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A Multiple Actuator Block model for vertical axis wind turbines

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ABSTRACT

In this paper a new model to predict the wake of vertical axis wind turbines (VAWT) is proposed and analysed. The model is based on the actuator disk and the Double Multiple Stream Tube methods. Specifically, the model, denoted as Multiple Actuator Block, is based on the definition, inside the computational domain, of multiple parallelepipedic blocks distributed along the path of the blades. Volumetric momentum sinks are imposed in these blocks to model the effect of the blades on the flow. To analyse the performance of the model a VAWT with three NACA0022, for which numerical and experimental results are available in the literature, has been considered. Different types of simulations with the Multiple Actuator Block model have been carried out and have been compared with a complete finite volume simulation using the sliding mesh technique. This simulation requires about ten times more CPU time than the simulations using the Multiple Actuator Block model. It has been found that the large scale features of the far wake can be reproduced using the Multiple Actuator Block model applying in the block the forces, obtained from the complete finite volume simulation or obtained from a boundary-layer type code, when the blade is inside the block.

1. Introduction

Wind energy has experienced significant progress during last decades and relevant studies have been carried out to improve the performance of the wind turbines. The studies encompass works from the wind distribution along time [1], to the combined aerodynamic–electrical simulation model to evaluate the effectiveness of the control system [2] including experimental and numerical works to analyse the wake of the turbines [3,4]. Moreover, the knowledge in this field has been partially improved by the development of predictive models as for example the actuator disk method [5,6], the Double Multiple Stream Tube model [7,8] or by the use of Computational Fluid Dynamics (CFD) [9] which gives information about the wake of the turbine [10,11].

The most used wind energy extractors are horizontal axis wind turbines (HAWT). The operation of these turbines is well known and the wake they produce has been studied numerically and experimentally [12]. Different methods have been established to predict the wake generated by the HAWT. Some of these approaches are built using rotor predictive methods based on the Actuator Disk (AD) concept that uses the principle of representing rotors by forces distributed on a permeable volume in a flow domain. The concept was introduced by the pioneering works of Froude [5] and Rankine [6] on momentum theory of propellers. A major step forward in the modelling of flow was the development of the generalized momentum theory and the introduction of the Blade Element Momentum (BEM) method by Glauert [13].

The classical Rankine-Froude theory [5,6] considers the axial-momentum balance far up- and down-stream the rotor for a uniformly loaded Actuator Disk (AD) without rotation. The rotor is modelled inducing a constant force along the axis of rotation and applying a momentum balance in a control volume.

The velocity conditions change when the flow interacts with the forces of the AD. The great advantage of the AD model is that it needs less computational effort than CFD vortex wake models giving good results [14–17]. The major drawback is that the blades of the turbine are not simulated; however this approach is adequate to obtain the large-scale features of the wake [18]. Also, the accuracy of the results depends on the accuracy of the forces used as input parameters of the model. It should be noted that the

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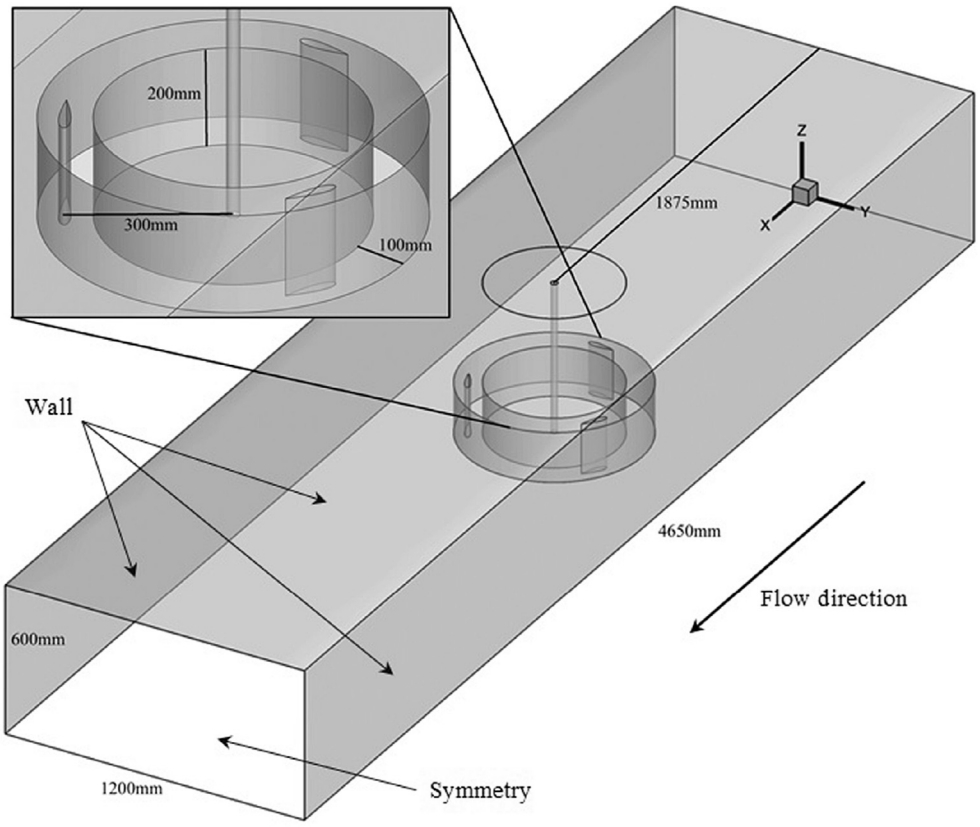
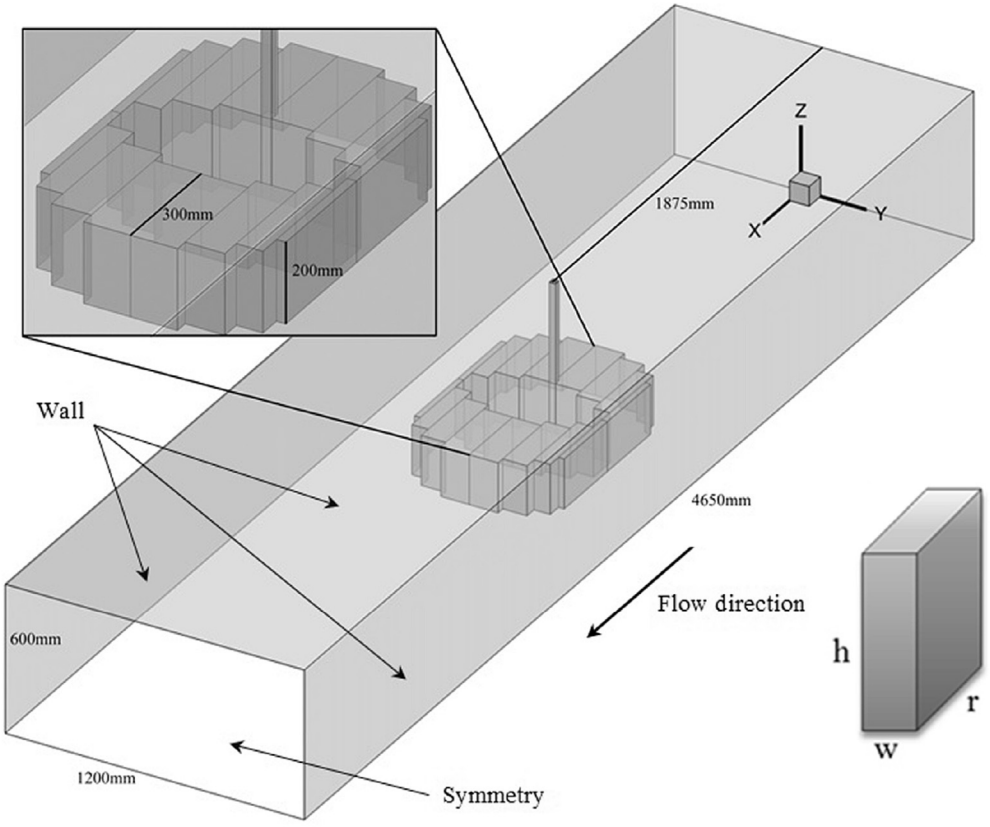


(a)



(b)

Fig. 1. Domains used in CFD studies. a) Complete finite volume domain with sliding mesh. b) Multiple Actuator Block (MAB) model domain.