CIRCULATION CONTROL ON WIND TURBINE BLADES IN ORDER TO ALLEVIATE AERODYNAMIC LOADS FLUCTUATIONS

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1. Introduction

The present abstract presents the results obtained by PRISME laboratory within a project funded by the "Conseil Général du Loiret" in collaboration with Vergnet SA, and how they will contribute to initiate the 2015-2018 French project SMARTEOLE. The ambition of the project is to improve the efficiency of the wind energy production by proposing innovative control solutions at the scale of the wind farm, the wind turbine and the blade, with an increasing degree of maturity, and developing a concept of smart rotor. At the blade scale, the objective is to control the aerodynamic loads on the blade by means of a modification of the pressure distribution, associated with a modification of circulation, with fluidic and/or plasma actuators distributed over the blade. The innovative potential of closed-loop active circulation control to mitigate aerodynamic loads for wind energy applications will be demonstrated through lab experiments.

2. Approach

An experimental approach in wind tunnel is used in the present study. Experiments about aerodynamic performance of a CC-driven airfoil are performed in 2D configurations and in rotating configurations (Fig 2 and 3). To do so, a wind turbine bench was designed, giving the possibility to measure the pressure distribution around an airfoil section in rotation, the power and the thrust of the wind turbine model, and the flapwise bending moment of each blade.

3. Main body of abstract

Wind energy is one of the most dynamic industries worldwide with an annual increase rate of activity of 20%. It is expected that it contributes also for France to reach its energy, economic and environment objectives by being a modern, reliable and cost competitive source of energy. The wind power is a growing market in France since the current installations supply 8.3 GW, with 631 MW installed in 2013.The national objectives plan to reach 25 GW of wind power installed in 2020 (19 GW onshore and 6 GW offshore). This ambitious challenge implies to dramatically increase the installed capacity with an average rate of 2 GW per year. The technology involved in the wind energy sector is wrongly considered as mature whereas the real-time wind turbine (WT) efficiency is strongly deteriorated by the relative unpredictability of the short-term wind conditions. In order to reduce the Levelized Cost of Energy (LCoE), the robustness and the life duration of the WT's must be improved to ensure operation availability and an optimal energy production during periods longer than 15 to 20 years. Indeed, WT's operate in a very hostile environment regarding their durability, since the wind conditions they encounter in the Atmospheric Boundary Layer are strongly inhomogeneous and unsteady. They are then subject to unsteady wind loads, responsible of combinations of unsteady mechanical loads with characteristic time scales from seconds to minutes. The wind conditions can become even more hostile when WT's are arranged in parks, since the WT wakes, which are characterized by a velocity deficit and production of turbulence, can impact other WT's. When not properly managed, this could lead in real life to blade damage after only 5 years of operation.

Alleviating the impact of these upstream wind fluctuations would lead to more sustainable life conditions for the rotors, and consequently, improved economics and reduced LCoE. This can be achieved by controlling in real-time the aerodynamic performance of the WT rotors in order to immediately compensate the overloads. The standard way to reduce load fluctuations on current WT's is based on the mechanical pitch control, modifying the overall blade pitch. This strategy contributes to mitigate loads but it has been observed that it cannot be optimal since it is characterized by a global modification of the pitch whereas it would be more optimal to combine this action with a more local one, directly on blade areas that contribute at the most to the torque generation. Furthermore, the action cannot be anticipated since the wind upstream of the blade is not measured, leading to a curative strategy instead of a preventive one. The project SMARTEOLE aims at optimizing the wind energy efficiency by developing innovative control concepts of WT's (gathered within the term of "smart rotor") - based on the real time measurement of the incoming flow conditions

The contribution of PRISME laboratory is focused on the proposition of innovative control solutions on the blades at a lab scale. A circulation control (CC) strategy had been chosen based on the active flow control through Multi Dielectric Barrier Discharge (DBD) plasma actuators at the trailing edge (TE) of the blade in order to increase or decrease the lift, responsible of the generated torque, on demand. Indeed, their orientation enable the generation of an upward or downward tangential jet, leading to a lift decrease or increase, respectively.

Controlling the circulation generated by an attached flow needs to have a rounded trailing edge. A large amount of circulation control CFD and experiments were performed. Initially, applications were focused on fixed wind aircraft and were progressively applied to any control surface (flap, aileron, engine, propeller ...), then submarine /hydrodynamics and rotary wings. The main objective was to increase the lift or circulation by acting at the trailing edge when large lifting forces and/or slow speeds are required, such as at take-off and landing of aircraft. Indeed, circulation control is able to significantly improve lift at low angle of attack (up to 80%).One can find a survey of circulation control applications in [1, 2, 3]. Recent applications are turned nowadays towards WT [3] and water turbines. Regarding plasma actuators, they were already used to control circulation on thick airfoils, showing the feasibility of this strategy [4-5]. Their efficiency needs to be improved to ensure an acceptable energy balance.

The generic airfoil profile to be modified was chosen to be a NACA65_4-421 for two reasons:

- Experimental works on aerodynamics of this profile had been already performed in PRISME Laboratory [6], leading to the possibility to compare performance of this profile and the CC-oriented one.
- It is a profile which is considered as appropriate for wind turbine blades. Vergnet SA implemented this profile on some parts of their blades of dynamic stall controlled wind turbines.

The trailing edge of the generic profile is replaced by a rounded TE with a radius of curvature of 2% of the chord. The shape adjustment between the modified TE and the pressure side is designed in order to increase the airfoil camber, as a counterparty of the expected degradation of the aerodynamic performance due to the round TE. Fig. 1 shows the comparison between the generic NACA65_4-421 airfoil profile and the CC-oriented airfoil profile NACA65_4-421-CC.

The first part of the paper will describe the CC-oriented profile and its aerodynamic performance obtained through wind tunnel experiments (Fig. 4 and 5). It will be compared with the performance of the generic profile with sharp trailing edge. Additionally, the control strategies must be implemented on a wind turbine bench in order to check its efficiency in rotating configurations. The wind turbine bench that had been designed thanks to a previous project with Vergnet SA will be then described and finally first results will be shown.

4. Conclusion

The present study aimed at characterising the aerodynamic performance of a circulation-control oriented profile based on the modification of a classical NACA65_4-421. Through load and pressure distribution measurements, the lift and drag coefficients had been obtained and compared to the original airfoil section. It had been proven that the roundness of the trailing edge did not deteriorate the aerodynamic performance of the profile because its effect was compensated by the additional camber.

A new wind turbine test bench had been designed, measuring the global power and thrust performance of the wind turbine and the local pressure distribution around the rotating airfoil. The blade design gave the possibility to change the location of the section equipped with the pressure taps.

First results were promising since the expected performance deduced from BEM theory were actually measured.

5. Learning objectives

The present study will be continued through the national project SMARTEOLE, where open-loop and closed-loop active circulation control will be applied to the new-designed profile, in a 2D configuration and then in rotating configurations. The ability to maintain a constant lift, and so a constant aerodynamic performance, whatever the incoming disturbances are, will be experimentally demonstrated. To do so, the incoming flow conditions and/or the airfoil angle of attack will be modified in real time with time scales representative of real situations. For the rotating airfoils, a wind turbine misalignment will be applied in order to supply a periodic disturbance that will be also counteracted by active CC control.

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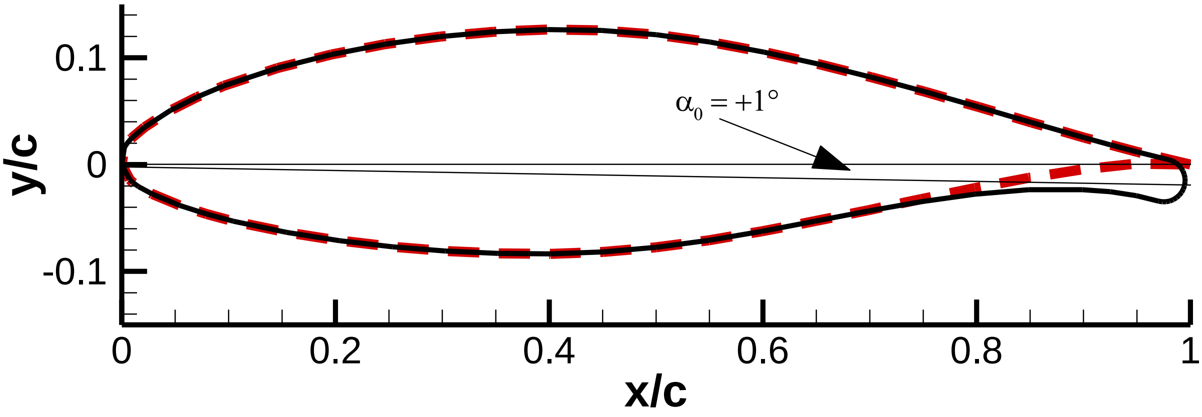

Figure 1: Comparison between the generic NACA65$_4$-421 airfoil profile and the circulation control-oriented NACA65$_4$-421-CC.

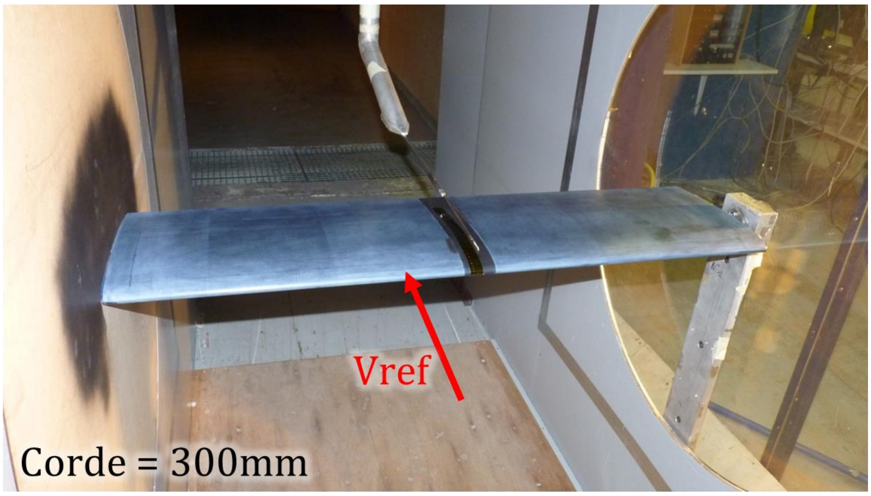

Figure 2: 2D CC oriented airfoil located in the test section of the wind tunnel.

Figure 3: 2-blade wind turbine bench.

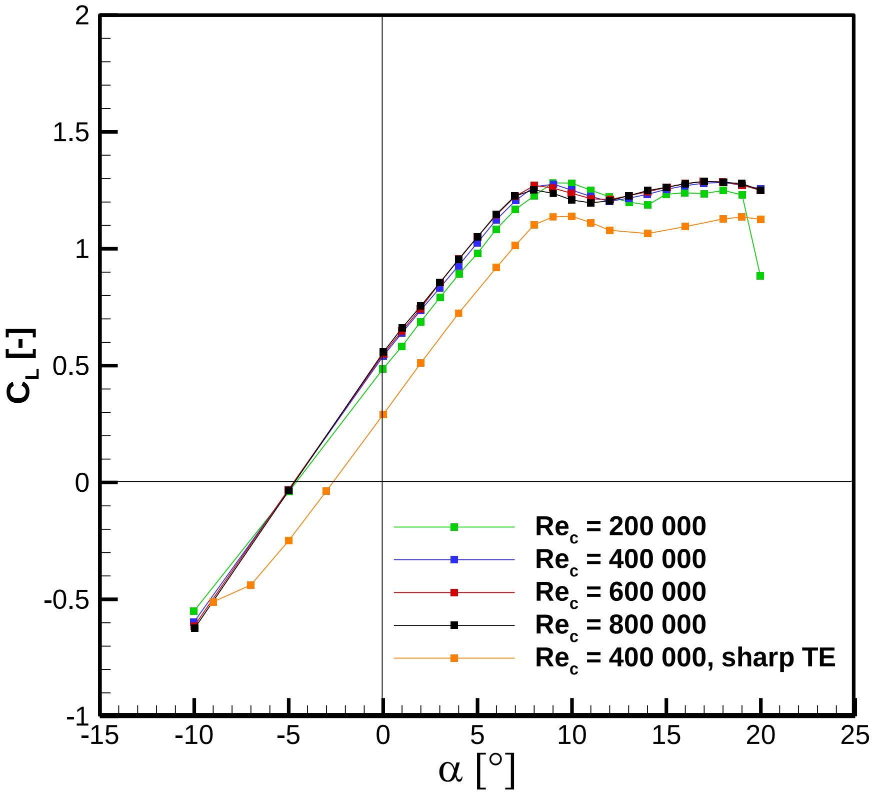

Figure 4: Lift coefficient versus angle of attack for the CC-driven airfoil and for different Reynolds number. Comparison with the sharp-edge profile.

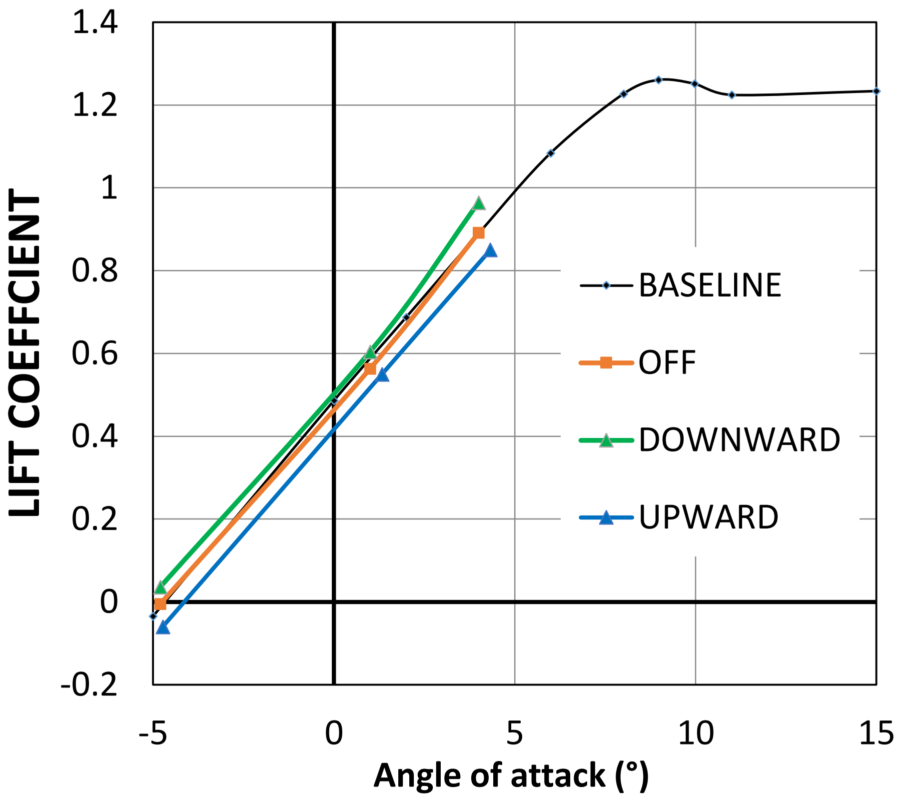

Figure 5: Lift coefficient versus angle of attack for the CC-driven airfoil for different plasma control configurations.