The instability of a membrane enclosed by two viscous fluids with a free surface

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Abstract

This study examines the stability of a flexible material interface between two fluids of the same viscosity in interaction with a free surface. When the layers are motionless, we provide evidence for the onset of a novel instability by means of analytical and numerical solution of the associated boundary value problem in the region stable against Rayleigh–Taylor instability, i.e. when the acceleration due to gravity acts from the lighter to the heavier fluid. This destabilisation phenomenon is attributed to the non-conservative tangential forces acting at the interface and the fluid-structure interaction. Furthermore, we examine the scenario in which an external forcing mechanism induces a monotonic parallel shear flow within the upper layer. In addition to the long-established inflectional instability predicted in the inviscid limit, we demonstrate the existence of membrane flutter in the absence of density stratification. The latter is either due to an over-reflection process of surface gravity waves or to the growth of Tollmien–Schlichting waves, as outlined in the context of boundary-layer theory. This fluid-structure configuration represents a paradigmatic model for investigating the interplay between inflectional, radiation-induced and shear-induced instabilities. It also serves as a viscous counterpart to the classical Kelvin–Helmholtz instability when layers with distinct densities are assumed.

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