumbers. The goal of this study is to gain further insight into the modal and non-modal perturbation growth mechanisms. We first approximate the mean flow with a piecewise linear profile and rationalize the modal instabilities in terms of the interaction between vorticity and gravity edge waves supported at the interfaces of vorticity and density discontinuities. The two branches of instability are identified and their physical origin is clarified. We then address the non-modal interaction of the edge waves, as well as assess the role of continuous spectrum in perturbation growth. The edge waves lead to a modest transient growth that extends into the regions of neutrality of the flow. However when the continuous spectrum is excited, substantial transient growth can arise. The optimal perturbations attain greater energy when compared with the energy of the fastest modal growing perturbation. These optimal perturbations utilize the continuous spectrum to excite at large amplitude the neutral or the exponentially amplifying modes of the system.