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Wind Turbine Scaling for the Investigation of Vortex Shedding and Wake Interactions

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Abstract : Traditionally, the focus of horizontal axis wind turbine (HAWT) blade aerodynamic optimisation studies has been the outer working region of the blade. However, recent works seek to better understand, and thus improve upon, the performance of the inboard blade region to enhance power production, maximise load reduction and better control the wake behaviour. This paper presents the design considerations and characterisation of a wind turbine wind tunnel model devised to further the understanding and fundamental definition of horizontal axis wind turbine root vortex shedding and interactions. Additionally, the application of passive and active flow control mechanisms – vortex generators and plasma actuators – to allow for the manipulation and mitigation of unsteady aerodynamic behaviour at the blade inboard section is investigated. A static, modular blade wind turbine model has been developed for use in the University of Glasgow's de Havilland closed return, low-speed wind tunnel. The model components - which comprise of a half span blade, hub, nacelle and tower - are scaled using the equivalent full span radius, R, for appropriate Mach and Strouhal numbers, and to achieve a Reynolds number in the range of 1.7x105 to 5.1x105 for operational speeds up to 55m/s. The half blade is constructed to be modular and fully dielectric, allowing for the integration of flow control mechanisms with a focus on plasma actuators. Investigations of root vortex shedding and the subsequent wake characteristics using qualitative – smoke visualisation, tufts and china clay flow – and quantitative methods – including particle image velocimetry (PIV), hot wire anemometry (HWA), and laser Doppler anemometry (LDA) – were conducted over a range of blade pitch angles 0 to 15 degrees, and Reynolds numbers. This allowed for the identification of shed vortical structures from the maximum chord position, the transitional region where the blade aerofoil blends into a cylindrical joint, and the blade nacelle connection. Analysis of the trailing vorticity interactions between the wake core and freestream shows the vortex meander and diffusion is notably affected by the Reynold's number. It is hypothesized that the shed vorticity from the blade root region directly influences and exacerbates the nacelle wake expansion in the downstream direction. As the design of inboard blade region form is, by necessity, driven by function rather than aerodynamic optimisation, a study is undertaken for the application of flow control mechanisms to manipulate the observed vortex phenomenon. The designed model allows for the effective investigation of shed vorticity and wake interactions with a focus on the accurate geometry of a root region which is representative of small to medium power commercial HAWTs. The studies undertaken allow for an enhanced understanding of the interplay of shed vortices and their subsequent effect in the near and far wake. This highlights areas of interest within the inboard blade area for the potential use of passive and active flow control devices which contrive to produce a more desirable wake quality in this region.

Keywords : vortex shedding, wake interactions, wind tunnel model, wind turbine
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