Magnetic field effects on stability of convective flows

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Two model problems are considered to study the effect of an externally imposed magnetic field on buoyancy convective flows in rectangular or cylindrical cavities. The first problem is an extension of the benchmark [1], which we extend by adding the action of an external arbitrary directed magnetic field. Convection of a low-Prandtl-number fluid in a laterally heated two-dimensional horizontal cavity is studied. Fixed values of the aspect ratio (length/height=4) and Prandtl number (Pr = 0.015), which are associated with the horizontal Bridgman crystal growth process and are commonly used for benchmarking purposes, are considered. The effect of a uniform magnetic field with different magnitudes and orientations on the stability of the two distinct branches (with a single-cell or a two-cell pattern) of the steady state flows is investigated. Stability diagrams showing the dependence of the critical Grashof number on the Hartmann number are presented. It is shown that a vertical magnetic field provides the strongest stabilization effect, and also that multiplicity of steady states is suppressed by the electromagnetic effect, so that at a certain field level only the single-cell flows remain stable. Analysis of the most unstable flow perturbations shows that starting with a certain value of the Hartmann number, single-cell flows are destabilized inside thin Hartmann boundary layers. This can lead to destabilization of the flow with increase of the field magnitude, as is seen from the stability diagrams obtained. Contrary to the expected monotonicity of the stabilization process with increase of the field strength, the marginal stability curves show non-monotonic behavior and may contain hysteresis loops.

The second problem is a continuation of the study of three-dimensional instability of convection in a cylinder heated non-uniformly from its sidewall [2], which we extend by an addition of the electromagnetic force caused by an axial magnetic field. Convection in a vertical cylinder with a parabolic temperature profile on the sidewall is considered as a representative model. A parametric study of the dependence of the critical Grashof number Gr_{cr} on the Hartmann number Ha for fixed values of the Prandtl number (Pr = 0.015) and the aspect ratio of the cylinder (A = height/radius = 1, 2 and 3) is carried out. The stability diagram $Gr_{cr}(Ha)$ corresponding to the axisymmetric – three-dimensional transition for increasing values of the axial magnetic field is obtained. It is shown that at relatively small values of the Hartmann number the axisymmetric flow tends to be oscillatory unstable. After the magnitude of the magnetic field (the Hartmann number) exceeds a certain value the instability switches to a steady bifurcation caused by the Rayleigh-Bénard mechanism. More details on both problems considered can be found in [3,4].

References

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