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THE PHYSICS OF STARTING PROCESS FOR VERTICAL AXIS WIND TURBINES

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1. INTRODUCTION

In urban areas the wind is very turbulent and unstable with fast changes in direction and velocity. In these environments, the use of small vertical axis wind turbines (VAWT) becomes increasingly attractive due to several advantages over horizontal axis wind turbines (HAWT). However, such designs have received much less attention than the more common propeller-type designs and the understanding of same aspects of their operation remains incomplete. This is particularly true of their starting characteristics. Traditionally, wind turbine performance is defined in terms of power-extraction performance (expressed dimensionless as power coefficient, C_p) and the turbine's ability to start is normally ignored. Nevertheless if a turbine cannot accelerate through start-up, its power-extraction performance is drastically limited. Therefore, it is crucial to have a good understanding of the mechanism of starting, in particular at relatively low Reynolds number ($\mathrm{Re}_c \cong 10^5$) from the perspective of urban applications. In present paper particular attention is paid to VAWT working which is not fully understood.

2. AERODYNAMIC OF A VAWT

a) b)

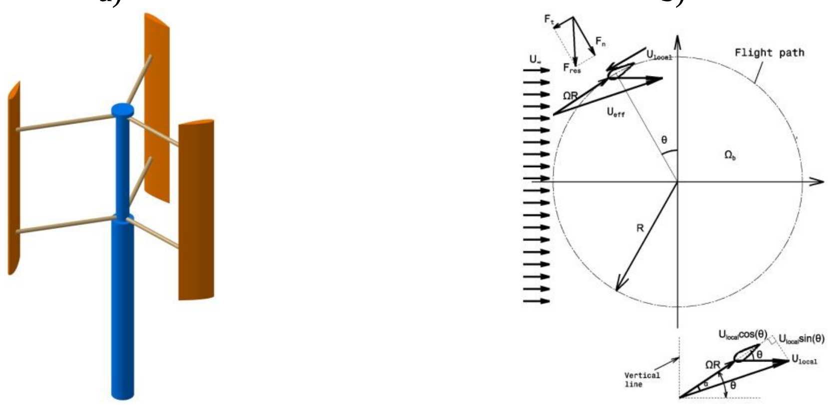

Figure 1 – Basics of VAWT: a) sketch of a fixed-pitch straight-bladed VAWT; b) typical flow velocities in Darrieus motion.

Figure 1a is a schematic of a straight-bladed-fixed-pitch VAWT which is the simplest, but typical form, of the Darrieus type VAWTs. Despite the simplicity, its aerodynamic analysis is still quite complex. One feature is that the relative velocities perceived by the blade always change as the blade moves at different azimuthal positions. Figure 1b illustrates typical flow velocities around a rotating

VAWT blade at a given azimuthal angle θ, as well as the aerodynamic forces perceived by the blade. The azimuthal angle θ is set to be zero when the blade is at the top of the flight path and is increases in a counter-clockwise direction. It should be noted that, even neglecting the variation of the induced local flow velocity, U_{local} both the magnitude and the direction of the effective velocity perceived by the blade, U_{eff}, change in a cyclic manner as the blade rotates through different azimuthal angles. This kind of motion is called the Darrieus motion [1]. An important parameter of Darrieus motion is the reduced frequency which governs the level of unsteadiness ($k = \Omega_b c / 2U_{eff}$). The unsteadiness, associated with the flow field and VAWT operating state, shown in Fig. 2, can be classified into three levels:

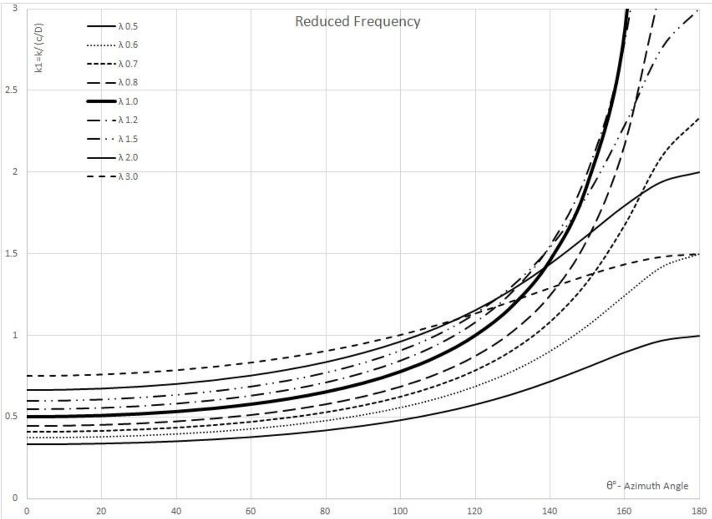

Figure 2 –Reduced frequency as a function of λ and the azimuth angle θ.

- Zero level is the distributed unsteadiness, when $k/(c/D) \leq 1.0$ and $\lambda \leq 0.5$; commonly its effect is neglected and a quasi-steady assumption is used;
- First level is the located unsteady phenomenon of dynamic stall with lift increment at low angle of attack ($\alpha \approx 25^0$),occurring at $\theta = 90^0$ when $k/(c/D) \leq 2.0$ and $\lambda \geq 2$; its effect is similar to a sinusoidal pitching airfoil;
- Second level is a located unsteady phenomenon of dynamic stall with drag reduction at high angle of attack ($\alpha > 45^0$), occurring at $\theta = 180^0$ when $k/(c/D) > 2.0$ and $\lambda \cong 0.7 - 1.5$; to this day it is still unknown.

In contrast to classical lift dynamic stall, which is a phenomenon well documented [2], [3], the drag dynamic stall computationnaly investigated by us at low tip speed ratios has not been identified in the wind turbine community. Therefore, in the present paper we only focus on the effective Darrieus motion of VAWTs at low tip speed ratios which directly affects rotor starting.

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