



HAL
open science

Experimental and numerical study on a model of offshore vertical axis wind turbine with pitching blades

Hubert Branger, Benoit Paillard, Sukanta Roy, Christopher Luneau,
Emmanuel Perrot, Denis Bourras

► To cite this version:

Hubert Branger, Benoit Paillard, Sukanta Roy, Christopher Luneau, Emmanuel Perrot, et al.. Experimental and numerical study on a model of offshore vertical axis wind turbine with pitching blades. 7th Conference on Bluff Body Wakes and Vortex-Induced Vibrations, BBVIV-7, Jul 2018, Carry Le Rouet, France. hal-02081410

HAL Id: hal-02081410

<https://hal.science/hal-02081410v1>

Submitted on 27 Mar 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Experimental and numerical study on a model of offshore vertical axis wind turbine with pitching blades

Hubert Branger^a, Benoit Paillard^b, Sukanta Roy^c, Christopher Luneau^d,
Emmanuel Perrot^e, and Denis Bourras^f

a: IRPHE, CNRS, Aix Marseille Univ, Centrale Marseille, Marseille, France

branger@irphe.univ-mrs.fr

b: EOLFI, Paris, France

c: Mech Engineering Dept, Curtin University Sarawak, Miri, Malaysia

d: OSU PYHTEAS, CNRS, Aix Marseille Univ, Marseille, France

e : CORETI, Gardane, France

f : MIO, Aix Marseille Univ, Université de Toulon, CNRS, IRD, MIO, Marseille, France

Due to growing interest in offshore wind energy, vertical axis wind turbines (VAWTs) have recently received renewed interest. Their low center of gravity, omni-directional capability, and ability to rotate even if the platform base is not strictly horizontal, make them a very interesting option for suitable large floating wind turbines. However, because of the lack of research and the complexity of the flow, lift-driven VAWTs require further investigations to be competitive with horizontal axis wind turbines (HAWTs). One potential improvement is to pitch the vertical blades during their rotation (Figure 1) in order to have a better angle of attack, thus increasing lift, decreasing drag, and enhancing rotational speed [1]. Pitching the blades allows also an easier initial rotational starting procedure [2], and the ability to slow down the rotation in strong wind conditions.

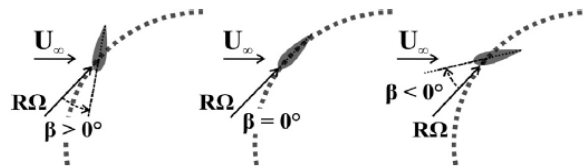


Figure 1: view from above: examples of pitch angle β for a VAWT blade.
 U_∞ is the incoming wind speed, R is the turbine radius, Ω is the angular velocity

In this context, we built a simple 1/100 scale model of a large three blade H-type Darrieus vertical wind turbine with active pitch-control (c.f. EOLFI SpinFloat project¹).

First, numerical simulations have been performed on various NACA 4-series, 5-series and Selig airfoil profiles at different chord Reynolds numbers using double multiple stream-tube model (DMST) with tip loss correction [3] [4] [5]. Based on the power coefficient, the best suitable airfoil Selig1046 has been selected. The measured polar of the lift coefficients C_L and drag coefficients C_D of the experimental blades are shown on figure 2 for different chord Reynolds numbers. Besides the blade profile, the turbine design parameters such as aspect ratio $A_R = L/D$ and solidity ratio $\sigma = nC/D$ (with L : the blade length, D the turbine diameter, n : the number of the blades, C the chord length), have also been investigated through the QBLADE model [6] [7] by varying the turbine diameter and the chord of the blades. Figure 3 is a view of the turbine we finally designed.

¹ <https://www.eolfi.com/en/eolfi-research-development/spinfloat>

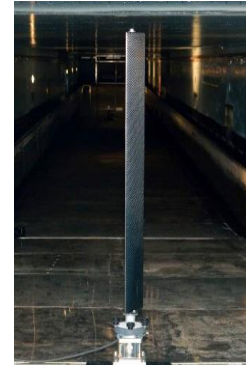
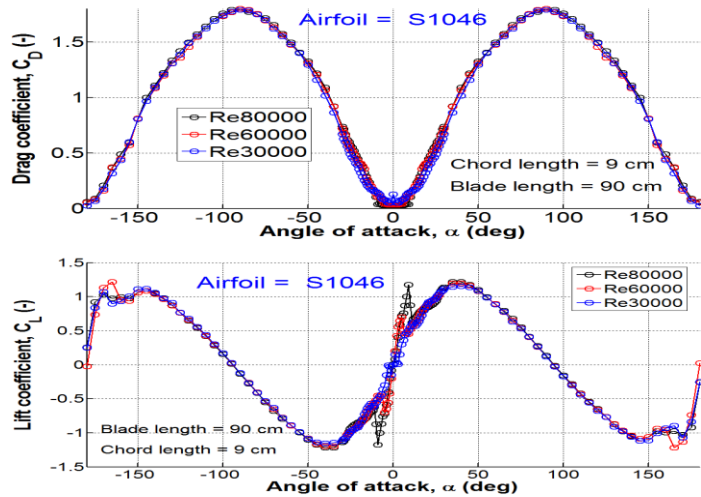
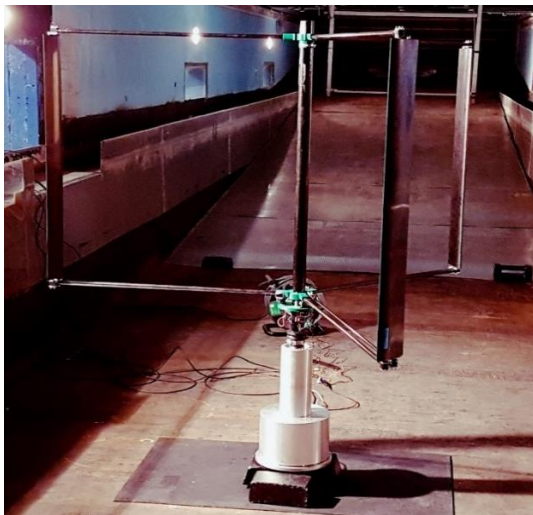


figure 2: Measured lift and drag coefficients with the Selig-1046 blade for 0° to 360° angle of attack.



VAWT characteristics:

- Diameter: 1.60 m
- Blade length: 0.90 m
- Blade chord: 0.09 m
- Blade max thickness: 0.015 m

Pitching performance:

- 3 servo motors
- Amplitude +/- 30° ,
- Celerity: 60°/0.1 s
- Max torque: 48 Kg.cm

Pitch Control:

- Control-command: every 0.3° in azimuthal rotation
- Teensy cards + computer + Arduino + Python programs

Figure 3: VAWT experimental model

We used three active servo-motors to pitch the blades. These actuators have fast response time with quite high torque performance to pitch continuously the blades even when the turbine rotates rapidly. The control-command procedure is driven with two teensy cards, a computer, Python and Arduino software.

An important parameter is the Tip Speed Ratio $TSR = R\Omega/U_\infty$ with U_∞ , the incoming wind speed, R the turbine radius, Ω the angular velocity. At low TSR, a large pitch amplitude is needed in order to reduce the angle of attack and hence to enhance rotor performance. Conversely, while a small pitch amplitude is sufficient to produce good performance at high TSRs. We made a specific study to determine optimized pitch amplitude as the TSR changes.

DMST- and QBLADE- type models were first used to have a first guess of possible pitch laws that could be used to enhance the turbine performance. Then, we performed 2D numerical simulations with a Computational Fluid Dynamics (CFD) commercial finite element URANSE solver CFX [8] in order to have more information on the pattern of the flow associated with each pitch function used.

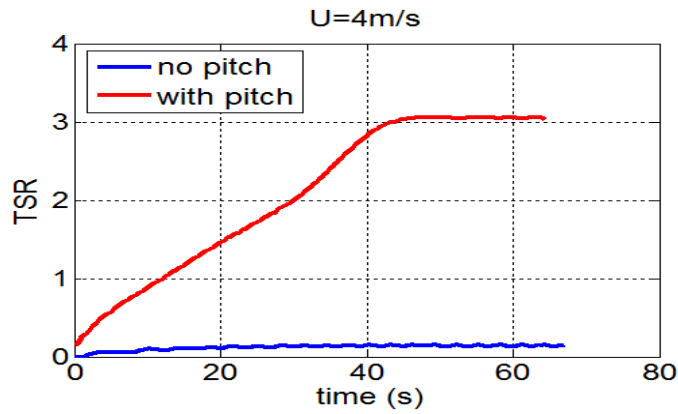


Figure 4: Time series of the recorded Tip Speed Ratio for the same incoming wind speed; blue: pitch off; red: pitch on.

Experiments were then conducted in the large IRPHE/PYTHEAS air-sea interaction facility² in Luminy Marseille, with force and moment evaluation, rotational sensors to detect the blade-azimuthal position and rotational speed, and particle image velocimetry (PIV) measurements. A particular care was taken on the control-command of the pitching laws to increase the aerodynamic performance and the turbine efficiency.

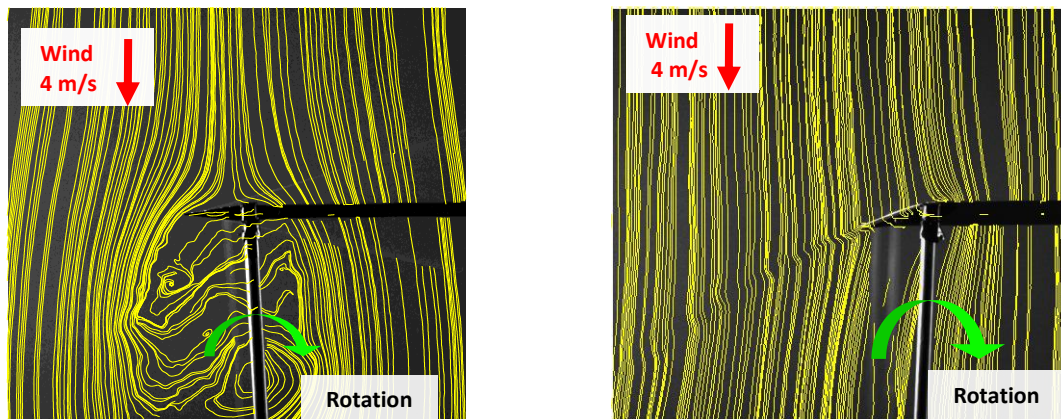


Figure 5: measured streamlines, same incoming wind speed: 4 m/s ; view from above. Left: Pitch Off; Right: Pitch On

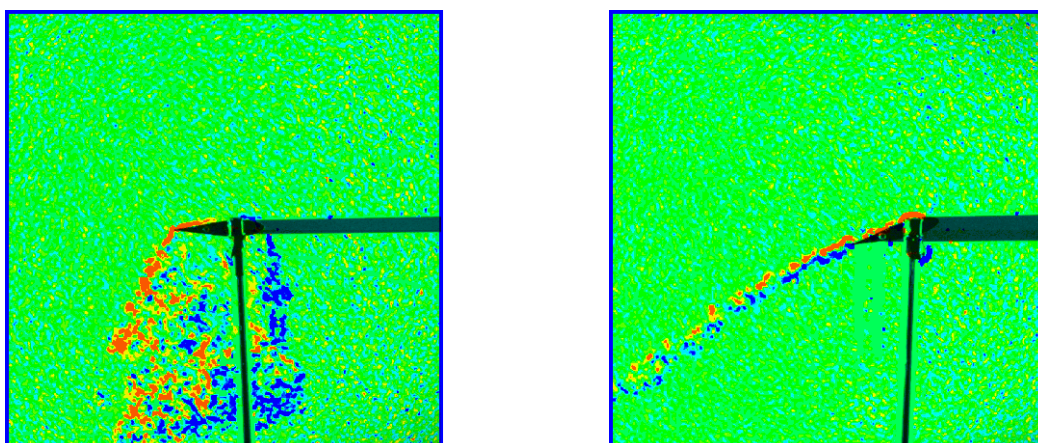


Figure 6: measured vorticity field, same incoming wind speed: 4 m/s ; view from above. Left: Pitch Off; Right: with Pitch On

An open source genetic algorithm optimization software, Dakota, was used to determine the best pitching laws, with input variables such as incoming wind speed, angular

² <https://www.osupytheas.fr/?-LASIF-Grande-Soufflerie-air-eau-de-Luminy->

velocity, blade azimuthal positions, TSR. Dakota contains algorithms with stochastic expansion methods, reliability, sensitivity variance analysis and advanced strategies with automatic direct real-time data exchange between on-going experiments and software [9] .

Finally, we found that at rather low wind speed, pitching the blade brings a considerable gain on the TSR (Figure 4). The rotational speed, in this example, is multiplied by 20 with the same incoming wind speed !

To better understand the positive gain obtained by those pitch laws, we then made PIV measurements of the flow around the blade in no-pitch and pitch conditions, for variable TSR. Figure 5 is an close-up example of the streamline field differences between no pitch and pitch on conditions for the same incoming wind speed $U = 4$ m/s. Figure 6 is the associated vorticity field. We see clearly the huge modification of the flow due to the blade pitching. The TSR (and by the way the blade velocity) is much higher when the pitch is on, thus generating visible better conditions for decreasing drag and increasing lift creating higher efficiency. Velocities, vorticity and streamlines were compared with the CFD numerical simulations.

References:

- [1] Abdalrahman G., Melek W. and Fue-San L., Pitch angle control for a small-scale Darrieus vertical axis wind turbine with straight blades (H-Type VAWT), *Renewable Energy*, 114, pp 1353-1362, 2017.
- [2] Douaka M., Aouachriab Z., Rabehic R. and Allamb N., Wind energy systems: Analysis of the self-starting physics of vertical axis wind turbine, *Renewable and Sustainable Energy Reviews*, 81, pp 1602–1610, 2018.
- [3] Paraschivoiu I. and Delclaux F., Double Multiple Streamtube Model with Recent Improvements (for Predicting Aerodynamic Loads and Performance of Darrieus Vertical Axis Wind Turbines), *Journal of Energy*, Vol. 7, No. 3, pp. 250–255, 1983.
- [4] Paraschivoiu I., Trifu O. and Saeed F., H-Darrieus wind turbine with blade pitch control, *Int. J. Rotating Machinery*, pp1-7, 2009.
- [5] Beri, H. and Yao Y., Double Multiple Streamtube Model and Numerical Analysis of Vertical Axis Wind Turbine, *Energy and Power Engineering*, Vol. 3, No. 3, pp. 262–270, 2011.
- [6] Marten D., Wendler J., Pechlivanoglou G., Nayeri C.N. and Paschereit C.O., Development and Application of a Simulation Tool for Vertical and Horizontal Axis Wind Turbines, *Proceedings of the ASME Turbo Expo 2013*, June 3-7, San Antonio, Texas, USA, 2013.
- [7] Biadgo A.M., Simonovic A., Komarov D. and Stupar S., Numerical and Analytical Investigation of Vertical Axis Wind Turbine,” *FME Transactions*, Vol. 41, pp. 49–58, 2013.
- [8] Paillard B., Astolfi J.A., and Hauville F., URANSE simulation of an active variable-pitch cross-flow Darrieus tidal turbine: Sinusoidal pitch function investigation, *Int. Journ. of Marine Energy*, Vol. 11, pp. 9–26, 2015.
- [9] Adams B.M. + 16 co-authors, Dakota: a multilevel parallel object-oriented framework for design optimization, parameter estimation, uncertainty quantification, and sensitivity analysis, Technical Report SAND2014-5014, Sandia National Laboratories, Albuquerque, NM, Updated 2016.

Acknowledgments: This work has been funded by the French Region PACA through the APRF project AEROPITCH DEB-14-1204-2014-10915, and has been carried out in the framework Labex MEC, (ANR-10-LABX-0092) and of the A*MIDEX project (ANR-11-IDEX-0001-02), funded by the French Government program managed by the French National Research Agency (ANR).