Magnetic Field Effects on Three Dimensional Stability of Natural Convection Flows in Differentially Heated Cavities

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ABSTRACT

The parametric study of two dimensional free convection flow in a square cavity, in the presence of a uniform internal heat source and a horizontal magnetic field, is extended in order to cover three dimensional disturbances. Mass continuity and the momentum, energy and electric charge conservation equations are solved for. We solve the generalized eigenvalue problem that arises from the finite element methodology, via the Arnoldi method. The calculation of the most unstable eigenvalues is afforded via a Cayley tranform [1] that selects the relevant region of the spectrum. In order to optimize in terms of storage and CPU time requirements the ScaLAPACK library is employed. MPI parallel techniques are underway in order to investigate the effect of large Ha number on the dynamics of the problem. The GMRES method is applied and the Stokes operator is used as a preconditioner in order to construct neutral stability diagrams.

First, the Rayleigh-Benard case is examined with the temperature gradient aligned with gravity, in the absence of volumetric heating in order to compare with available experimental observations [2]. Parametric analysis is conducted by setting the aspect ratio of the cavity to 1/20 and varying the magnetic field intensity. As Ha increases 3d instabilities dominate in the sense that they are characterized by a smaller Gr_{Cr}. The eigenvector is progressively characterized by a core region of quasi 2d flow while temperature variations are gradually confined near the side layers. When Ha=200 the above methodology provides a much better prediction of the experimental value for the onset of steady convection than stability analysis based on the quasi 2d flow assumption [2].

Parametric analysis is also conducted by varying the volumetric rate of heat production in the cavity, while maintaining the temperature gradient perpendicular to gravity. In this context, the base flow configuration consists of two recirculation rolls arising due to internal heating. In all cases examined, pertaining to low Pr and relatively high volumetric flow rate, the travelling wave mode dominates followed by a standing wave mode. Both modes are not associated with the modes dominating the two dimensional dynamics of the cavity and appear as a result of a centrifugal instability due to curvature of the stream lines in the base flow configuration [3]. Three dimensional disturbances are less stable than two dimensional ones, while increasing the Ha number increases Gr_{Cr} as well.

The latter instability is probably associated with the onset of transient convection reported in [2], that destabilizes the quasi 2d arrangement of standing vortices emerging as a result of the primary thermal instability. The above dynamical pattern, along with direct numerical simulations, may be combined with mock-up experiments [4] in order to simulate free convection of liquid lithium flow in Helium Cooled Lithium Lead (HCLL) blankets [5] in the context of future fusion applications.

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