Supergen ORE Hub - Early Career Researcher Research Fund
Dr Yinan Wang, University of Warwick

The funded activity was to consist of a two-week visit to NTU Singapore. Due to prolonged travel restrictions over the course of the fund, the funded activity switched to online discussions and data exchange. The main objective of the investigation is to review and identify ways to model the dynamic response and feedback control response of very large HAWT, in particular the 20MW reference wind turbine, under external gust and turbulence.

First, in a series of discussions with the team at NTU, the activity reviewed the state-of-art of very large HAWT dynamics modelling across the range of fidelities from aerofoil-level to turbine-level. With the intended target in mind, the discussion identified a gap in existing simulation regimes between 2D strip-theory and full 3D aerodynamic models.

The funded activity then led to a discussion and the subsequent proposal of a vorticity-based correction. This serves as a minimally-invasive method to capture medium- to long-range spanwise aerodynamic interactions for an otherwise 2D strip-theory model. The NTU team also shared their experience in implementation of such a numerical scheme. Implementing the correction led to a computational technique to improve upon the accuracy of pure strip theory unsteady simulations with only a small computational overhead.

A third part of the activity is the use of high-quality atmospheric boundary layer turbulence simulations by NTU as the disturbance experienced by the HAWT, in which the proposed numerical method would then be tested. On the other hand, the NTU team also provided a reference numerical model of the 20MW turbine using a standard 3D inviscid formulation for comparison.

The results led to the inclusion of the method in an upcoming journal article where the findings will be presented. They will also be disseminated in the upcoming AIAA SciTech conference. Further works are underway to apply the method to other similar aeroelastic systems.

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Very large horizontal-axis wind turbine is an emerging technology to meet an ever-increasing energy demand of modern society. On these turbines, scaling laws naturally lead to more flexible turbine blades, significant vibrations and increased susceptibility to atmospheric disturbances.

Better numerical models for the dynamic response of these very large turbines are necessary for the design, control and reliable operation of these turbines in the future. For this, we reviewed a range of numerical methods within an acceptable computational cost currently available to for this purpose:

-Medium-fidelity 2D formulations, including 2D CFD simulations, viscous-inviscid panel methods, are needed to account for unsteady viscous effects at the aerofoil-level, including nonlinearity in the sectional lift curve, flow separation and dynamic stall. These are often expensive to directly extend to 3D.
-Low- to medium-fidelity 3D formulations, for example unsteady lifting-line, unsteady panel, and vortex-lattice methods with viscous-inviscid coupling, are required to describe unsteady spanwise interactions, including tip effect and blade-wake interactions, as well as axial induction itself. These are however restrictive in terms of the formulation available at an aerofoil-level.

From the review, a gap in simulation regimes currently exist between the two categories of models, making it currently difficult to capture the complete range of phenomenon described here in a single simulation.

We proposed a vorticity-based correction as a minimally-invasive method to capture medium- to long-range unsteady spanwise aerodynamic interactions, for an otherwise 2D strip-theory model. The correction is described by spanwise vortex rings whose strength is identified by the conservation of vorticity, and can be conducted with only a small computational overhead. At a distance far enough downstream, the correction reduces into collocated vortex rings that are subsequently advected according to standard UVLM. In the limit of small-disturbance attached flow over thin aerofoil, this method reduces to the standard UVLM formulation.

The method is now used to improve the accuracy of wind turbine aeroelasticity simulations using a reference 20MW turbine under external gust and atmospheric turbulence as a part of ongoing work on the subject.

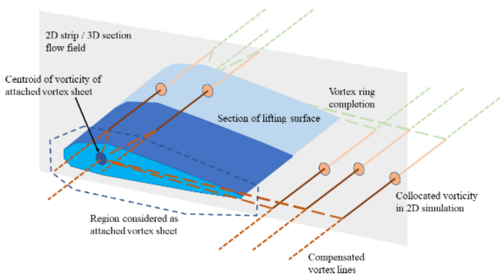
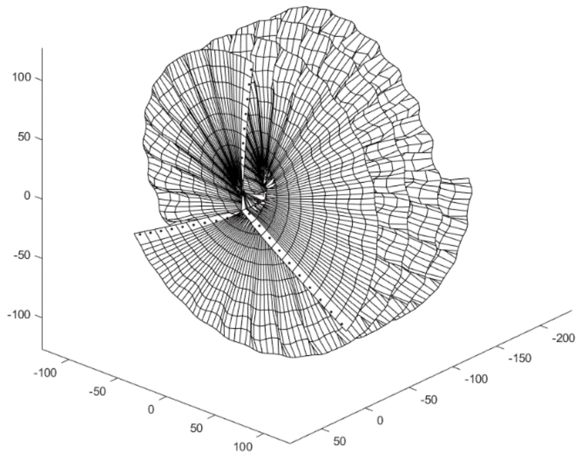


Illustration of the proposed correction to 2D strip theory models using vortex rings



Far-field wake behind a wind turbine. Not visible is a near-field model consisting of a 2D vortex panel model with partial dynamic flow separation.