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Natural convection in an air-filled cavity: Experimental results at large Rayleigh numbers ☆

Didier Saury *, Nicolas Rouger, Francis Djanna, François Penot

Institut Pprime, UPR CNRS 3346, CNRS-ENSMA-Université de Poitiers, Département Fluides Thermique Combustion, ENSMA, Téléport 2, 1 avenue Clément Ader - BP 40109, F-86961 Futuroscope CEDEX, France

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ABSTRACT

A large-scale experimental setup is built and instrumented. It consists in a 4 m-high cavity with a horizontal cross-section equal to 0.86×1.00 m². Two opposite vertical walls are heated and cooled down; other walls (lateral walls, ceiling and floor) are made of insulating medium covered with a thin and low-emissivity film designed to minimize radiative effects into the cavity. The temperatures of active walls are imposed, constant and equally distributed around the ambient temperature in order to reduce heat losses. The temperature difference between the hot and cold walls is chosen to respect the Boussinesq approximation. Under these assumptions, Rayleigh number values up to 1.2×10^{11} ($\Delta T = 20$ °C) can be obtained. The centre-symmetry is verified on the thermal stratification. Influence of the temperature difference and of wall emissivities on the stratification parameter (dimensionless vertical temperature gradient) is discussed. Velocity measurements allow the velocity field to be obtained and provide information on flows encountered in the cavity. Temperature measurements are also carried out in the whole cavity. In the paper, a complete experimental characterization is provided: airflow inside the cavity is analyzed and the Nusselt number along the hot and the cold wall is presented.

1. Introduction

For many decades, studies on phenomena occurring in differentially-heated cavities have been of great interest [1–37]. This is particularly the case today, since public figures have come to realize that economic development must be accompanied by a reduction of greenhouse gas and by policies aimed at reducing energy consumption. In many areas the stakes are high and it is of paramount interest to understand the phenomena occurring in order to control them. Natural convection occurs “naturally” almost everywhere as soon as a density gradient exists and it entails heat exchanges. We need to understand and control the attendant phenomena and to thereby promote or reduce the associated heat transfers. The differentially-heated cavity is an interesting academic configuration allowing for a worthwhile study of the natural convection phenomenon and its chaotic behavior [34–36]. Moreover, applications to concrete cases (building, aeronautics…) often require precise understanding of phenomena occurring at high Rayleigh numbers ($>10^{11}$). Numerous numerical or experimental studies have already been carried out at low Rayleigh numbers [1–5,8–33] where airflow remains laminar or weakly turbulent ($Ra_H < 10^9$). Recently, a few numerical investigations at higher Rayleigh numbers have appeared, but only experimental validation will confirm their credibility [6,7,37].

2. Experimental setup description

This study was carried out in a differentially-heated cavity shown in Fig. 1. The cavity is 3.84 m high, 1 m wide and 0.86 m deep. Two opposite vertical walls are differentially-heated (one is heated while the other is cooled). Their temperature is imposed so that the core of the cavity is at ambient temperature. The two walls, made of aluminum plate ($k = 134$ W m^{-1} K^{-1} and $\varepsilon = 0.15$), are kept at a constant temperature by a glycol-water circuit flowing in 2 separated cryothermostats imposing the temperature. The other walls (back, front walls, floor and ceiling) are made of 8 cm thick polyurethane foam panels ($k = 0.035$ W m^{-1} K^{-1}) placed between the heated and cooled walls. The floor is also made with extruded polyurethane foam panels. Finally, 3 cm-thick panels are added around the cavity on the outer side. On the inner side of the cavity, a thin (40 μm) low-emissivity film ($\varepsilon = 0.1$ with the film and $\varepsilon = 0.6$ without) is added in order to reduce wall radiation.

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* Corresponding author.
E-mail address: dider.saury@ensma.fr (D. Saury).

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