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Suppression of Rayleigh–Taylor instability using electric fields

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Abstract

This study considers the stability of two stratified immiscible incompressible fluids in a horizontal channel of infinite extent. Of particular interest is the case with the heavier fluid initially lying above the lighter fluid, so that the system is susceptible to the classical Rayleigh–Taylor instability. An electric field acting in the horizontal direction is imposed on the system and it is shown that it can act to completely suppress Rayleigh–Taylor instabilities and produces a dispersive regularization in the model. Dispersion relations are derived and a class of nonlinear traveling waves (periodic and solitary) is computed. Numerical solutions of the initial value problem of the system of model evolution equations that demonstrate a stabilization of Rayleigh–Taylor instability due to the electric field are presented.

Keywords: Rayleigh–Taylor instability; Electric fields; Traveling waves; Solitary waves

1. Introduction

Electric fields acting parallel to an interface separating two immiscible fluids of different material properties, have been shown to induce a dispersive effect (Melcher and Schwarz [8], Tilley et al. [10], Papageorgiou and Vanden-Broeck [9]). Such effects on Rayleigh–Taylor (R–T) instabilities have not been studied systematically. Further more in inviscid R–T flows, a finite-time singularity is encountered (Baker et al. [1]) and the effect of electric field regularization is an interesting physical mechanism that can affect such phenomena. In the related problem of liquid sheet rupture, it has been shown by Tilley et al. [10] that rupture singularities can be delayed or completely suppressed by sufficiently strong electric fields. Such a paradigm is investigated here for the R–T problem. In the case of background shear, Kelvin–Helmholtz (K–H) instabilities are present and produce larger short-wave growth rates as compared to R–T instability. The effect of horizontal electric fields on K–H flows has been considered by Grandison et al. [5,6], who studied nonlinear model equations as well as numerical traveling wave solutions of the two-dimensional Euler equations, when the field is strong enough so as to provide a stabilization in conjunction with surface tension. Fields which act perpendicularly to the undisturbed interface, on the other hand, are unstable at least for the regimes of perfect conductors or perfect dielectric fluids. For example, a vertical field can destabilize a (stably stratified) viscous fluid layer wetting the top surface of a horizontal substrate, and cause asymptotic thinning of the layer – Tseluiko and Papageorgiou [13]

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