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Numerical analysis of the effects of Gurney Flaps on vertical-axis wind turbines performance

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1 Introduction

In recent years, a renewed interest has arisen towards Vertical Axis Wind Turbines (VAWTs), due to their advantages in non-conventional installations with respect to the well-established horizontal axis architecture (HAWT). The main obstacle to their diffusion is currently represented by the lower peak efficiency achievable by these machines, when compared to their horizontal-axis counterparts, due to the complex and unsteady aerodynamics involved in their functioning. To increase the energy conversion efficiency, passive airfoil add-ons, which are able to delay the onset of stall and to increase the lift-to-drag ratio, may provide a valuable contributions. In such perspective, an attractive solution is represented by Gurney Flaps (GFs). These passive devices in fact, by altering the vortex pattern developing around the airfoil trailing edge, are able specifically to increase the profile efficiency and resistance to stall, considerably improving the overall turbine performance at the low/medium tip-speed ratios.

Moving from this background, the research group has carried out an extended numerical investigation on the effects of Gurney Flaps on VAWT performance. High-fidelity 2-D CFD simulations have been carried out on both static and rotating profiles. In order to get a better understanding of the device behaviour and maximize its performance, several configurations, obtained by varying the flap length and its inclination w.r.t the airfoil chord, have been tested and critically compared. The scope of the research is to provide a deeper insight on the potential benefits offered by Gurney Flaps to VAWT performance, together with some guidelines for their design.

2 Methodology

2.1 Pitching CFD Model

For the present study, an ad hoc pitching airfoil 2-D CFD model was developed using the commercial software ANSYS® FLUENT® 18.2. The model is characterised by a pressure-based, U-RANS formulation, combined with the *k-ω SST* turbulence model. For more details on the numerical set-up, please refer to [1]. Based on a dedicated sensitivity analysis, a temporal resolution of 1500 timesteps per pitching cycle was considered adequate. In order to assess its reliability, the developed CFD model was validated against ad hoc static wind tunnel tests (NACA0021, Re=180k, h_{GF}/c=2.5%), carried out at the Hermann-Föttinger Institute (TU Berlin, Germany).The behaviour of the airfoil in Darrieus-like motion was mimicked by feeding the newly developed pitching model with the angle of attack history deriving from the CFD simulation of full rotors, properly extracted from the flow field via the method outlined in [2]. More in detail, the two 1-bladed rotors from [3] and the 3-blade one from [4] were adopted as test cases. Such strategy allowed to include the rotor solidity effects into the investigation, and at the same time to significantly reducing the computational cost w.r.t a full rotor simulation.

2.2 Design space

For each of the rotors described in Section 2.1, three different GF configuration were tested, shown in Fig. 1: GF_{in} (flap directed towards the axis of rotation), GF_{out} (flap pointing in the opposite direction w.r.t. the axis of rotation), GF_{ft}. In turn, each rotor-flap combination was analyzed for 4 different profile thicknesses t (NACA0012, NACA0015, NACA0018 and NACA0021) and 5 Gurney Flap lengths h_{GF} (1%, 2%, 3%, 4% and 5% of the chord).

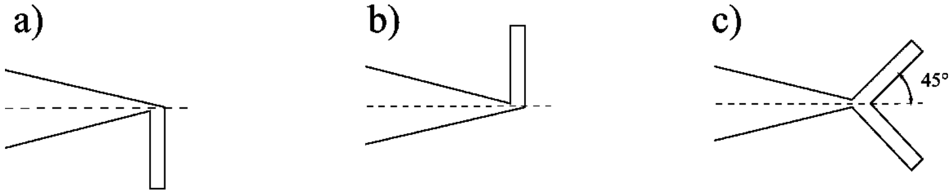

Figure 1 Different Gurney Flap shapes considered for the present study (a) GF_{in} (b) GF_{out} (c) GF_{ft}.

3 Results

Table 1 reports the characteristics of the optimum points, in terms of h_{GF} and t, for the different turbine-flap combinations considered in the present study. It is first apparent that GF_{out} provides a higher power coefficient increment C_P/C_{P0} (where the suffix 0 refers to the baseline without GF) w.r.t. GF_{ft}, for all the test cases under analysis. Such discrepancy becomes more relevant going towards high-solidity rotor configurations and thicker airfoils. The fishtail configuration GF_{ft} on the other hand, in spite of its lower performance in terms of efficiency enhancement, is characterized by a lower blade load imbalance between the upwind and downwind sides of the rotor. For this configuration, maximum C_P/C_{P0} is reached for low-solidity architectures, possibly combined with thicker airfoils.

Table 1 Characteristics of the maximum efficiency configurations derived from the present study.

solidity	0.057		0.125		0.25	
GF shape	GF_{out}	GF_{ft}	GF_{out}	GF_{ft}	GF_{out}	GF_{ft}
t [%c]	18.38	19.87	15.52	19.94	14.06	19.74
h_{GF} [%c]	3.48	2.08	3.50	2.84	3.42	2.42
C_P/C_{P0}	1.38	1.35	1.50	1.29	1.88	1.74

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