University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Doctor of Philosophy

of

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"Towards Multidisciplinary Design Optimization Capability of Horizontal Axis Wind Turbines"

Department of Mechanical Engineering

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10:00 A.M.
David Turpin Building
Room A144

Supervisory Committee:
Dr. Curran Crawford, Department of Mechanical Engineering, University of Victoria (Supervisor)
Dr. Afzal Suleman, Department of Mechanical Engineering, UVic (Member)
Dr. Jane Ye, Department of Mathematics and Statistics, UVic (Outside Member)

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Dr. Linda Welling, Department of Economics, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

Research into advanced wind turbine design has shown that load alleviation strategies like bend-twist coupled blades and coned rotors could reduce costs. However these strategies are based on nonlinear aero-structural dynamics providing additional benefits to components beyond the blades. These innovations will require Multidisciplinary Design Optimization (MDO) to realize the full benefits.

This research expands the MDO capabilities of Horizontal Axis Wind Turbines. The early research explored the numerical stability properties of Blade Element Momentum (BEM) models. Then developed a provincial scale wind farm siting models to help engineers determine the optimal design parameters.

The main focus of this research was to incorporate advanced analysis tools into an aero-elastic optimization framework. To adequately explore advanced designs with optimization, a new set of medium fidelity analysis tools is required. These tools need to resolve more of the physics than conventional tools like (BEM) models and linear beams, while being faster than high fidelity techniques like grid based computational fluid dynamics and shell and brick based finite element models. Nonlinear beam models based on Geometrically Exact Beam Theory (GEBT) and Variational Asymptotic Beam Section Analysis (VABS) can resolve the effects of flexible structures with anisotropic material properties. Lagrangian Vortex Dynamics (LVD) can resolve the aerodynamic effects of novel blade curvature.

Initially this research focused on the structural optimization capabilities. First, it developed adjoint-based gradients for the coupled GEBT and VABS analysis. Second, it developed a composite lay-up parameterization scheme based on manufacturing processes.

The most significant challenge was obtaining aero-elastic optimization solutions in the presence of erroneous gradients. The errors are due to poor convergence properties of conventional LVD. This thesis presents a new LVD formulation based on the Finite Element Method (FEM) that defines an objective convergence metric and analytic gradients. By adopting the same formulation used in structural models, this aerodynamic model can be solved simultaneously in aero-structural simulations. The FEM-based LVD model is affected by singularities, but there are strategies to overcome these problems. This research successfully demonstrates the FEM-based LVD model in aero-elastic design optimization.