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Critical Analysis Of Dynamic Stall Models In Low-Order Simulation Models For Vertical-Axis Wind Turbines

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Abstract

The efficiency of vertical-axis wind turbines (VAWTs) still lacks from those of horizontal-axis rotors (HAWTs). To improve on efficiency, more accurate and robust aerodynamic simulation tools are needed for VAWTs, for which low-order methods have not reached yet a maturity comparable to that of HAWTs' applications. In the present study, the VARDAR research code, based on the BEM theory, is used to critically compare the predictiveness of some dynamic stall models for Darrieus wind turbines. Dynamic stall, connected to the continuous variation of the angle of attack on the airfoils, has indeed a major impact on the performance of Darrieus rotors. Predicted lift and drag coefficients of the airfoils in motion are reconstructed with the different dynamic stall models and compared to unsteady CFD simulations, previously validated by means of experimental data. The results show that low-order models are unfortunately not able to capture all the complex phenomena taking place during a VAWT functioning. It is however shown that the selection of the adequate dynamic stall model can definitely lead to a much better modelling of the real airfoils' behavior and then notably enhance the predictiveness of low-order simulation methods.

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Keywords: Darrieus; wind turbine; dynamic stall; BEM; CFD; airfoil

1. Introduction

Increasing interest is presently being paid by researchers and industrial manufacturers in re-discovering vertical axis wind turbines (VAWTs), after most major research projects came to a standstill in the mid 90's [1]. The inherent

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advantages of the VAWT (Darrieus) concept (i.e. independence on wind direction, generator positioned on the ground, low noise emissions, good performance in misaligned flows [2]) may outweigh their disadvantages in some specific application, e.g. the urban context [3]. At the present state-of-the-art, however, the global efficiencies of Darrieus turbines still lack from those of horizontal axis rotors (HAWTs) [1], due to their intrinsically more complex aerodynamics coming from the revolution of the blades around an axis orthogonal to flow direction. This generates a continuous variation of the angle of attack, which leads to additional phenomena, like for example dynamic stall [4].

Several semi-empirical methods and correlations have been proposed to account for VAWT's dynamic stall in low-order simulation models (e.g. the Blade Element Momentum Theory - BEM), mainly adapting the original ones developed for helicopter blades [1]. Even though more accurate tools are today available for the simulation [5], low-order methods still represent an industry standard, especially in the preliminary design phase. On this basis, the enhancement of their predictiveness can still provide notable benefits to a more effective design and development of VAWTs [6]. In the present study, the VARDAR research code is then used to critically compare the predictiveness of some widely used dynamic stall models for Darrieus wind turbines by comparing the corrected polars to those obtained upon analysis of calibrated CFD simulations.

Nomenclature

a	induction factor	[-]
A_M	empirical constant of the Berg model	[-]
c	blade chord	[m]
c_L, c_D, c_P	lift, drag, power coefficients	[-]
F_n, F_t (C_n, C_t)	normal, tangential forces (force coefficients)	[N]
R, D, H	turbine radius, diameter, height	[m]
T	torque	[Nm]
TSR	tip-speed ratio	[-]
U	wind speed	[m/s]
W	relative speed on the airfoil	[m/s]
α	incidence angle (AoA)	[deg]
β	pitch angle	[deg]
ϑ	azimuthal angle	[deg]
ρ	air density	[kg/Nm^3]
ω	revolution speed	[rad/s]

2. Simulation codes and case study

2.1. The VARDAR code

The VARDAR research code has been developed by the Department of Industrial Engineering of the Università degli Studi di Firenze, Italy. The code makes use of the BEM theory, by which the rotor performance is calculated coupling the momentum equation in the mainstream direction of the wind and a lumped-parameters aerodynamic analysis of the interactions between the airfoils in motion and the oncoming flow by means of pre-calculated polars (e.g. [1]). In particular, the VARDAR code has been specifically developed for H-Darrieus wind turbines based on the Double Multiple Streamtubes Approach with Variable Interference Factors (DMSV), originally proposed by Paraschivoiu [1] (Fig. 1a), which was the further developed with specific sub-models.

In this approach, the elementary torque for each azimuthal position is therefore given by Eq. 1:

$$T_{blade}(\vartheta) = F_t \cdot R = \frac{1}{2}\rho c W_\vartheta{}^2 C_{t(\vartheta)} R H \tag{1}$$

$$C_t = C_L \cdot \sin\alpha - C_D \cdot \cos\alpha \tag{2}$$