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Computational Simulations of the Thermally Stratified Atmospheric Boundary Layer above Hills

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Abstract

Some characteristics of thermal effects in numerical simulations of the atmospheric boundary layer (ABL) flow which develops above hilly terrain are discussed in this paper. The differences and unstable stratification effects between the windward and leeward sides of a hill model were investigated for different upwind velocity. Particularly, the buoyancy effects on the structure of turbulent boundary layers in a wide range of stability conditions were studied. Steady Reynolds-averaged-Navier-Stokes (RANS) equations along with the SST k-ω turbulence model are used for Computational Fluid Dynamics (CFD) simulations of the thermally stratified flow and turbulence above hills. The computational results indicate an improved accuracy of the turbulent heat transfer for engineering applications including flow separation and reattachment, rotation, and buoyancy.

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Keywords: Thermal stratification; turbulence; complex terrain; CFD; climatic wind tunnel ;

1. Introduction

Wind conditions influence the effect of wind on both building constructions and the dispersion of pollutants from different surface or elevated sources. Those are the processes occurring in the atmospheric boundary layer (hereinafter ABL). The physical and thermal properties of the underlying surface in connection with the dynamics and thermodynamics in the lower layers of atmosphere influence wind velocity distribution in thermally stratified ABL. The atmospheric turbulences are characterized by a high rate of irregularities, dimensionality, diffusivity, dispersion and a very wide range of motion scales.

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It is usually assumed that the effect of thermal convection can be ignored; in fact, the ABL has almost always a vertical heat flux. Vertical fluxes, either stable (upwards) or unstable (downwards), influence flow field velocity profiles. The thermal effects on the air flow are investigated both experimentally [1,2], and numerically [3,4]. They are of global interest, especially from the viewpoint of the effect on the burden on building constructions, as well as on the architectural solution of objects [5-8].

In the presented work are presented changes in the velocity field in the stratified border layer, in the area of a thermally loaded object which is flown around. Through cooperation with the experimental research centre CWT CET in Telč [9, 10, 11], an task matching the experimental measuring in an aerodynamic climatic tunnel using the CFD codes [12] is modelled. It concerns the flow around a heated model of a hill with a height of *h* = 200 mm (Fig. 1) with different air speeds and object surface temperatures [13,14].

Fig. 1. Scheme of the object which is flown around and a model of this in an aerodynamic tunnel [12], dimensions in [mm].

2. Numeric modelling

The solution is performed using Ansys Fluent software. From the viewpoint of numeric modelling, the issue is interesting in terms of flow characteristics. It is flow with a transition from low turbulence at the beginning to fully developed turbulence behind the obstacle which is flown around [15,16]. The object which is flown around and which is thermally burdened contributes both to the change of momentum and turbulent flow properties [17]. The Transition SST model was chosen for the solution, because it is suitable for showing the significant change of flow field momentum in the transition area of turbulent flow at low *Re* numbers. The standard k-ω model is an empiric model based on the solution of two transport equations for kinetic energy k (1) and dissipation of this energy ω (2).

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left(\Gamma_k\frac{\partial k}{\partial x_j}\right)+G_k-Y_k+S_k \tag{1}$$

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial(\rho\omega u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left(\Gamma_\omega\frac{\partial\omega}{\partial x_j}\right)+G_\omega-Y_\omega+D_\omega+S_\omega \tag{2}$$

k – is kinetic energy [m^2s^{-2}],
ω – is the specific dissipation rate [s^{-1}],
G_k – is the generation of turbulence kinetic energy due to mean velocity gradients [m^4],
G_ω – is the generation of ω [$kg\cdot m^{-3}s^{-2}$],
Γ_k, Γ_ω– are effective diffusivities of k and ω,
Y_k, Y_ω– are dissipations of k and ω due to turbulence [$kg\cdot m^{-1}s^{-3}$], [$kg\cdot m^{-3}s^{-2}$],
S_k, S_ω– user-defined source terms and
D_ω – cross-diffusion term [$kg\cdot m^{-3}s^{-2}$].