Numerical investigation of natural convection in an asymmetrically heated inclined channel-chimney systems

Importance of the choice of artificial inlet-outlet boundary conditions

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The present paper is concerned with the results of the numerical investigation of unsteady laminar, natural convection in an asymmetrically heated inclined open channel ($i = 0, 45, 60$ and 75 °) with walls at uniform heat flux ($q_w = 10, 50, 75$ and 100 W·m^{-2}). Two methodological approaches have been adopted to investigate the air flow in this case: 2D and 3D DNS, and four sets of inlet-outlet velocity-pressure boundary conditions have been considered. Significant differences are observed in the flow dynamics between 2D and 3D results.

Geometry

The case under consideration is a two-dimensional open channel asymmetrically heated by a constant parietal heat flux imposed on its left side (see Fig.1). The channel is made of a set of two parallel rectangular plates of dimension $H \times l$ with $H = 0.64$ m. For three-dimensional numerical investigation the depth $l = 0.304$ m is considered. Different heat fluxes and three channel widths are studied resulting in aspect ratios (H/b) of the channel equal to 6.5 ; 10.67 and 12.8 respectively. Thirty cases were considered.

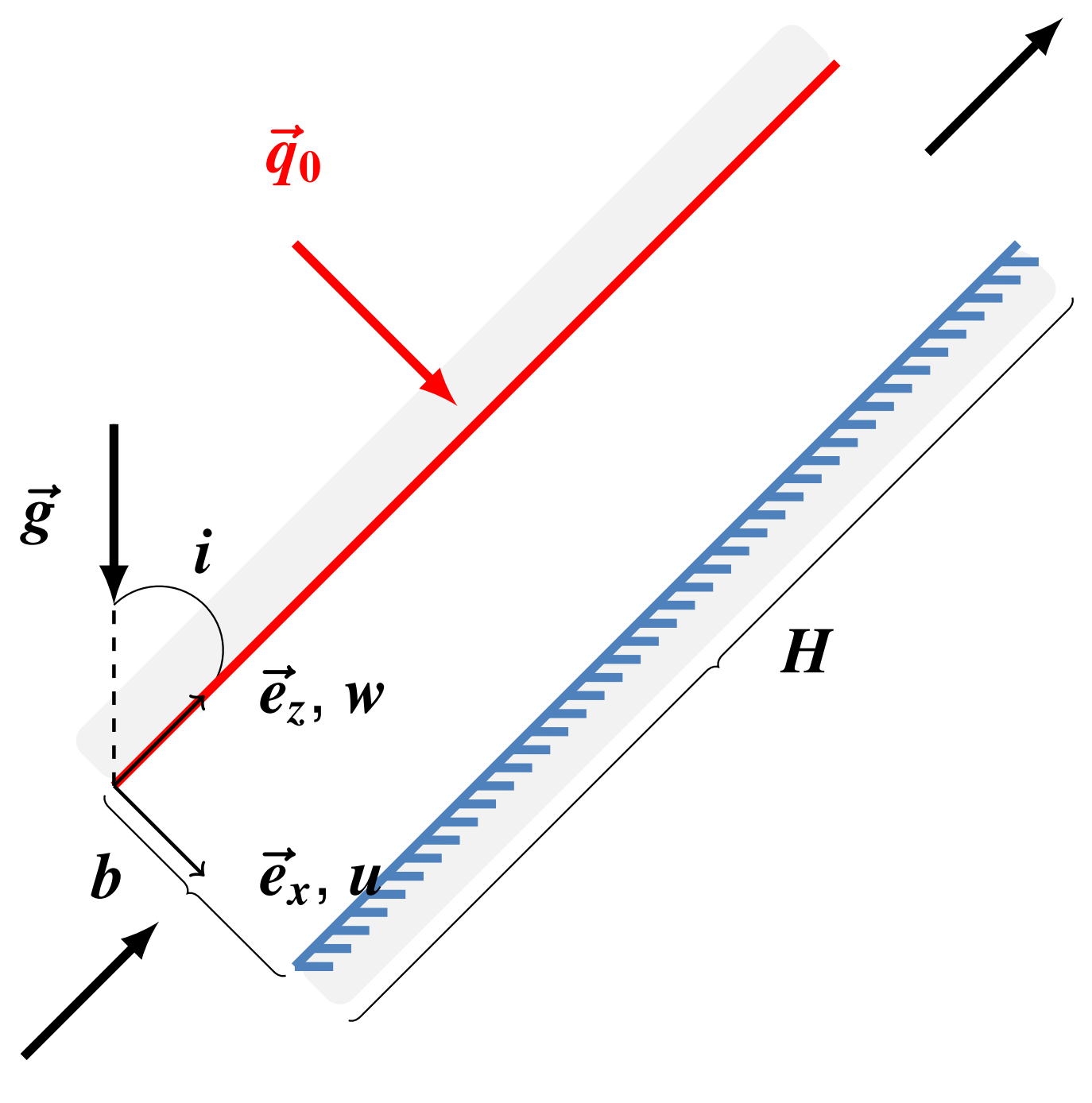


FIGURE 1: Computational domain.

Dimensionless Boussinesq 2D Navier-Stokes equations :

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \Pr Ra_H^{-1/2}\frac{\partial^2 u_i}{\partial x_j \partial x_j} + Pr\theta(\sin(i)\delta_{ix} - \cos(i)\delta_{iz}) \tag{2}$$

$$\frac{\partial \theta}{\partial t} + \frac{\partial u_j \theta}{\partial x_j} = Ra_H^{-1/2}\frac{\partial^2 \theta}{\partial x_j \partial x_j} \tag{3}$$

Numerical Approach

The numerical code has been developed thanks to the environment OpenFOAM [1]. Time derivatives in the momentum and the energy equations are approximated by a second-order backward differentiation scheme. An implicit formulation is employed for the diffusion terms. An explicit second-order backward Adams Bashforth extrapolation for the nonlinear terms is implemented. Finally, the spatial and time derivatives are approximate with second-order schemes. A Pressure Implicit with Splitting of Operators (PISO) procedure is used for the pressure-velocity coupling.

Results for $H/b = 10.7$ and $Ra_H = 5.9 \times 10^9$

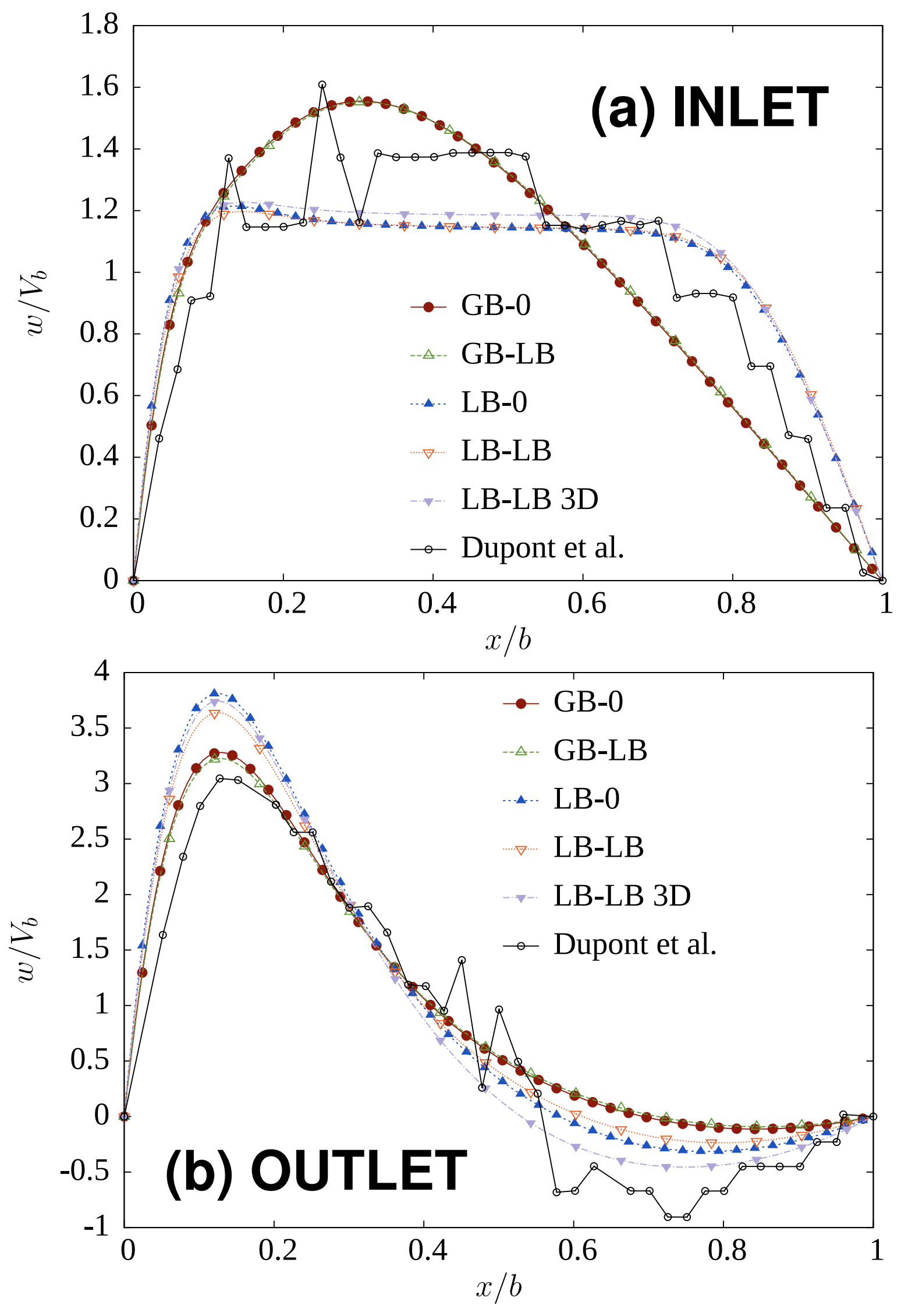
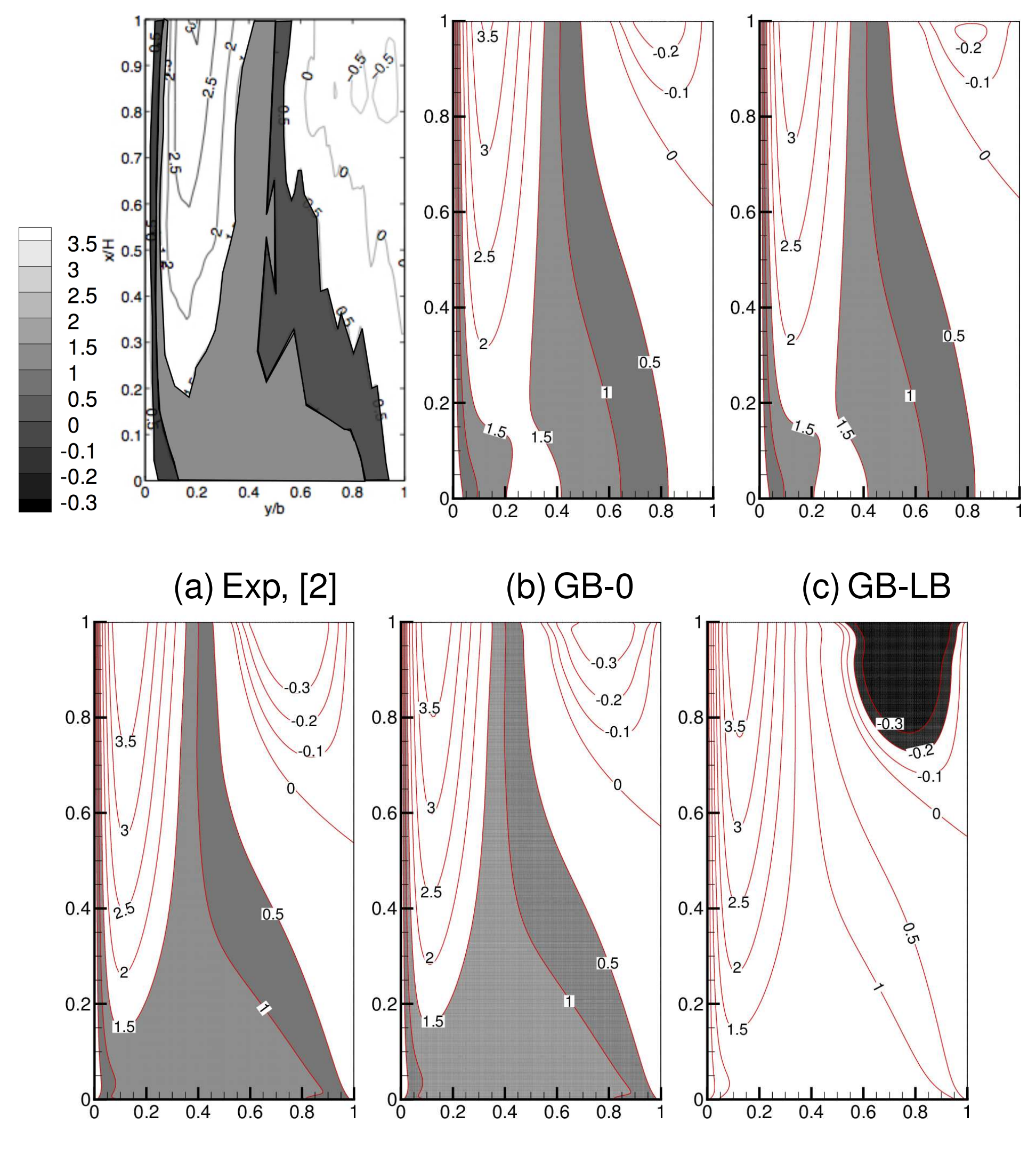


FIGURE 3: Vertical velocity profiles w/V_b. Comparison between numerical and experimental results. (a) $z/H = 0.078$. (b) $z/H = 0.859$.



(a) Exp, [2] (b) GB-0 (c) GB-LB

(d) LB-0 (e) LB-LB (f) 3D LB-LB

FIGURE 4: Iso-contours of the dimensionless w/V_b in the channel for different boundary conditions.

Boundary conditions

The boundary conditions are $\frac{\partial\theta}{\partial x}(x = 0, z) = 1$ on the thermally active wall, and $\frac{\partial\theta}{\partial x}(x = b/H, z) = 0$ on the adiabatic wall. A non-slip boundary condition for the velocity is imposed along the walls and due to the PISO method, Neumann boundary conditions are imposed along the walls for the pressure. The imposed conditions at inlet ($z = 0$) are : $\theta = 0$; $u = \frac{\partial w}{\partial z} = 0$. At the outlet ($z = 1$) : if $\vec{V}.\vec{n} < 0$, then $\theta = 0$, else $\frac{\partial\theta}{\partial x}(x, 1) = 0$; $u = \frac{\partial w}{\partial z} = 0$.

- ▶ Global Bernoulli boundary condition (GB) :

$$P(x,z) = -\frac{1}{2}\left(\int_0^1 w(x,z)dx\right)^2 = \frac{1}{2A_{in}^2}G^2 \tag{4}$$

- ▶ Local Bernoulli boundary condition (LB) :

$$P(x,z) = -\frac{1}{2}w(x,z)^2 \tag{5}$$

At the outlet, a free jet condition is also considered, depending on the flow direction : $P = 0$ if $V.n > 0$. Four resulting sets of boundary conditions are synthesized through notations (GB-0, GB-LB, LB-0 and LB-LB) according to Table 1.

TABLE 1: Pressure boundary condition.

		Inlet	
		GB	LB
Outlet	0	GB-0	LB-0
	LB	GB-LB	LB-LB

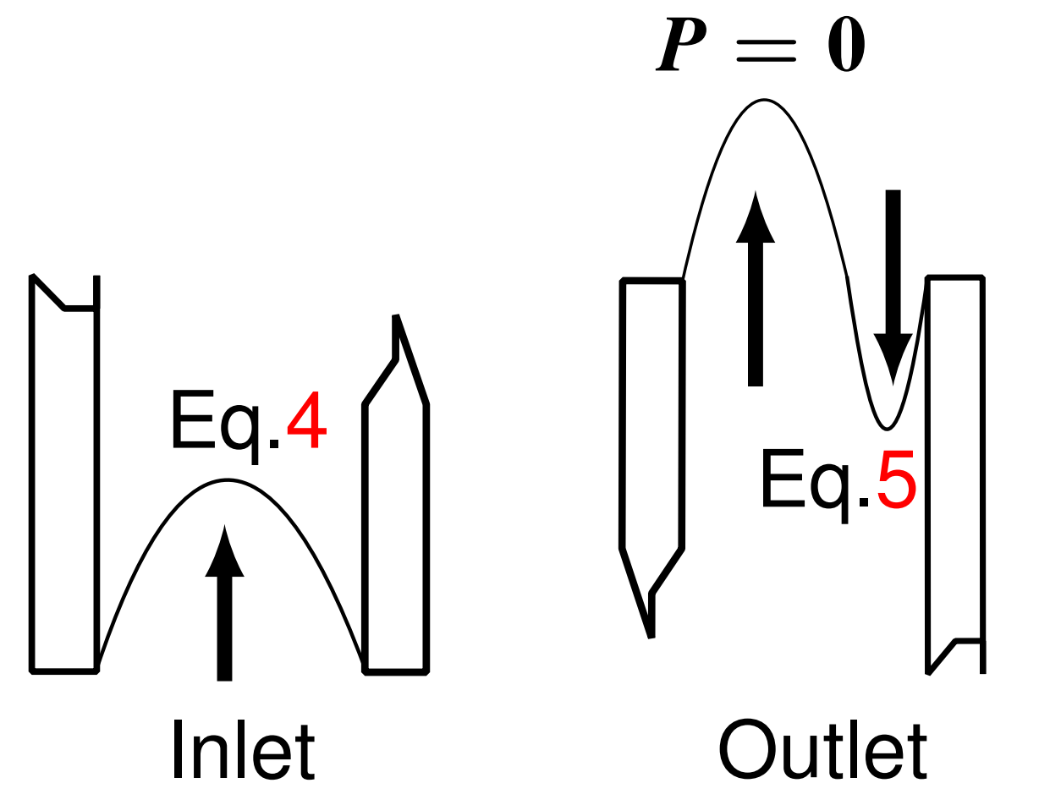


FIGURE 2: Example boundary condition (GB-LB).

Conclusions

- ▶ differences exist for the domain of existence of a return flow in the upper part of the channel,
- ▶ surface radiative exchanges influence the flow, particularly near the inlet and outlet sections,
- ▶ local pressure boundary conditions at the inlet/outlet sections (LB-LB) improve the results when compared to global conditions (GB),
- ▶ three-dimensional effects show negligible effects for the main upward flow but improve the prediction of the reverse flow.

References

[1] OpenFOAM 2.1,http ://www.openfoam.com, 2012.

[2] S. Samot, F. Dupont, and F. Penot. Mesure de température dans un écoulement renversé à la sortie d'un thermosiphon vertical chauffé à flux constant. In *Congrés Francais de Thermique*, page 6, Touquet, 2010.

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