11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

DIRECT AND LARGE EDDY SIMULATIONS OF NON-OBERBECK-BOUSSINESQ EFFECTS IN A TURBULENT TALL WATER-FILLED DIFFERENTIALLY HEATED CAVITY

Deniz Kizildag, Ivette Rodríguez, F. Xavier Trias and Assensi Oliva

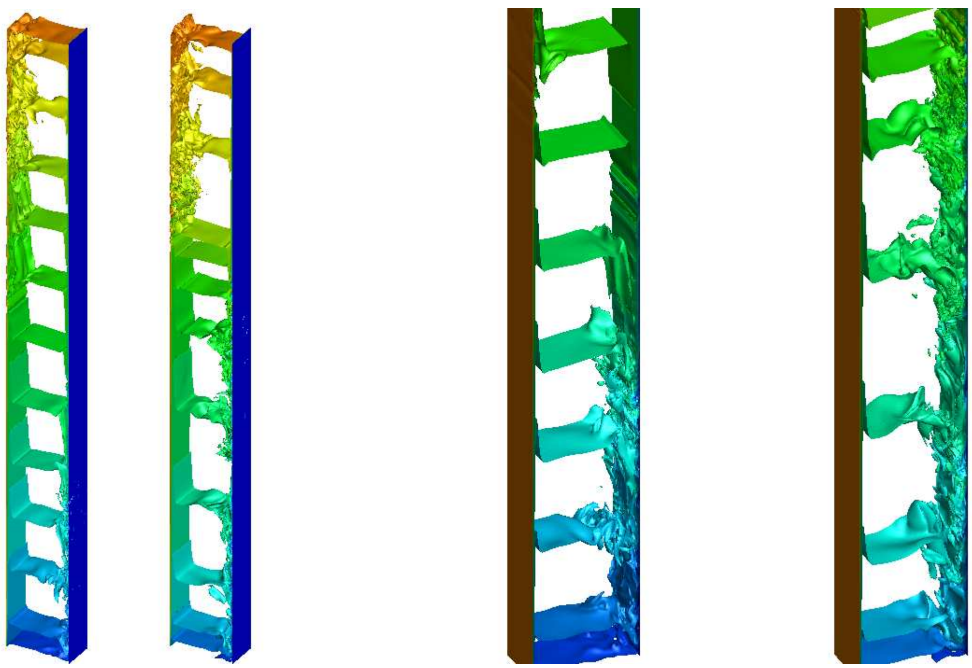
Heat and Mass Transfer Technological Center (CTTC)
Universitat Politècnica de Catalunya - BarcelonaTech (UPC)
Colom 11, 08222 Terrassa, Barcelona, Spain
cttc@cttc.upc.edu

Key words: *Non-Oberbeck-Boussinesq, Turbulent Natural Convection, Direct Numerical Simulation, Large Eddy Simulation.*

The canonical differentially heated cavity (DHC) flow has been extensively studied in the literature due to its potential to model many applications of academic and industrial interest. The vast majority of the conducted studies was for air-filled cavities (Prandtl number $Pr \approx 0.7$) considering the so-called Oberbeck-Boussinesq (OB) approximation. If the cavity is water-filled, obtaining solutions gets more complicated as the boundary layer becomes thinner [1], thus requiring finer grids to capture the smallest scales of the turbulent flow. Moreover, for water-filled cavities under practical working conditions, the OB approximation is questionable [2] as a consequence of important variations in the thermophysical properties, especially in the viscosity. Recently, Kizildag et al. [3] studied the non-Oberbeck-Boussinesq (NOB) effects in a tall water-filled DHC on a 2D domain at a wide range of temperature differences by means of direct numerical simulations (DNS). In their investigation, a substantially different flow configuration is observed beyond a temperature difference of 30 $^\circ C$, where NOB effects are found to be relevant.

The objective of the present investigation is twofold. First, by means of 3D DNS, the NOB effects are submitted to study in order to check the adequacy of the conclusions obtained by means of 2D hypothesis for a similar flow configuration [3]. To that end, two DNS studies of the turbulent natural convection in a DHC of aspect ratio 10 at $Ra = 3 \times 10^{11}$ and $Pr = 3.41$ (corresponding to water at 50 $^\circ C$) are carried out, one with OB approximation, the other considering NOB effects, for a temperature difference of $\Delta T = 80$ $^\circ C$ between the isothermal confining walls. Second, the assessment of three sub grid-scale (SGS) models are carried out for the configuration under study: (i) the wall-adapting local eddy-viscosity (WALE) model , (ii) the QR model, (iii) the WALE model within a variational multiscale framework. Similarly, two test batteries are simulated considering both OB and NOB conditions. The three SGS models are assessed by means of comparison with the corresponding DNS. To the best knowledge of the authors, the present study is the first one to assess the performance of the above-mentioned models under the NOB conditions.

So far, first part of the work is performed, obtaining DNS results under both the OB and NOB conditions. The preliminary results reveal the influence of the NOB effects as can be seen in Figure 1. Note that if NOB effects are considered, the boundary layers at hot and cold isothermal walls behave differently. The symmetry of the flow is broken, yielding a different flow configuration, affecting the heat transfer and thermal stratification in the cavity. Further results will be presented in the final paper and in the conference.



(a) (b)

Figure 1: Instantaneous isotherms of the DNS. (a) whole domain (b) detailed view in the vicinity of the cold wall. OB (left); NOB (right).

REFERENCES

[1] J. Patterson, J. Imberger, Unsteady natural convection in a rectangular cavity, Journal of Fluid Mechanics 100 (1980) 65–86.

[2] D. Gray, A. Giorgini, The validity of the Boussinesq approximation for liquids and gases, International Journal of Heat and Mass Transfer 19 (1976) 545–551.

[3] D. Kizildag, I. Rodríguez, A. Oliva, O. Lehmkuhl, Limits of the Oberbeck-Boussinesq approximation in a tall differentially heated cavity filled with water, International Journal of Heat and Mass Transfer 68 (2014) 489–499.