Active-Flow Control for High Efficiency Micro-Wind Turbine

Motivation & Objectives
A micro wind turbine is used to generate power in the range of 1 kW to 50 kW at rated wind speed of 10 m/s. These turbines are deployed in urban areas, where the average wind speed is between 5 and 7 m/s. To generate useful power at these wind speeds, turbines must have greater efficiency. In this work, the greater efficiency is achieved by attaching the flow to the blade surface at higher angle of attack. The present project work analyzes two design approaches for attaching the flow to the blade surface by numerical simulations using a finite volume method solver.

Results
Variant A: The pulsed jets, requiring unsteady analysis, are approximated using steady jets, in order to save computational costs and time. Results show good correlation between unsteady and steady-state analysis. Lift performance has been studied and it is shown that the best lift performance is achieved, when the geometric configuration locates the slit at 10% of the chord and with an angle of 10 deg to the surface of the blade. The flow parametric analysis indicates that the lift and stall angle are linearly dependent on the ratio of the jet velocity over the freestream velocity ($V_j/V_f$) from a ratio of 1.5 up to a ratio of 4. Energetic balance shows an increase of 10% in the power extracted from the wind energy.

Streamwise vortices Variant A
In the case of Variant A, hydrodynamic instability causes vortices. This fact was first discussed in reviewed literature only quite recently, Neundorf et al. in 2004 and Has et al. in 2006. These authors explain that a “wall-jet blown over a convex surface exhibits the same instability as the Taylor-Görtler centrifugal instability due to negative radial velocity gradient on a concave wall”. However, these kind of vortices are not visible in a finite volume method solver. LES is required.

Streamwise vortices Variant B
Variant B: For this case, the assumption of approaching pulsed jets with steady jets is extrapolated based on the results obtained with Variant A. Flow parametric analysis shows a linear dependence of the lift and stall angle on the ratio $V_j/V_f$. It is further shown that the vortices generated in this case are produced by the “kidney” effect and are not produced by the torque induced by the anti-parallel jets as believed in previous papers about this subject. Energetic balance shows an increase of 24% in the power extracted from the wind energy.

Coandă effect
The stall delay is due to the Coandă effect. The Coandă effect is the tendency of a fluid jet to be attracted to a nearby surface. It is a result of entrainment of ambient fluid around the fluid jet. When a nearby wall does not allow the surrounding fluid to be pulled towards the jet (i.e. to be entrained), the jet moves towards the wall instead.

Conclusion and future work
The lift coefficients and stall angle have been distinctly improved by using the jets. The data gathered can be used to design a new airfoil taking advantages of all the new features. However LES analysis to corroborate or correct the results would be judicious. Pulsed jets can be, in a finite volume method solver, approached by steady jets of the same velocity, which simplify hugely the cases. For the Variant A the streamwise oriented vortices presumably present in reality are not visible because of the finite volume method. For Variant B the vortices, created by the difference of velocity between the jet and the main flow, named kidney effect, are noticeable. Pulsed jets in reality are more efficient than steady jet because they enhance the blending of the boundary layer by changing alternatively the direction of the vortices and by creating aerodynamic instabilities which generate also vortices. LES analysis is necessary to obtain more accurate results, especially concerning the difference between steady jets and pulsed jets. It is clear that aerodynamic instabilities play a role in the boundary layer behavior.

Based on the lift coefficient and the stall angles, a new design of wind turbine should be done. Using this device on an existing device wouldn’t take advantage of all the improvements, notably for the low wind speed design.

Acknowledgements
Honeywell India
Purnaprajna Mangshud
Gopal Samy Mathial

Author
Claude Dufour
Supervisor
Dr. Mark Sawley