Small-Scale Vertical Axis Wind Turbine Blade Optimization Through Numerical Modeling Techniques

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Introduction

The objective of this research is to investigate the vibration behaviour and power output of a newly developed Vertical Axis Wind Turbine (VAWT) for the purpose of maximizing energy production while ensuring low vibration under all steady and unsteady wind conditions. The focus of this research is on developing a validated Computational Fluid Dynamics (CFD) model of the turbine which can be used to determine potential vibration excitation and power output based on aerodynamic aerofoil loading. Instrumentation of the current turbine prototype (Fig. 1) will provide the data necessary to validate the numerical turbine model. The ultimate goal is to create a design tool which can be used in turbine blade selection and design for the purpose of optimizing turbine performance.

Figure 1: 3.5 kW VAWT prototype installed on top of the McMaster Innovation Park building, Hamilton.

Numerical Model

Development of a CFD model of a VAWT cross-section initially focused on a single blade cross-section under steady state conditions. Validation of the single blade cross-section model was then successfully obtained by comparison to experimental wind tunnel data of steady state lift and drag forces for the blade profile under consideration. A second CFD model was then designed to incorporate the effects of rotation of three blades at a given arm radius subjected to a constant velocity cross-stream flow. This model included transient time step calculations and analysis, and the presence of a rotating mesh.

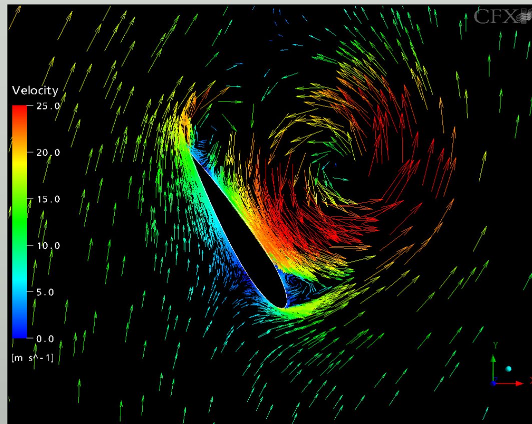

Figure 2: Relative flow velocity vectors over the blade surface highlighting the significant complexity of the flow. Ambient flow is from the left at 13.5 m/s and the blade is rotating counter clockwise at 21.5 rad/s. The large vortex dominating this figure forms on the blade's upstream pass, convects along with the blade as it travels downstream and impacts the blade on its downstream pass.

Results

From the multi-blade CFD model interesting and valuable information on the flow characteristics about the rotating turbine blades was revealed:

- The flow over the blade was far more complex then the simple case of increasing and decreasing angle of attack (Fig. 2)
- The pressure field throughout and surrounding the turbine as a function of angle of attack was obtained (Fig. 3)
- Integration of the pressure profile over the surface of the blade produced the thrust and radial force components on the blade over a full rotation (Fig. 4)
- Initial blade power output and vibration excitation loads can be predicted from these results (neglecting mechanical losses)

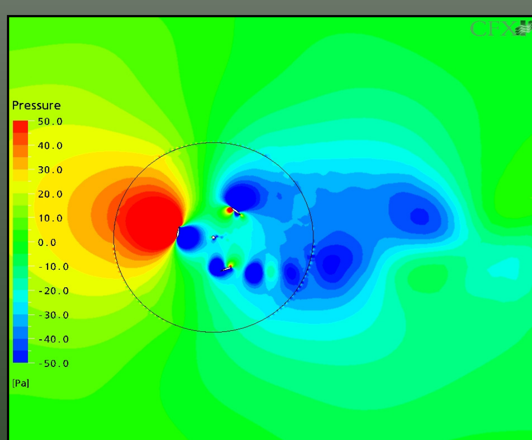

Figure 3: Pressure field surrounding the turbine as predicted by the CFD model. The large circle indicates the boundary between the rotating domain that contains the blades and the large stationary domain. The low pressure regions highlighted in blue indicate the presence of multiple shed vortices being convected downstream.

Experimental Field Testing

In conjunction with the development of the CFD model, experimental validation of the multi-blade CFD model through measurement of the loading and vibration of the turbine prototype is being performed. This includes:

- Mounting of load cells and accelerometers on the blades and struts
- Development of a wireless telemetry system for data acquisition due to the continuous motion of the turbine during testing
- Flow visualization of the flow patterns over the turbine blades
- Further testing of the turbine prototype in the 9m x 9m cross-section NRC wind tunnel in Ottawa, allowing for careful control and monitoring of the flow

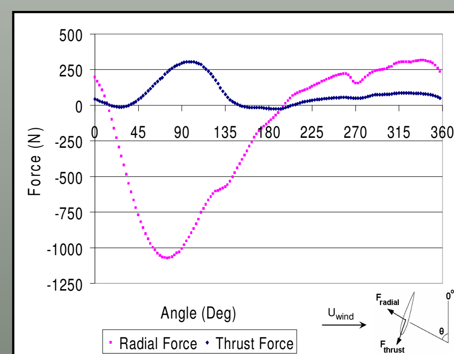

Figure 4: Thrust and radial forces on a vertical axis wind turbine blade cross-section as a function of angle of rotation, θ. The importance of the upstream pass (0°<θ<180°) on power output and vibration excitation is evident in the magnitude of the forces applied to the turbine blades within this region.

Conclusions

- Considerable flow complexity exists about the blades due to the cyclic turbine motion
- The vibration excitation and thrust loading on the turbine blades can be determined
- A tool has been developed which can be used to aid in the design of future VAWTs

Acknowledgements

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