Journal of Computational and Applied Mathematics 270 (2014) 78–87

Contents lists available at ScienceDirect

Journal of Computational and Applied Mathematics

journal homepage: www.elsevier.com/locate/cam

Three-dimensional simulation of a complete Vertical Axis Wind Turbine using overlapping grids

Michele Nini, Valentina Motta, Giampiero Bindolino, Alberto Guardone *

Department of Aerospace Science and Technology, Politecnico di Milano, Via La Masa, 34, 20156 Milano, Italy

ARTICLE INFO

Article history:
Received 2 October 2013

Keywords:
Vertical Axis Wind-Turbine
RANS
CFD
Overlapping grid
Finite volume scheme

ABSTRACT

Three-dimensional simulations of the aerodynamic field around a three-blade straight-axis Vertical Axis Wind Turbine (VAWT) are presented for two values of the Tip Speed Ratio λ (TSR), namely $\lambda = 1.52$ and $\lambda = 2.5$. Numerical simulations were carried out using the over-set grid solver ROSITA (ROtorcraft Software ITAly). The Reynolds-Averaged Navier–Stokes equations are completed by the Spalart–Allmaras turbulence model. A strong interaction between the blade and the blade wakes is evidenced. Dynamic stall is observed in the case $\lambda = 2.5$. The computed flow-field presents diverse three-dimensional effects, including the interaction between the blades and the tip vortices and the aerodynamic disturbances from the turbine shaft and the support arms. Three-dimensional effects are more relevant for $\lambda = 2.5$. The comparison to experimental data confirms the general features of the flow.

1. Introduction

Wind power represents one of the most relevant and promising renewable alternatives to fossil fuels. The most common devices used to extract wind energy are the horizontal axis wind turbines (HAWT). For medium to small power installation, vertical axis wind turbines (VAWT) can be preferred, due to insensitivity to the horizontal wind direction and low construction costs. Moreover, the lower noise emission makes vertical axis wind turbine more suitable for an urban environment. Unfortunately, the aerodynamic field around a VAWT is very complicated. Rotational motion and the peculiar geometry cause the occurrence of dynamic stall, the generation of tip vortices and the interaction between blades and shaft. As a result, the flow-field is fully tri-dimensional and it represents a challenging aerodynamic problem. A review of VAWT aerodynamics and technical peculiarities is presented in [1] for both the Savonius and the Darrieus VAWT types. In the present paper, the focus is on Darrieus-type turbines. In Refs. [2–4], the flow field around a straight-axis Darrieus-type VAWT is computed using a two-dimensional approximation, to investigate blade–wake interaction, the onset of dynamic stall and the optimal geometric configuration, including the airfoil shape, the optimal blade-to-axis distance and the number of blades. Reference experimental results for two-dimensional models are presented in [5–7], where the effects of the wind tunnel walls on the turbine aerodynamics are accounted for. Three-dimensional effects are studied in Refs. [8–10]. In [8], a single isolated blade is simulated for diverse airfoil geometry and blade solidity σ (airfoil chord to turbine diameter ratio). In [10], a comparison between three-dimensional simulations and experiments is presented for rotors with two and three blades, with a relatively large value of the solidity ($\sigma = 1$, $\sigma = 2/3$).

* Corresponding author.
E-mail address: alberto.guardone@polimi.it (A. Guardone).

http://dx.doi.org/10.1016/j.cam.2014.02.020
0377-0427/

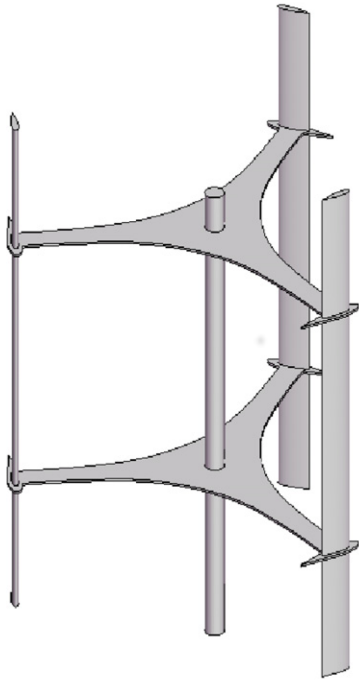

Fig. 1. Wind turbine geometry. All relevant parameters of the turbine geometry are listed in Table 1.

Table 1
VAWT geometric characteristics.

Blade length ($2H$)	1.457 m
Rotor diameter (D)	1.030 m
Solidity (Nc/D)	0.25
Blade airfoil	NACA0021
Chord (c)	0.086 m

In the present paper, three-dimensional simulations of a three-blade VAWT with $\sigma = 0.25$ are presented. The considered geometry is that proposed by Battisti and collaborators [11], for which experimental results are available and are used for comparison. The complete turbine configuration is modeled, including the shaft and the support structure. Differently from Ref. [9], here the support structure is composed by two flat radial elements (see Fig. 1) which are very relevant to the overall aerodynamic flow-field.

The paper is structured as follows: in Section 2, the VAWT model and the numerical method will be presented. In Section 3, results in symmetry and normal planes will be shown and compared with the available experimental data. Finally, in Section 4 concluding remarks are reported.

2. Model description

The turbine was designed and built by *Tozzi Nord Wind Turbine*, within a research project in collaboration with the University of Trento and Politecnico di Milano. The vertical axis wind turbine has three straight blades connected to the shaft by two support arms. The relevant VAWT parameters are reported in Table 1. The CAD model of the complete turbine is shown in Fig. 1.

2.1. Numerical method

Numerical simulations were performed using the finite-volume ROSITA solver developed at Politecnico di Milano for the solution of the Reynolds-Averaged Navier–Stokes (RANS) equations with the Spalart–Allmaras turbulence model [12].

The code is very suitable for the CFD study of moving and rotating bodies (e.g. rotors), due to the capability of treating a system of moving multi-block grids. A Chimera flux-interpolation technique allows to preserve a first/second order accuracy in space. The Chimera algorithm is based on the Chesshire and Henshaw method [13]; the basic idea is to interpolate the fluxes in overlapped regions, using as reference points those belonging to the finer grid. Loads over surfaces are finally