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Offshore floating wind turbines offer a compelling means of harnessing the massive resources available in deeper waters, but you must understand the physics that underlie their behavior.

MOST UTILITY-SCALE WIND TURBINES look the same: three blades, tapering in spanwise chord and twist from root to tip, rotor located upwind relative to the nacelle. This apparent convergence of designed form implies a thorough understanding of the aerodynamically-derived forces acting on a wind turbine. In reality, wind turbine aerodynamics are exceptionally complex. These complexities are further compounded when wind turbines are placed offshore as part of an integrated floating system.

The long-term survivability of floating platforms has been demonstrated by their continued use in the oil and gas industries. Drawing from this precedent, the three dominant offshore floating wind turbine concepts to arise out of the wind industry are the spar-buoy, the tension leg platform (TLP), and the barge. Each platform type possesses inherent positive and negative attributes that play a significant role in floating wind turbine design and siting.

Despite the significant potential benefits of offshore floating wind turbines (OFWTs)—access to better wind resource and increased placement flexibility—there remain significant engineering challenges. Of particular interest is the impact of platform motions on rotor aerodynamics. Some critical questions that must be answered include: What do the additional dynamics of these systems, and the resulting changes in the flow velocity seen by the rotor, mean from an aerodynamic perspective? How will wind turbine performance differ compared to a conventional offshore turbine of similar size? Will platform-motion-induced loading require changes in blade and rotor design? University of Massachusetts researchers at the Wind Energy Center have set out to investigate the aerodynamics of offshore floating wind turbines and answer these important questions.

Thomas Sebastian—whose doctoral thesis spurred this work—and I characterized the unique operating conditions that make aerodynamic analysis of OFWTs a challenge via reduced frequency analysis of the NREL 5MW turbine. Platform modes and turbine operating conditions that may result in unsteady flow were identified via a series of aero-elastic simulations and reduced frequency analysis. Additionally, operating conditions that may result in a breakdown of the momentum balance equations were identified for the various platform configurations. This study demonstrated that OFWTs are subjected to significant aerodynamic unsteadiness compared to fixed-bottom offshore turbines, and indicated a need for higher-fidelity aerodynamic analysis approaches.

Momentum balance approaches are conceptually simple, but rely on a number of ad hoc, empirically-derived corrections. Recognizing that the external flow of a wind turbine is nominally inviscid, incompressible, and irrotational permits the use of potential flow methods. These assumptions are global, physically consistent descriptions of the flow rather than experimentally limited extrapolations. Time-marching free vortex wake methods (FVMs), a subset of potential flow, numerically advect the wake lattice, which is composed of Lagrangian markers connected by vortex filaments. This approach has been used for a number of decades, in particular in rotorcraft aerodynamic analysis. Recognizing this, Sebastian and Lackner developed the Wake Induced Dynamics Simulator (WInDS) code, a lifting-line theory (LLT) based FVM developed for OFWTs and validated via comparison to analytical models and experimental data.

WInDS simulations of OFWTs were conducted, using observations from the earlier reduced frequency study to determine which platform modes and operating conditions warranted a closer look. Wake evolution as well as wake-induced loading on the rotor was studied and clearly demonstrated the effect of the platform motions on the wake, which in turn had a significant impact on rotor loading as far as four rotor diameters downstream. Transitions between windmill and quasi-propeller states were also observed. Comparisons to unsteady momentum balance methods indicated that the time lag associated with these approaches is artificially short and that these simple methods may be insufficient for OFWT simulations.

In conclusion, OFWTs offer a compelling technology solution to exploit the massive wind resource available in deeper waters. But to have confidence in the ability of OFWTs to operate reliably and efficiently, it is extremely important to understand the physics that underlie their behavior. In particular, the aerodynamic behavior of these systems is complex, and differs in several important ways from the more easily modeled behavior of fixed bottom and land-based wind turbines. The analysis performed by Sebastian and Lackner quantified how OFWTs aerodynamically differ from fixed bottom turbines, and utilized FVM simulations—of higher fidelity than traditional momentum balance approaches—to investigate the aerodynamic performance of floating wind turbines. The results indicated unique aspects of OFWTs aerodynamics, and future opportunities for improvements in the design and modeling of OFWTs.

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