PhD Proposal 2017

School: Ecole Centrale de Nantes	
Laboratory: LHEEA lab (Hydrodynamics, Energetics and Atmospheric Environment)	**Web site: lheea.ec-nantes.f**
Team: H2I (Hydrodynamics, Interfaces and Interactions)	**Head of the team: David Le Touzé**
Supervisors: David Le Touzé Antoine Ducoin	**Email: antoine.ducoin@ec-nantes.fr**
Collaboration with other partner during this PhD: **In France:** *CORIA Laboratory-UMR 6614, CNRS-University & INSA of Rouen, St. Etienne du Rouvray, France*	**In China:**

Title: Direct Numerical Simulation of boundary layer instabilities over vertical axis wind turbine blades	
Scientific field (*): Fluid mechanics	
Key words: Renewable Energies, Wind turbines, Direct Numerical Simulation, boundary layer instabilities	

(*) : *Chemical engineering, Computer Science, Image and data processing, applied mathematics, Electrical engineering, Automation and Robotics, System Engineering, Industrial Engineering, Fluid Mechanics, Aerodynamics, Acoustics, Combustion, Material Science, Optics, Electronics, Nano technology, Micro-system, Bioscience, Solid mechanics, Surface Science, Civil engineering.*

Details for the subject:

Background, Context:

Although, the wind energy market has been dominated by the horizontal axis wind turbines (HAWTs); recently, vertical axis wind turbines (VAWTs) are also finding emerging interest for off-grid applications ([1]). As have been reported in the literature [2], the VAWTs possess a number of distinct advantages over HAWTs such as easy installation and maintenance, less installation space, self-starting at low wind speeds, wind acceptance from any direction, no need of yaw mechanism, easy fabrication, and less noise among others.

Savonius-style wind turbines (SSWT) are a class of vertical axis wind turbines, which appear to be promising for energy conversion because of their better self-starting capability, flexible design promises and low wind operations. The Savonius blades are characterized by relatively large surface, which have a thin circular shape to produce large drag that is used for power generation. However, because of small scales of these turbines, they usually operate at relatively low Reynolds numbers, which can induce laminar to turbulent transition along the blade, and hence directly alter the turbine performances. Moreover, it appears that most of the numerical studies consider fully turbulent flow, where the near and far wake of the turbine is usually investigated in the performance analysis, whereas the boundary layer transition on the blade can directly influence the near wake of the turbine.

In this context, it appears that the current numerical methods used to predict the SSWTs performances are not adapted to the prediction of boundary layer transition. It becomes necessary to get reference calculations through Direct Numerical Simulation to demonstrate the physic of transition, to evaluate its effect on performance and eventually to establish some correlation law that could be implemented in the existing commercial softwares.

Research subject:

Typically, the suction side of the advancing blade of SSWT is submitted to strong adverse pressure gradient, causing a well known vortex shedding process, which is responsible for the wake flow. This topic has been the subject of many researches in the past decades, as it obviously depends on tip speed ratio (TSR) and directly influences the turbine efficiency [3]. The flow on the pressure side of the blade is generally considered as fully attached and is characterized by high pressure, low velocity level that produces most of the drag used in the energy conversion. A gap between the two blades is often used to accelerate the flow on the pressure side of the returning blade to increase the drag production, however it has been show in Roy and Ducoin (2016) [4] that it induces boundary layer development at this side, see figure 1 (a). Because of the concave curvature of the blade and the small scale of the turbine, centrifugal instabilities (pairs of longitudinally elongated counter rotating vortices) may occur; and depending on the flow characteristics, can cause natural transition on the blade, and modify the drag force significantly. Moreover, this can highly disturb the trailing edge vortex (see the red color Figure 1(a)) that is partially responsible for the wake flow. This can also lead to a rapid degradation of mechanical structures and materials fatigue and it becomes necessary to lead detailed analysis of the flow physic to evaluate its influence.

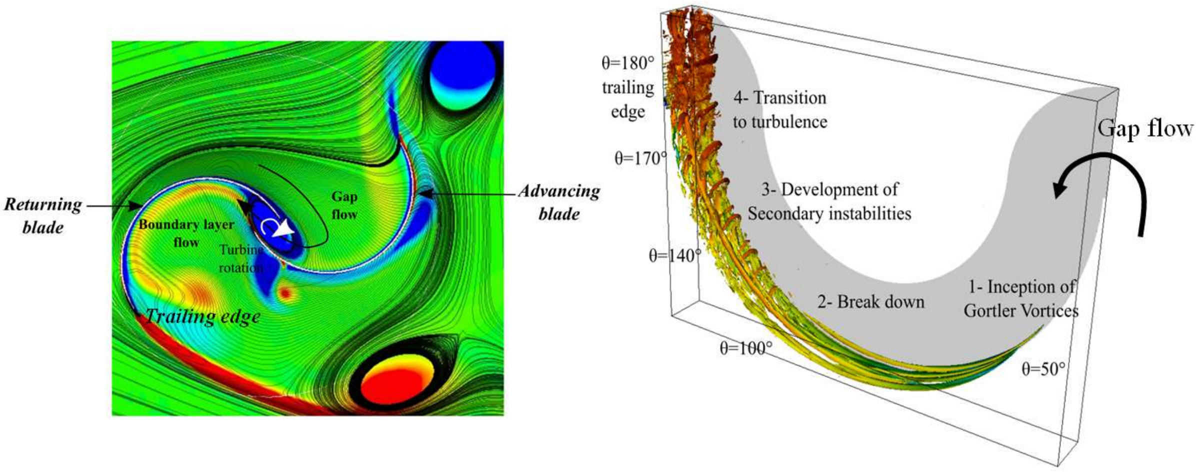
In this project, Direct Numerical Simulations (DNS) will be carried out in order to capture the flow instabilities and transition to turbulence occurring on the blade of a SSWT. In this context, a very first DNS has been performed recently by Ducoin et al. (2016) [5] and a result is shown in Figure 1 (b). Under simplified computational domain and operating condition (no turbine rotation, only the pressure side of one blade modeled and constant inflow condition), it has been successfully demonstrated that natural transition occurs on the blade pressure side, caused by the breakdown of centrifugal instability.

work plan:

The first step of the PhD is to develop a numerical model that is able to reproduce realistic conditions of the turbine under rotation, with respect to the computational hours allocated for the project. The second step is then to investigate the physics of transition and the possible effect on the blade, and turbine performance, it includes :

- The study of the instability mechanism that lead to transition to turbulent flow,
- the investigation of the interaction between boundary layer instabilities and the near wake of the blade,
- a receptivity analysis of the blade to the flow instabilities according to inflow conditions,
- an evaluation of the effect of transition on the turbine performance and power, on the structural vibrations and fatigue.

The results will then be utilized to establish correlation laws to be implemented in the current industrial softwares. It will also be used for the boundary-layer control at the blade surface, and to modify the SSWT blade’s profile to achieve higher performances.



(a) **(b)**

Figure 1. Simulations of flow over Savonius Style Wind Turbines (SSWT) (a) 2D RANS calculation from Roy and Ducoin (2016), (b) 3D DNS calculation from Ducoin et al. (2016)

References:

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