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LES and URANS computations of buoyancy driven flows within differentially heated cavities

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1 Introduction

The reliable computation of buoyant flows is important in a number of engineering sectors, including the nuclear one. Here, turbulent natural convection of air in both two dimensional vertical and inclined rectangular cavities are investigated numerically by means of an unstructured finite volume code (*Code_Saturne*) for an aspect ratio of $H/L = 28.6$, Rayleigh number of $0.86 \cdot 10^6$. The two opposing long walls are maintained at uniform and different temperatures. The flow within the cavity is computed, first, using several Unsteady-Reynolds-Averaged-Navier-Stokes ($URANS$) models, high-Reynolds-number models, such as the Standard $k-\varepsilon$ and Reynolds Stress model $R_{ij} - \varepsilon\, SSG$ and low-Reynolds-number models, like the Shear Stress Transport $k-\omega SST$ and the $\upsilon^2 - f$ model. The results obtained are compared to two recent experimental data (Betts and Bokhari, 2000; Craft et al., 2009). The cases of vertical and inclined cavity at 60^o, heated from the upper side, give similar results of temperature and velocity fields and most of the models are in good agreement with the experiments. On the other hand, once the 2-D cavity is inclined at 15^o to the horizontal, heated from the lower side, under unstable stratification, the majority of $RANS$ models over-predict velocity and temperature because of the three-dimensional nature of the flow with the presence of four longitudinal vortices. The 3D $RANS$ simulation is then adopted for accurate prediction of flow details and wall heat transfer. Now, High-Reynolds-number models seem to capture the flow pattern, however, low-Reynolds-number models disagree with measurements and they tend to capture only one recirculation cell. Finally, LES prediction is also presented in order to provide a validation data-set to the previous $URANS$ computation.

2 Numerical methods

The present computational study is carried out using a finite volume *Code_Saturne*. In natural convection, the flow fluid arises naturally from the effect of density differences, resulting from variation in temperature or concentration in a force field such as gravity. It means that the incompressible Navier-Stokes equations in natural convection cases can be written as:

$$\rho\frac{\partial U_i}{\partial t} + U_j\rho\frac{\partial U_i}{\partial x_j} = -\frac{\partial P}{\partial x_i} - \frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j} - \rho\overline{u_i u_j}\right) + \rho g_i \tag{1}$$

The density changes only in the form of a gravity force ρg_i. The changes in density can be related to changes in temperature via the thermal expansion coefficient β defined as:

$$\beta = -\frac{1}{\rho}\frac{\partial\rho}{\partial T} \tag{2}$$

In order to use the eddy viscosity models in buoyant cases, the production of kinetic energy must be altered by adding a gravity term. That is:

$$P = \mu_t\frac{\partial U_i}{\partial x_j}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) + G \tag{3}$$

where

$$G = \rho\beta g_i(T - T_o) \tag{4}$$

Inclination of the cavity means that the gravity vector is divided into two components along the two directions x and y. The components of gravity are:

$$g_x = g\cos(\alpha) \tag{5}$$

$$g_y = -g \sin(\alpha) \tag{6}$$

α is the angle of inclination of the cavity.

3 Results

In Fig. 1, time-averaged temperature normalised by the temperature difference $\triangle T$, obtained from the LES computational study, is compared to experimental data of Craft et al. (2009). Time-averaged temperature plotted in the central plane of the cavity at different heights, is fairly well predicted by LES. When the mixing of the thermal field is strong the convective effects become higher in the flow which make the temperature in the core of the cavity isothermal and invariant across the height of the cavity. The cavity herein is inclined at 15^0 to the horizontal and heated from the lower side, according to the qualitative results shown in Fig. 1, the temperature distribution correspond with those of Benard convection, which indicates a two boundary layer flows along the hot and cold walls.

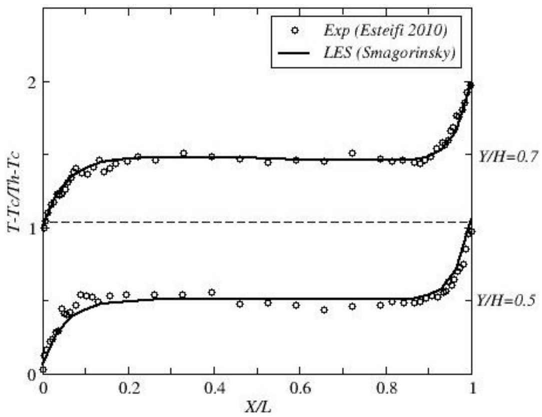

Figure 1: Time-averaged temperature profiles at two different heights inside the cavity (inclination of the cavity 15^0)

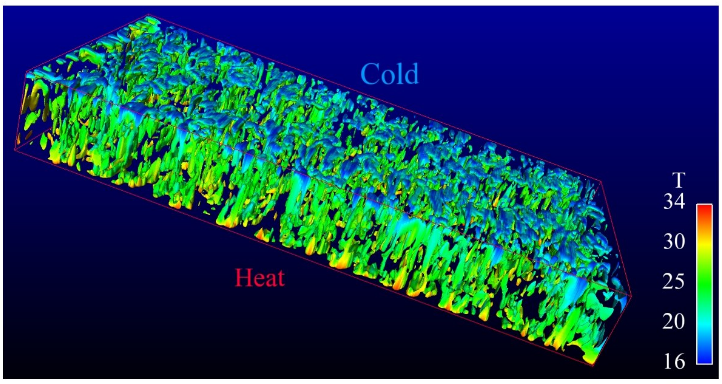

Figure 2: Iso-Q contours coloured by the temperature (inclination of the cavity 15^0)

In order to identify coherent vortices and distinguish them from the mean shear, the structure parameter Q is calculated and plotted in Fig. 2. Using this parameter it is possible to observe the turbulent structures in the core of the heated cavity.

References

Betts, P. L. and I. H. Bokhari (2000). Experiments on turbulent natural convection in an enclosed tall cavity. *International Journal of Heat and Fluid Flow 21*(6), 675 – 683.

Craft, T. J., H. Iacovides, D. Cooper, K. Esteifi, and A. Omranian (2009). The investigation of buoyant flows in differentially heated cavities. *0*, E–0101.