UNSTEADY NATURAL CONVECTION IN A DIFFERENTIALLY HEATED PARTITIONED CAVITY

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Summary Unsteady natural convection in a differentially heated partitioned cavity is numerically investigated. Results show that the transition of the natural convection flow in the cavity from an initially motionless state undergoes three main stages: an initial stage (including the formation of vertical thermal boundary layers and horizontal intrusions), a transitional stage and a quasi-steady periodic stage.

INTRODUCTION

Natural convection in a differentially heated cavity has been given considerable attention [1, 2] due to its numerous applications such as in solar collectors, the thermal design of buildings, nuclear reactor design and the cooling of electronic equipment. In particular, the study of the natural convection effect on heat transfer through the cavity is of practical significance.

Previous studies (e.g. [3]) show that the natural convection flow in a differentially heated partitioned cavity is depressed in comparison with that in a non-partitioned cavity, and thus heat transfer through the cavity is reduced. Most previous studies (e.g. [3]) are limited to laminar natural convection in a partitioned cavity for relatively low Rayleigh numbers (e.g. $Ra < 10^7$) except the study by Hanjalic et al. [4] who performed two-dimensional simulations of turbulent natural convection at a Rayleigh number of 4.5×10^{10}. Paolucci and Chenoweth [5] pointed out that natural convection in a non-partitioned cavity undergoes a transition from a steady laminar regime to a periodic or turbulent regime as the Rayleigh number is increased. A similar transition could occur in a partitioned cavity. Therefore, it is necessary to investigate natural convection in the transition from a laminar regime to a turbulent regime in a partitioned cavity, in particular, the effect of the partition at relatively high Rayleigh numbers. This motivates the present study.

NUMERICAL PROCEDURES

Under consideration is a two dimensional partitioned cavity, which is illustrated in figure 1. The governing equations are the dimensionless two-dimensional Navier-Stokes and energy equation with the Boussinesq approximation (refer to [2]). The working fluid (air) is initially motionless. At $t = 0$, the temperature of the fluid on the left side of the partition is lowered to T_c and that on the right side of the partition is raised to T_h. All boundaries and the partition are rigid and non-slip; the top and bottom walls are adiabatic; the two sidewalls are isothermal; and the partition of a zero thickness is conducting (That is, the horizontal conduction between the neighbouring fluids at the two sides of the partition is considered). Note that here $H/L = 2$ and the Rayleigh number $Ra = 3.4 \times 10^9$, which is defined by $g\beta(T_h\text{-}T_c)H^3/\nu\kappa$, where g, β, κ and ν are the acceleration due to gravity, the coefficient of thermal expansion, the thermal diffusivity and the kinematic viscosity, respectively. In this paper, the length, time and temperature ($T\text{-}(T_h+T_c)/2$) are non-dimensionalized by H, H^2/κ and ($T_h\text{-}T_c$) respectively (also see [2] for details).

The governing equations are implicitly solved using a finite-volume SIMPLE algorithm. The advection terms are discretized by a QUICK scheme. The time integration is by a second-order backward difference method. A non-uniform grid system with coarse grids in the core and fine grids concentrated in the proximity of all wall boundaries (423 × 298) is constructed in order to capture the basic flow features of unsteady natural convection in the cavity. A time step of 3.7×10^{-7} is adopted here.

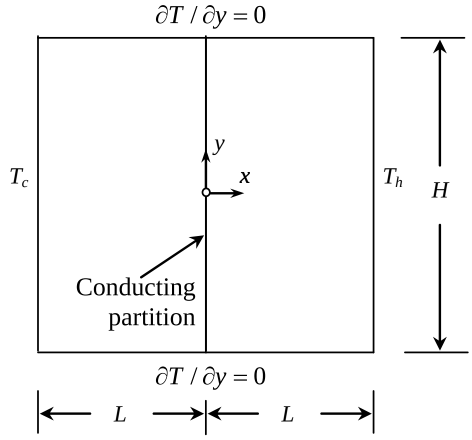

Figure 1. Schematic of the computational domain and boundary conditions.

RESULTS

For the purpose of illustrating the transition of the natural convection flow in the partitioned cavity from the initially motionless state to a quasi-steady state, figure 2 plots a time series of the temperature at a point close to and on the upper left side of the partition. The development of the flow may be classified into three distinct stages: an initial stage, a transitional stage and a quasi-steady periodic stage, as marked in figure 2. At the initial stage, the temperature growth with an overshoot and subsequent travelling waves of the temperature signal, which are referred to as the leading edge effect (LEE, also see [6]), are clear. With the passage of time, the temperature increases further (which is a result of the stratification in the core, also see figure 4c), and the amplitude of the temperature oscillations becomes larger during the transitional stage. At the quasi-steady stage, the temperature signal at this particular location oscillates around an average value (-0.026), as seen in the insert of figure 2. Figure 3 shows the power spectrum of the temperature series at the quasi-steady stage (from $t = 0.0446$ to 0.0535). Clearly, the base frequency (f) is approximately 20000 with additional higher harmonic frequencies of $2f$, $3f$ and $4f$ (marked in figure 3), and the dominant frequency mode is at $2f = 40000$.

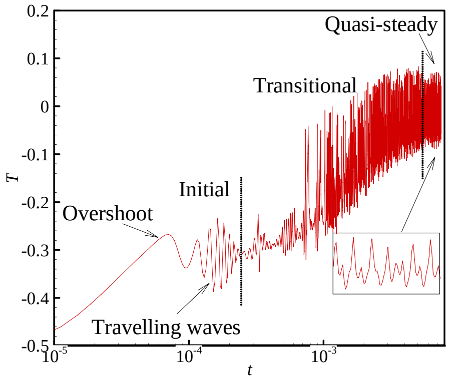

Figure 2. Time series of the temperature at $x = -0.0083$ and $y = 0.375$.

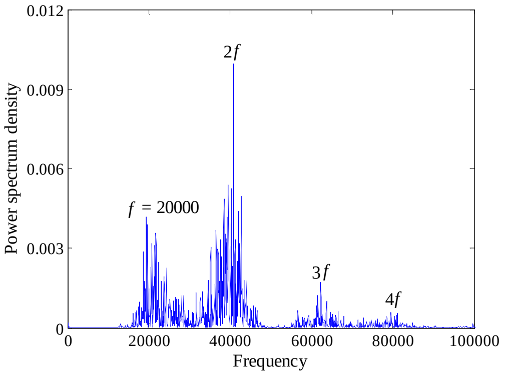

Figure 3. Power spectrum of the temperature at $x = -0.0083$ and $y = 0.375$.

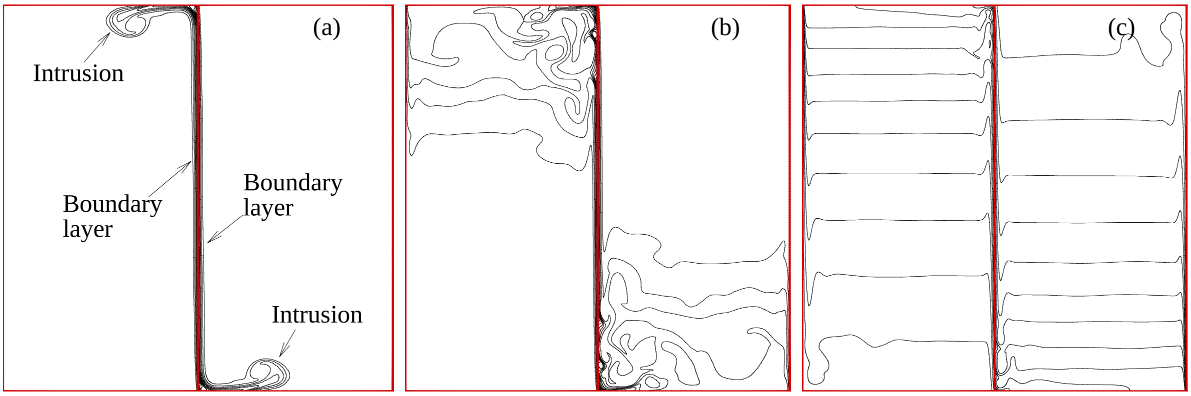

Figure 4. Development of the natural convection flow in a partitioned cavity (isotherms: from -0.4375 to 0.4375 with an interval of 0.0625). (a) $t = 7.2 \times 10^{-5}$. (b) $t = 7.2 \times 10^{-4}$. (c) $t = 5.0 \times 10^{-2}$.

Figure 4(a) shows that, at the initial stage, vertical thermal boundary layers and horizontal intrusions are formed on both sides of the partition. It is seen in this figure that the two sets of the thermal flows are symmetric about the center of the partition. Subsequently, the intrusions strike the isothermal sidewalls, resulting in complex flow structures at the downstream sections of the vertical boundary layer flows, as shown in figure 4(b). As time increases further, the fluid in the cores on both sides of the partition is stratified (figure 4c). Indeed, the flows in the downstream corners of the vertical boundary layers are periodic at the quasi-steady stage, which is consistent with the temperature signal shown in figure 2.

CONCLUSIONS

The transition of the natural convection flow in a partitioned cavity from an initially motionless state to a quasi-steady periodic state passes through three main stages: an initial stage, a transitional stage, and a quasi-steady periodic stage. At the quasi-steady periodic stage, the boundary layer flows are oscillatory for $Ra = 3.4 \times 10^9$, and the dominant frequency of the oscillations is approximately 40000.

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