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Evolution to chaotic mixed convection in a multiple ventilated cavity

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ABSTRACT

The characteristics of transition from laminar to chaotic mixed convection in a two-dimensional multiple ventilated cavity is analyzed in this paper. The horizontal air streams enter the cavity from the two inflow-openings near the top of both vertical walls, while the outflow openings are near the bottoms of both vertical walls. The results obtained for a range of the Richardson number, Ri, from 0.01 to 5 at Pr = 0.71, the Reynolds number, Re, from 1000 to 2500 and the inlet flow angle, φ, based on 0°, 20°, 45° and 70°. The results show that, as Ri increases, the solution may exhibit a change from steady-state to periodic oscillation, and then to non-periodic oscillatory state. However, the flow inside the cavity becomes steady-state again as Richardson number increases further. The results also show that the effect of inlet flow angle on the oscillations of mixed convection is evident, the configuration with $\varphi = 0°$ is the most unstable among the four values of φ. The non-periodic oscillatory solution at Re = 2500 is studied by means of phase portraits, correlation dimension, Kolmogorov entropy and Lyapunov exponents to detect chaos. The phase portraits show the evolution of the attractor from a stable fixed point to a limited cycle to chaos, and finally, to a stable fixed point again, and the correlation dimension, Kolmogorov entropy and the largest Lyapunov numbers all show that the behavior of mixed convection in this dynamical system lies on a low-dimensional chaotic attractor according to the non-periodic oscillatory solution.

1. Introduction

The instability of mixed convection in an enclosure has attracted wide attentions in the past decades, and a very large amount of research works have been performed for various geometries. Examples of such flows and transport phenomena can be found in cooling of electronic systems, space station cabin, modern building, clean room of hospital, and so on. Hence detailed investigations are necessary to ensure efficient design and minimizing power requirement for such ventilated systems.

A partial review of the relevant works about the flow instability of mixed convection may be found in Wang and Yang [1], Su and Chung [2], Wang and Jaluria [3]. Many researchers investigated the instability of natural convection in enclosure using numerical method. Paolucci and Chenoweth [4] numerically studied the transition from laminar to chaotic flow in a differentially heated vertical cavity. They obtained the critical Rayleigh number as a function of aspect ratio and developed expressions relating the fundamental frequencies of the oscillatory flow to the Rayleigh number and aspect ratio. Ha et al. [5] presented a two-dimensional solution for unsteady-state natural convection in an enclosure with an adiabatic square body (located at the center between the bottom hot and top cold walls) using an accurate and efficient Chevyshev spectral collocation method. Erenburg et al. [6] numerically studied the multiplicity, stability and bifurcations of low-Prandtl-number (Pr = 0.021) steady natural convection in a two-dimensional rectangular cavity with partially and symmetrically heated vertical walls, and the observed phenomena also occurred at larger Prandtl numbers, which was illustrated for Pr = 10.

Gelfgat [7] studied the oscillatory regime of nature convection of air in a 8:1 two-dimensional rectangular cavity with global Galerkin method. Similar work was also presented by Benouaguef et al. [8] who studied natural convection in a cavity with adiabatic horizontal walls and the vertical walls composed of two regions of the same size maintained at different temperatures: the upper half temperature is less than the lower half temperature.

The stability and bifurcations of mixed convection have attracted increasing interests over the last decade. Various researchers investigated the instabilities of mixed convection in open enclosures using experimental and numerical method. Rowley et al. [9] numerically investigated the resonant instabilities and oscillations in two dimensional compressible flow past an open cavity using

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