Chapter 10
Computation of the lobe-and-cleft instability

C. Haertel

ETH, Institute of Fluid Dynamics, CH-8092 Zuerich, Switzerland

M. Thunblom, F. Carlsson

Department of Thermo- and Fluid Dynamics, Chalmers University of Technology, SE-41296 Gothenburg, Sweden

Abstract Results are discussed from a research project in which high-resolution simulations along with linear-stability analysis are employed to study fundamental aspects of the frontal instability that is typically observed at the leading edge of density-driven and particle-driven gravity currents spreading along solid boundaries. In the analysis, the prototype situation of a mutual exchange flow in a plane channel ("lock-exchange flow") is considered where the fronts travel at essentially constant speed. This allows for a steady-steady analysis in a moving frame of reference. To disclose the origin of the leading-edge instability, the response of two-dimensional gravity currents to small three-dimensional disturbances is studied. The respective stability equations are discretized using high-order compact finite differences, resulting in an algebraic eigenvalue problem that is solved in an iterative fashion. It is demonstrated that the frontal breakdown is caused by an unstable stratification of the flow at the leading edge.

10.1 Introduction

Gravity currents of heavy fluid which propagate in an environment of lighter fluid are encountered in numerous geophysical applications, well-known examples being sea-breeze fronts, thunderstorm outflows, or muddy underflows in lakes or oceans [1]. However, their study is also of interest in the engineering sciences because of their relevance in many problems related to industrial safety and environmental protection [1, 2]. For example, gravity currents often form after the accidental release of dense industrial gases which, under the influence of gravity, may spread over relatively large distances.

Among the most intriguing features of gravity currents propagating along solid boundaries is the intense three-dimensional (3D) motion at the leading edge that accounts for a substantial portion of the entrainment of ambient fluid into the gravity-current head [3, 4]. The flow in this region is composed