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ON THE MODELING OF AN ATMOSPHERIC FREE CONVECTION IN AN IDEALIZED V-SHAPED VALLEY

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This paper presents first few results of a newly developed numerical model aimed to address the problem of a free and forced convection in atmospheric boundary layer flows over a complex terrain. The problem chosen for this initial study describes the flow in a simple two-dimensional V-shaped valley. The flow is generated by heating/cooling valley walls which results in free convection circulation. Different wall temperatures and background stratification rates are considered. The equations of fluid motion are based on the Boussinesq approximation of momentum equations, supplemented by the divergence-free incompressibility constraint. Turbulence is described by a modified $SST k - \omega$ model.

Problem description – Thermally induced free convection is a phenomenon that determines the atmospheric circulations at various scales. In mountain regions it is responsible for such effects as katabatic/anabatic winds and thermally generated turbulence. The 2D problem is solved in a domain Ω, which is a subset of $y - z$ plane. The problem setup is shown in the figure 1.

The valley dimensions are set as: width $W = 200m$ and depth $D = 50m$. The case solved here consists of a simple symmetric v-shaped valley with one heated and one cooled wall.

The *initial conditions* were chosen to represent static ($\boldsymbol{u} = \mathbf{0}$) and thermally undisturbed ($\Theta' = 0$) state. In the presence of variations of the terrain profile, an important flow develops due to buoyancy effects. The flow structures generated by this mechanism are responsible for large-scale mixing of the fluid and enhancement of the heat transfer from the wall. Despite of a very simple geometrical configuration of the considered case, there are several difficulties associated with its mathematical modeling and numerical simulation.

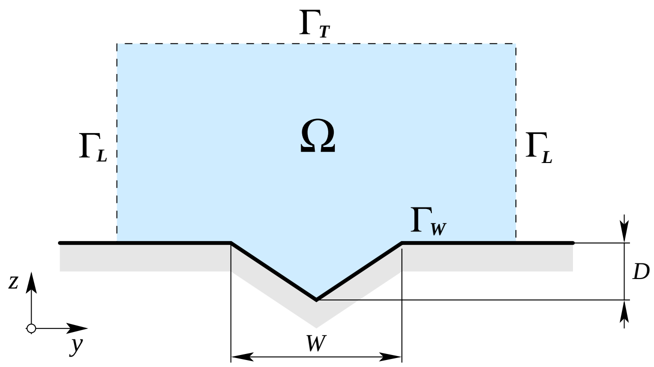

Figure 1: Geometrical configuration of the problem.

Mathematical model – The Boussinesq approximation for an incompressible, thermally stratified fuid flow is considered

$$\nabla \cdot \boldsymbol{u} = 0 \quad (1)$$

$$\frac{\partial \Theta'}{\partial t} + \boldsymbol{u} \cdot \nabla \Theta' = \widetilde{\kappa} \Delta \Theta' - \boldsymbol{u} \cdot \widetilde{\boldsymbol{\gamma}} \quad (2)$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = -\frac{\nabla p'}{\rho_*} + \nu \Delta \boldsymbol{u} - \frac{\Theta'}{\Theta_*}\boldsymbol{g} \quad (3)$$

To take into account the thermally generated turbulence the standard $SSTk - \omega$ model was modified to include the buoyancy effects.

$$\rho \left(\frac{\partial k}{\partial t} + \boldsymbol{u} \cdot \nabla k \right) = P + G_b - \beta^* \rho k \omega + \nabla \cdot \left[\left(\mu + \frac{\mu_T}{\sigma_k} \right) \nabla k \right] \quad (4)$$

$$\rho \left(\frac{\partial \omega}{\partial t} + \boldsymbol{u} \cdot \nabla \omega \right) = \frac{\chi \rho}{\mu_T} P G_{b\omega} - F_4 \beta \rho \omega^2 + \nabla \cdot \left[\left(\mu + \frac{\mu_T}{\sigma_\omega} \right) \nabla \omega \right] + 2\rho \frac{1 - F_1}{\sigma_{\omega 2} \omega} \nabla k \cdot \nabla \omega \quad (5)$$

Numerical solution – The whole model is solved using a finite-volume method on a structured grid. An explicit multistage Runge-Kutta method was used for time integration. Non-linear digital filters are used to avoid non-physical oscillation and stabilize the computational process.

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