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Analysis of coupling between hydrodynamic and thermal instabilities in non-Boussinesq convection

Sergey A. Suslov

Department of Mathematics and Computing
University of Southern Queensland
Toowoomba, Queensland 4350, Australia
E-mail: ssuslov@usq.edu.au

Abstract

High temperature convection flows arise in many technical applications such as thermal insulation systems, chemical vapour deposition reactors etc. Under the high temperature conditions the fluid property (density, viscosity, thermal conductivity) variations can reach up to 50% of the average values across the flow region. The associated symmetry breaking nonlinearities are responsible for a wide spectrum of flow instabilities not found in low temperature flows typically described by the Boussinesq approximation of the Navier-Stokes equations. In this work we use the set of Low-Mach number equations suggested by Paolucci in early 1980's to describe a high-temperature mixed convection flow between two vertical plates. We find that the non-Boussinesq instabilities have either hydrodynamic (shear, common to both low- and high- temperature flows) or thermal (buoyancy, purely non-Boussinesq) character and they can occur simultaneously at certain values of the governing physical parameters (the so-called codimension-2 points). We show by means of weakly nonlinear analysis that such situations can be successfully modelled by two coupled cubic complex Landau-type equations. Subsequently the unfoldings of the double Hopf bifurcations detected in non-Boussinesq mixed convection are investigated and the complete set of resulting flow patterns is studied as functions of governing parameters. Finally we interpret the results obtained for the model dynamical system from the physical point of view and discuss the nature and asymptotic outcomes of instability mode competition at large times.