Numerical modelling of cross-flow turbines: 2D blade-resolved against 2D actuator line method simulations

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ABSTRACT

Transverse-axis turbines have technical benefits that may contribute to accessing untapped tidal energy potential in the UK coast and around the world. At the same time the blades of these rotors develop complex hydrodynamic interactions, making it difficult to predict hydrodynamic efficiency and therefore creating a bottleneck in optimising and commercialising the device concept.

The blades of a cross-flow turbine are subject to a range of complex aerofoil hydrodynamic phenomena such as separation and reattachment, dynamic stall, and blade-vortex interaction as described in Consul *et al.* (2013). For this reason, 2D Unsteady Reynolds Averaged Navier-Stokes (URANS) simulations have been widely used for the study of these rotors as a viable compromise between accuracy and numerical cost (Consul *et al.* (2013), Ferrer and Willden (2015), Feinberg *et al.* (2019)).

At the same time, Cheng *et al.* (2017) demonstrated that 3D flow effects may lead to a 33.3% drop in power when comparing 2D and 3D URANS blade-resolved simulations, suggesting that it is important to model 3D effects in such devices. A viable model that resolves three-dimensional features but overcomes the computationally exhaustive task of meshing and resolving the aerofoil boundary layer, are 3D actuator line method (ALM) simulations of cross-flow and vertical axis turbines (Bachant *et al.* (2016), Gharaati *et al.* (2024)).

It is currently unclear if the ALM can adequately model the cross-flow turbine interactions emerging from 2D URANS simulations. In this work we perform a fair comparison between the two methods: the flow emerging from 2D URANS simulations of cross-flow turbines is compared to that emerging from 2D ALM simulations. We further hypothesize that the ALM will agree best with the blade-resolved methods for utility scale rotors (where the relative distance between the blades is larger) while for lab-scale rotors the blade turbulence will dominate the device hydrodynamics.

Existing simulation frameworks are employed: for 2D blade-resolved URANS simulations, the framework by Feinberg *et al.* (2019) is adapted, while for 2D ALM simulations, we use that of Zormpa *et al.* (2025). A range of tip-speed ratios is simulated to capture a number of flow regimes for cross-flow turbines as discussed in Ferrer and Willden (2015). Two rotors are tested, a lab scale and a utility scale one in order to test the applicability of the ALM in both scales.

References

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