LARGE-EDDY SIMULATION OF THE TRANSITIONAL FLOW IN NATURAL CONVECTION IN A HORIZONTAL ANNULUS

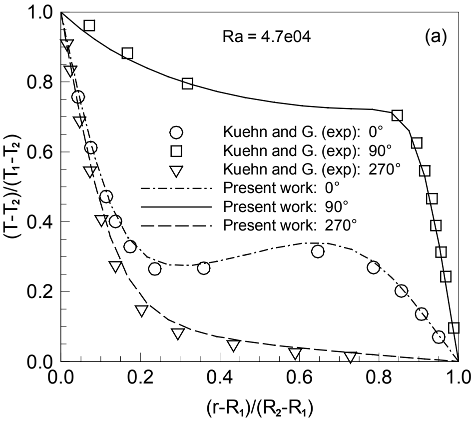
Elie Luis M. Padilla, Aristeu Silveira-Neto
School of Mech. Eng. – Federal University of Uberlândia, Uberlândia, MG, Brazil, 38400-902

Summary In the present study three-dimensional analysis of the transitional flow in natural convection in horizontal cylindrical annulus was performed, using Large-Eddy Simulation (LES) methodology with dynamical sub-grid scale model. The beginning of the transition process and the beginning of turbulent regimes is indicated. The characteristics of the oscillatory and the influence on heat transfer coefficient were analyzed. The results showed that coherent structures exist in this type of flow.

Natural convection heat transfer in cylindrical annuli is a very common problem in practical and technological applications. Natural convection in horizontal cylindrical cavity has been studied extensively, both theoretically and experimentally. The majority of these studies are focused on laminar or turbulent regimes. Exist very few works that focalises the phenomenon of transition to turbulence. The problem was first studied by Beckmann [1], who obtained overall heat transfer coefficients using air, hydrogen and carbon dioxide. After, wards other experimental studies have been reported. Several correlations have been proposed using experimental heat transfer data, as reported by Itoh et. al. [2] and McLeod and Bishop [3]. Crawford and Lemlich [4] achieved one of the first numerical solution for natural convection between horizontal concentric cylinders for air using a Gauss-Seidel iterative method. Numerical solutions were presented by many authors, using differents methodologies. However, only three-dimensional results of Fukuda et. al. [5] shows the flow becoming unstable. Physical oscillations appear when the Rayleigh number is increased .

In the present study three-dimensional analysis of the transitional flow in natural convection in horizontal cylindrical annulus was performed, using Large-Eddy Simulation (LES) methodology with dynamical sub-grid scale model. The cavity is formed by two concentric cylinders of radius R_1 and R_2 respectively. The distance between cylinders is L and the axial length is L_{ax}. The inner surface is maintained at temperature T_1 and the outer surface is maintained at temperature T_2 $(T_1 > T_2)$. The flow is considered incompressible, with constant physical proprieties. Buoyancy force is modeled with the Boussinesq approximation. In order to use the LES, the Navier-Stokes and energy equations are filtered. This procedure gives rise to the subgrid-scale Reynolds tensor and the subgrid heat flux that represent the turbulent transport of momentum and heat between the large scale and the subgrid scale. The subgrid-scale Reynolds tensor is modeled with the hypothesis of Boussinesq and the subgrid heat flux ($\dot{q}_t$) with the expression $\dot{q}_t = -\alpha_t \, \partial \overline{T} / \partial x_j$. The thermal diffusivity was estimated from the value of turbulent Prandtl number, $\mathrm{Pr}_t = \nu_t / \alpha_t = 0.6$ (Silveira-Neto et. al. [6]). The eddy viscosity (ν_t) was calculated using the dynamical model of Germano et. al. [7], modified by Lilly [8].

The finite volume method is applied in cylindrical coordinates with an staggered grid. The second order Adams-Bashforth temporal scheme and the second order central-difference spatial scheme were used. The governing equations were solved with a fractional time-step method, employing the following boundary conditions: non-slipping and impermeability in the radial direction and periodicity in the tangential and axial directions. The time-step is conditioned by the CFL criterion. The validation was performed for laminar and transitional natural convection, by comparing with experimental date of Kuehn and Goldstein [9] (Fig. 2) and Fukuda et. al. [5] respectively.



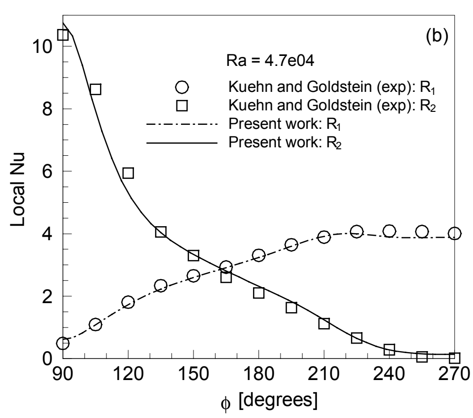


Figure 2. Comparison with experimental dates for Ra = 4.7x10^5, (a) temperature, (b) local Nusselt number.

The numerical analysis was performed for several values of Rayleigh number (Ra), a value of radius ratio ($\eta = R_2/R_1$) and two values of aspect ratio ($\Gamma = L_{ax}/L$). The temperature fields are shown in Fig. 3 and Fig 4. The Rayleigh number for both figures is Ra = 1.7x10^5, η = 2 and Γ= 2.8 . Fig. 3 shows three planes normal to the z axis, at $z = 0$,

$z = 0.5L_{ax}$, $z = L_{ax}$. The visualization is also presented for three differents times: (a) 29.6 s, (b) 29.8 s and (c) 30 s. In both figures the flow transition is visualized in three directions (r, ϕ, z). It can be seen that the flow presents dynamical oscillations in three directions. For example the oscillation in z direction can be visualized in both figures and presents periodicity. This behavior may be observed clearly in time (Fig. 4(a), 4(b) and 4(c)). Clearly the plume generated at the top of the annulus oscillates right and left, as observed experimentally by McLeod and Bishop [3] and experimentally and numerically by Fukuda et. al. [5]. These authors also observed that the instabilities presents three-dimensional characteristics as we can observe in these figures. The beginning of the transition process and the beginning of turbulent regimes is indicated. The characteristics of the oscillatory flow (such as the variables fluctuations, power spectra and intensity of turbulence) and the influence on heat transfer coefficient were analyzed. The results showed that coherent structures exist in this type of flow.

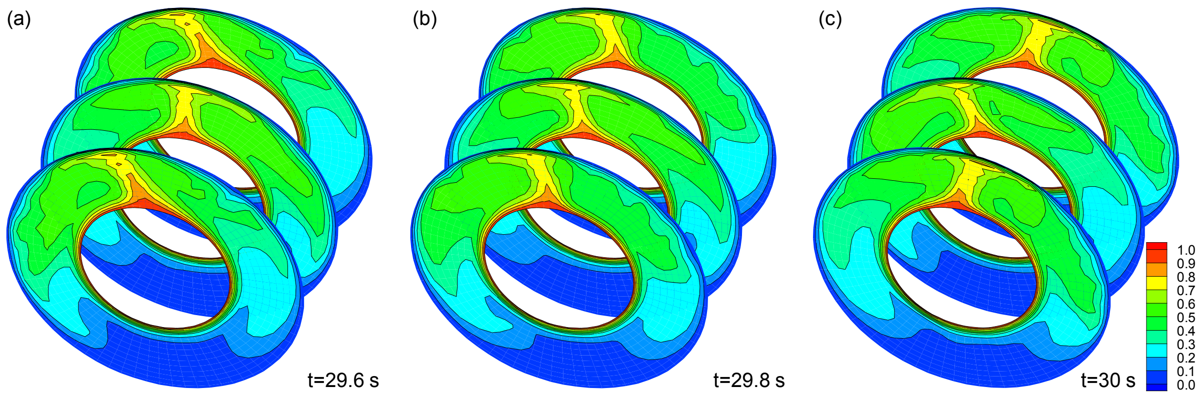


Figure 3. Temperature fields over the planes $z = 0$, $z = 0.5L_{ax}$, and $z = L_{ax}$ for $Ra = 1.7\text{x}10^5$, $\eta = 2$ and $\Gamma = 2.8$.

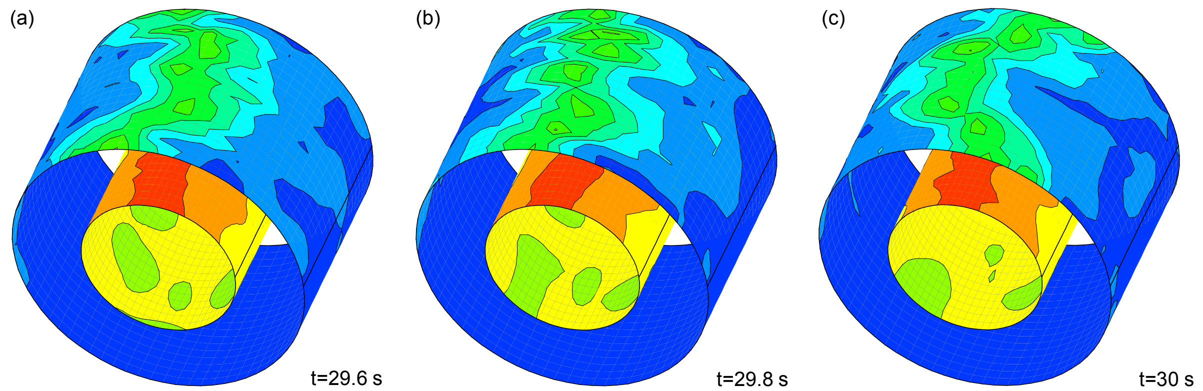


Figure 4. Temperature fields over the planes $r = 1.036L$ (near the inner cylinder) and $r = 1.963L$ (near the outer cylinder) $z = L_{ax}$ for $Ra = 1.7\text{x}10^5$, $\eta = 2$ and $\Gamma = 2.8$.

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