Unsteady Flow Simulation and Numerical Investigations of Dynamic Stall Phenomenon for Vertical Axis Wind Turbine

F.Frunzulica[1,2], H.Dumitrescu[2] & Al. Dumitrache[2]

[1]POLITEHNICA University of Bucharest, Faculty of Aerospace Engineering, Polizu 1-6, RO-011061, Bucharest, Romania
[2]"Gheorghe Mihoc – Caius Iacob" Institute of Mathematical Statistics and Applied Mathematics, P.O. Box 1-24,RO-010145, Bucharest, Romania
Corresponding author: ffrunzi@yahoo.com

In the last years, for home user, the wind turbine with vertical axis (VAWT) began to be more attractive due benefits in exploitation, the power range covering usually the domain 2 kW-20 kW.

In terms of aerodynamics, when the wind speed approaches the speed of operation (for low value of tip speed ratio, $\lambda = \Omega\ r / V_w$) the blade airfoil of VAWT exceeds the critical angle of incidence for static conditions. Angle of incidence varies quickly across blade and the blade works in dynamic stall condition.

The dynamic stall has an effect of increasing the lift when the incidence increases rapidly and decrease lift when incidence decreases rapidly, compared with aerodynamic static characteristics (delays both flow detachment and flow reattachment). These sudden variations of unsteady aerodynamic forces greatly enhance the unsteady loads on the blade and can be dangerous for the integrity of the blade structure.

The model has 3 and/or 5 blades, H-Darrieus VAWT type with fixed solidity, and NACA 0012 airfoil.

The complexity of the unsteady aerodynamics of the VAWT makes it extremely attractive to be analyzed using Computational Fluid Dynamics, where an approximation of the unsteady Navier-Stokes equations is solved. Based on the Reynolds number, the solver will be set adequately to laminar, transitional or turbulent flow.

The present work will be structured in the following sections:

A. Investigations of the dynamic stall characteristics ($\lambda = \Omega\ r / V_w \in [1,3]$, VAWT work in "lifting" regime) for isolated airfoil in the pitching motion with an incidence law corresponding to the ideal blade incidence in the VAWT rotation (fig. 1). We will study possibility to use the dynamic stall characteristics in a preliminary design program based on the free wake method.

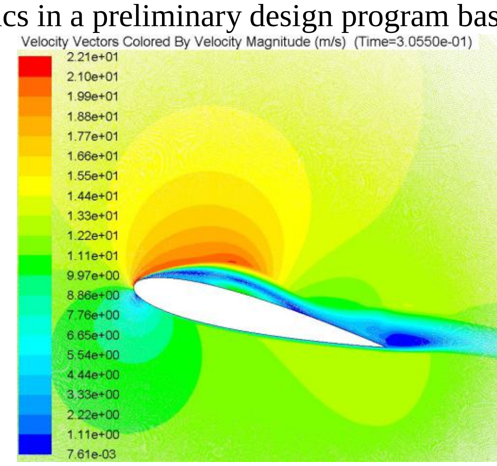

Fig. 1. Instantaneous velocity vectors for pitching moving dictated by the law $\alpha = \operatorname{atan}(((1-a)\cdot\cos(\varphi))/(\lambda + (1-a)\cdot\sin(\varphi)))$, where a=1/3 is the axial induction factor and $\varphi(t)$ is the azimuth angle

B. The same analysis will be performed using three flow control methods (two passive and one active) integrated in airfoil, described in the next paragraph. The objective is to evaluate the efficiency of these methods to improve the performance of VAWT.

C. Two-dimensional unsteady flow simulation for VAWT with and without flow control devices (fig. 2).

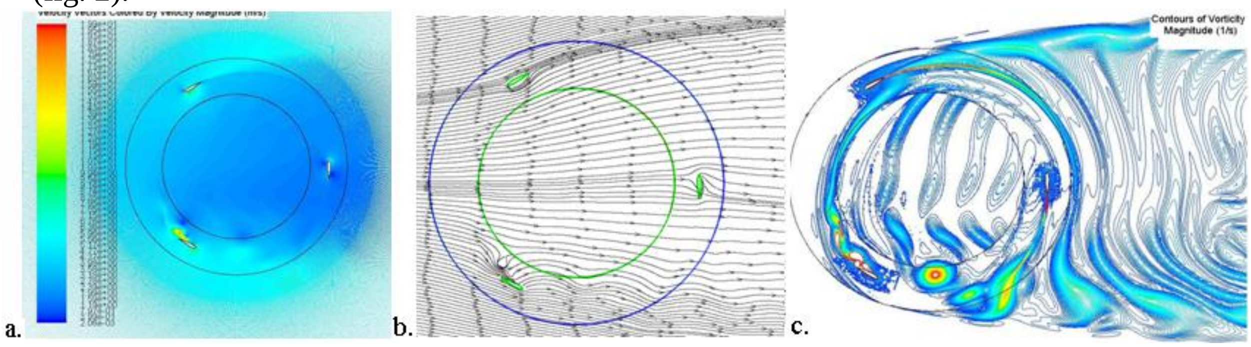

Fig. 2. Velocity field for VAWT(a), streamlines (b), and (c) contour of vorticity magnitude for Darrieus VAWT (λ =2.5, solidity = 0.3, V_w=5 m/s, Re=0.35e+05)

D. Conclusions about numerical investigations…

We will use three methods to flow control on the VAWT blade:

1. Active control. Circulation control is implemented, usually, by tangential blowing a small high-velocity jet over a highly curved surface, such as a rounded trailing edge. This causes the boundary layer and the jet to remain attached along the curved surface due to the Coanda effect (the tendency of a moving fluid to attach itself to a surface and flow along it) and causing the jet to turn without separation as in Fig. 3.

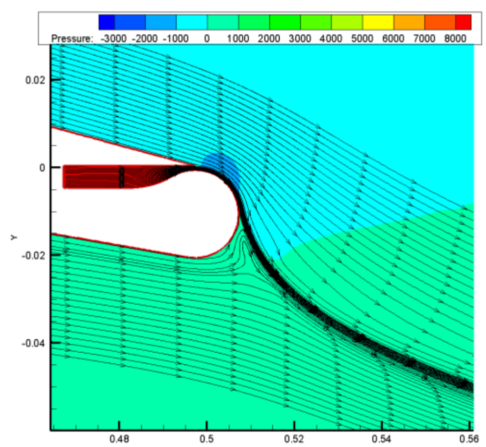

Fig. 3. Circulation control at trailing edge ($V_{int\,r} = 22\ m/s,\ \ V_\infty = 30\ m/s$)

The airfoil with this device has a large-radius rounded trailing edge (to maximize the lift), and the drag increase substantially when the jet is turned off. The circulation control for design of VAWT can be advantageous because any increase in the magnitude of the lift force (while keeping drag small, and lift/drag high) will contribute to a increasing in induced torque.

If the flow over the airfoil separates at the leading edge is necessary secondary Coanda jets at the leading edge to maintain the flow attached to airfoil.

Forced jets have a few disadvantages: complexity of internal piping from a source of pressure or vacuum, and the parasitic cost to produce this pressure. While circulation control with forced jets has the potential for increased power generation, the power is consumed in the generation of the jet. A challenge is to reduce the power consumption to produce the jet and using efficiently the jet to control flow separation.

2. Passive control.

2.1. One technique of increasing the lift of airfoils is the use of passive devices, one of these being known as Gurney flap. The Gurney flap is a small tab attached perpendicular to the lower surface of the airfoil in the vicinity of the trailing edge, with a height that can vary from 1% to 5%. The results showed a significant increment in lift compared to the baseline airfoil. This device increases the drag, but the percentage increase in lift is greater, resulting in an increased lift/drag ratio and therefore a better efficiency and performance. The flow structure downstream of a Gurney flap has a dual recirculation region that produces increasing lift due the significant turning of the upper-surface trailing-edge flow (Fig. 4) and reduces form drag due the longer region of attached flow near the trailing edge.

Due to its simple geometry, construction of the Gurney flap is simple and implementation of this device is easily accomplished. We will investigate the efficiency of simple and double tab mounted on the blade airfoil.

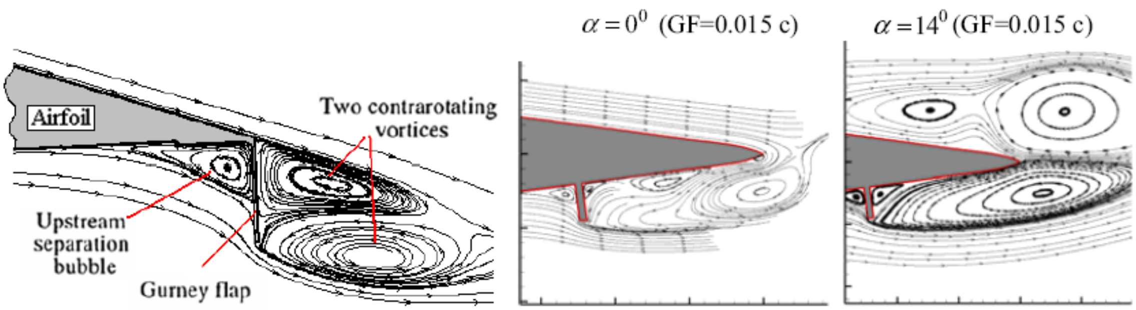

Fig. 4. Flow near Gurney flap.

2.2. Another passive device uses a slot between lower-pressure and high-pressure points (near the separation point) on the upper surface of the thick airfoil (at positive angle of attack). The tendency of redistribution of the pressure will maintain the boundary layer attached to the upper surface. Thus the form drag is reducing and the lift changes the orientation. The advantage of this method is that not implying additional source of power and can be used as a passive/active control of flow. In fig. 5 we present a slot used to increase Coanda effect on the circular surface.

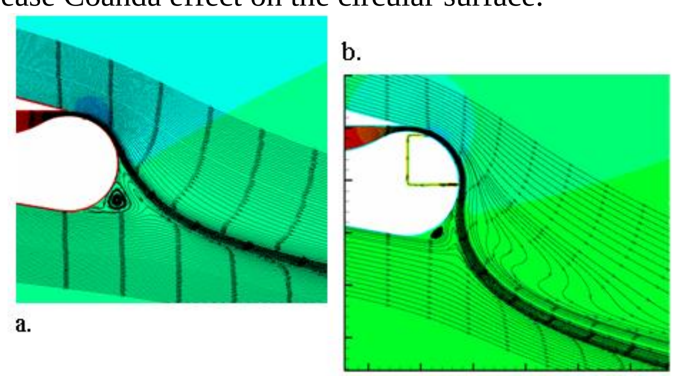

Fig. 5. The slot (b) increase the length of attached flow on the circular surface ($V_{intr} = 16\ m/s,\ \ V_\infty = 30\ m/s$)

In conclusion, the paper has two main objectives: one is to investigate the two-dimensional dynamic stall phenomenon around the NACA 0012 airfoil (for a given incidence variation law similar to local incidence in the VAWT rotation) without and with flow control device and the second one is to analyze the unsteady 2-D flow of VAWT rotor without and with flow control device mounted on blade. We evaluate their effects on the increasing performances of VAWT but these can be used with success in aviation.