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Large eddy simulation of atmospheric boundary-layer flow in real complex terrains

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SUMMARY:
Accurate evaluation of atmospheric boundary-layer flow in complex terrains is very important for wind energy utilization. In recent years, the research on boundary-layer flow of typical complex terrains is increasingly abundant, but for real complex terrains, the study of boundary-layer flow still needs to be improved. In this paper, large eddy simulation(LES) is adopted to study boundary-layer flow about Askervein hill. First, the accuracy of the numerical simulation is verified. Then, the effects of different mountain heights and wind turbines wake effects on boundary-layer flow of real complex terrains were evaluated from two perspectives of flow pattern and turbulence flow field characteristics. The characteristics of terrain acceleration effect, time-average flow field, turbulence flow field characteristics, power spectrum of fluctuating wind speed are analyzed systematically in real complex terrains, and the relevant flow mechanism is expounded. The research results show that the mountain heights and wind turbines wake effect have significant influence on the boundary-layer flow of real complex terrains.

Keywords: large eddy simulation, atmospheric boundary-layer flow, real complex terrain

1. INTRODUCTION

As a means of effectively utilizing wind energy, wind power generation has attracted more and more attention from researchers. As we all know, wind turbines should be arranged at the position with the highest average wind speed, and the flow conditions and complex terrains are two important factors affecting the wind speed distribution of the wind field (Cao et al., 2012). For plain areas, the terrain is flat, and the characteristics of the wind field are mainly affected by the incoming flow conditions. For complex terrain areas, affected by factors such as mountain heights and ground roughness, there are high turbulence, terrain acceleration and wind shear effects. These factors have an important impact on the power generation and operation safety of wind turbines (Yang et al., 2021). Therefore, it is very important to accurately evaluate the wind field characteristics under complex terrains.

In recent years, the parametric research results of wind field characteristics under typical complex terrains have become more and more abundant, and the research results can be mainly divided into three categories. The first category is to change the characteristic parameters of the typical complex terrains itself (such as different heights, different slopes, and ground roughness), and compare and analyze the flow field distribution and turbulence characteristics of two-dimensional(2D) ridges and three-dimensional(3D) hills under typical complex terrains (Liu et al., 2020). The second category is to consider the influence of different inflow conditions (such as uniform flow, turbulent flow, and atmospheric stratification) on the characteristics of typical complex terrains wind fields (Yang et al., 2021). The third category not only considers the influence of typical complex terrains but also the influence of wind turbines, and analyzes the influence of the relative position of wind turbines and typical complex terrains, and the relative size of wind turbines and typical complex terrains on the wind field characteristics of typical complex terrains (Zhang et al., 2021).

With the rapid development of mountain wind farms construction, the demand for its practical engineering application is becoming more and more urgent, and researchers have begun to turn their attention to real complex terrains. Based on RANS simulation, Kim et al. (2000) compared the accuracy of the standard k-ε model and the RNG k-ε model for simulating the real complex terrains wind field, and the results showed that the RNG k- ε model was more accurate. Hu et al. (2021) used large eddy simulation to analyze the terrains acceleration effect and turbulence characteristics of real complex terrains from the perspective of flow field for an real terrain in Changsha. However, the above studies only considered the influence of real complex terrains, ignoring the interaction between wind turbines and real complex terrains.

At present, there are a few studies on the wind field characteristics of real complex terrain considering the height of mountains and wind turbines. Under real complex terrains, the flow mechanism of the atmospheric boundary layer is still unclear. Therefore, this paper adopts the research method of large eddy simulation and takes Askervein hill as the research object. Discuss the influence of mountain heights and wind turbines on the flow pattern and turbulence characteristics of real complex terrains, in order to provide technical support for the micro-siting over real complex terrains.

2. NUMERICAL METHOD

2.1 Governing equations and solution schemes

The governing equations for the flow are the unsteady incompressible Navier-Stokes equations with LES turbulence model, which are derived by filtering continuity and Navier-Stokes equations as

$$\frac{\partial \rho \tilde{u}_i}{\partial x_i} = 0$$

(1)

$$\rho \frac{\partial \tilde{u}_i}{\partial t} + \rho \frac{\partial \tilde{u}_i \tilde{u}_j}{\partial x_j} = -\frac{\partial \tilde{p}}{\partial x_i} + \mu \frac{\partial}{\partial x_j}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right) - \frac{\partial \tau_{ij}}{\partial x_j} \tag{2}$$

The filtered Navier-Stokes equations are solved with the commercial CFD code ANSYS Fluent 19.1 using the control volume method. The second-order central difference scheme is used for the convective and viscosity terms, and the second-order implicit scheme is used for the unsteady term. SIMPLE algorithm is employed for solving the discretized equations.

2.2 Computational domain and numerical mesh

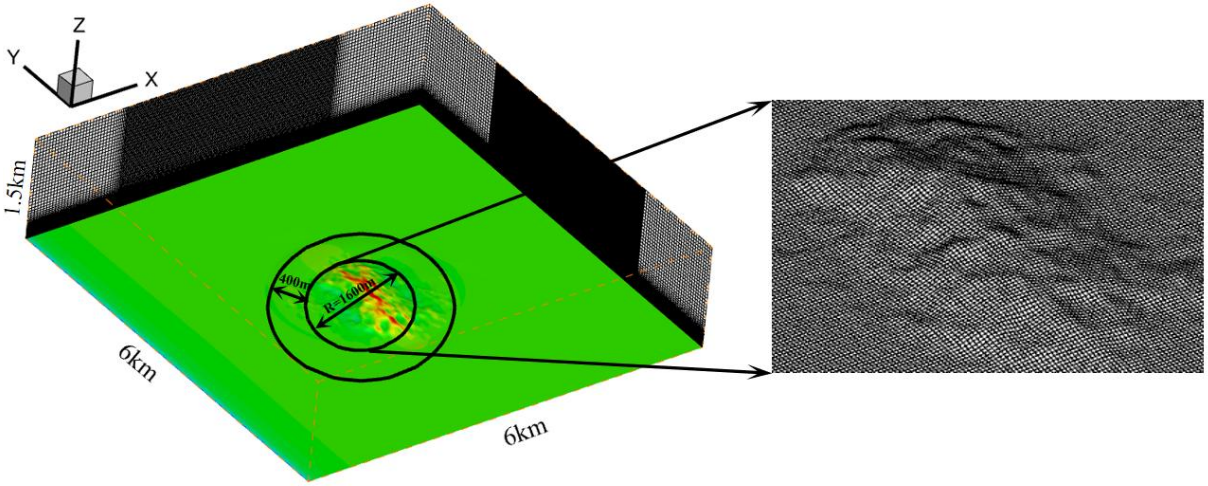

Figure 1. Configuration of the computational domain and local mesh of the terrain.

In order to ensure that the flow is fully developed and taking into account the height of Askervein hill, the calculation domain size is set to 6km×6km×1.5km. In the geometric modeling, the highest point HT of Askervein hill is taken as the origin. In order to reduce the influence of the surrounding terrain, a 400m transition ring is set near the model, see Fig. 1. The size control method is used to refine the model in mesh division and the total number of grids is 4982499.

3. RESULTS

3.1. Validation of numerical model

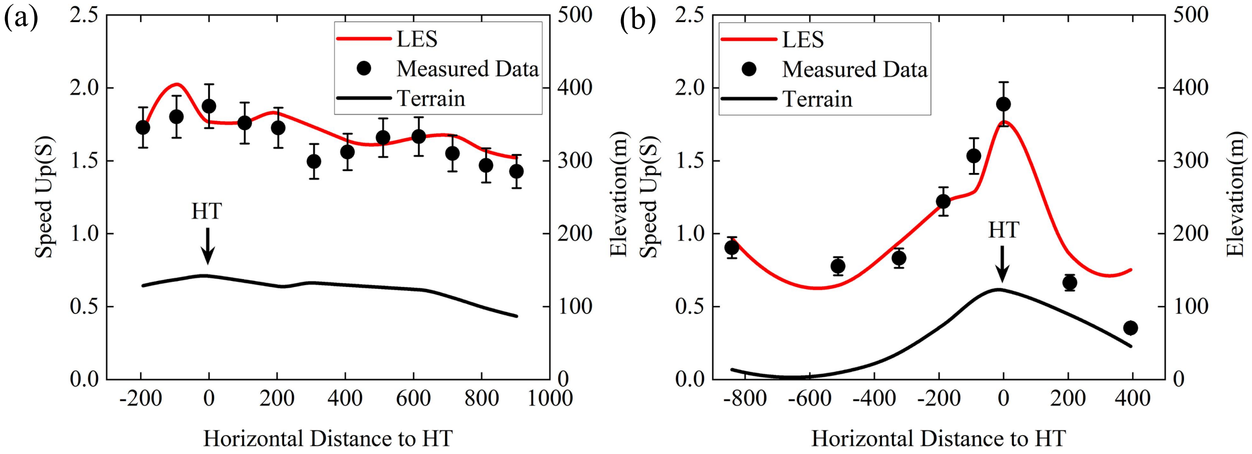

Figure 2. Wind speed ratio at 10 m along (a) line B and (b) line AA.

In the field measurement, more than 50 wind-measuring towers were set up along the line A, line B, and line AA, and the height of most of the wind-measuring towers is 10m. The test obtained a wealth of wind measurement data. In order to verify the accuracy of the numerical calculation, the numerical simulation results are compared with the field measured results, see Fig. 2. Due to space limitations, only the results of line A and line B are given here. It can be seen from the figure that the numerical simulation results and field measurement results show a good consistency, indicating that the numerical simulation results are reliable.

3.2. Flow patterns and turbulence characteristic around the Askervein hill

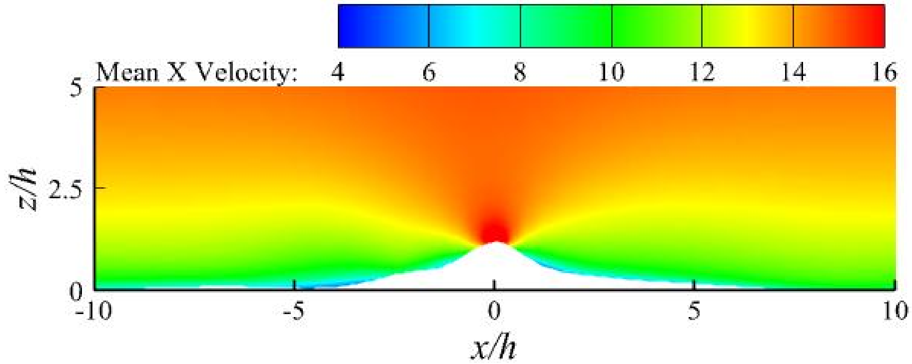

Figure 3. Contours at y=0 for streamwise wind speed .

In Fig. 3 it is shown the contours at y=0 for streamwise wind speed. It can be found that the wind speed is lower on the windward and leeward sides of the hill, and the wind speed increases on the top of the hill, and there is an obvious wind acceleration effect. It shows that the wind resources are abundant at the top of the mountain, which is the best place to arrange wind turbines.

4. CONCLUSIONS

(1) The numerical simulation results are basically consistent with the field measurement results, indicating that the numerical calculation method is trustworthy.

(2) There is an obvious wind acceleration effect at the top of the hill, which is the best place to arrange wind turbines.

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