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FIG. 1. Soap film visualization of a (a) stationary and (b) clockwise rotating vertical axis wind turbine (VAWT). The incoming flow was gravity-driven and the turbine rotation was motor-driven. The Reynolds number was $Re \approx 3000$ in both cases, based on the chord length ($L = 0.01$ m) and estimates of freestream velocity ($U \approx 2.2$ ms^{-1}) and kinematic viscosity ($\nu \approx 7 \times 10^{-6}$ m^2 s^{-1}). The tip speed ratio (blade speed/freestream speed) in the rotating case was TSR ≈ 1.04. The interference pattern created by a monochromatic light source (sodium lamp) convects with the flow and illustrates the intricate structure of the spatially evolving wake. Most striking is the range of scales present in the wake. This is clearly visible not only in the stationary case but also apparent in the rotating case, with small-scale vortices shed from the blades in the near wake and large-scale vortical structures that develop in the far wake. Source: APS-DFD (http://dx.doi.org/10.1103/APS.DFD.2014.GFM.P0007).

Vertical axis wind turbine in a falling soap film

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(Received 16 August 2015; published online 24 September 2015)
[http://dx.doi.org/10.1063/1.4930912]

Vertical axis wind turbines (VAWTs) have demonstrated a potential to significantly enhance the efficiency of energy harvesting within a wind farm.[1,2] One mechanism that contributes to this enhancement is a VAWT's inherent insensitivity to wind direction coupled with blockage within an

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array of turbines.[3,4] Much like the flow around a bluff body, turbine blockage can locally accelerate the flow near one turbine, providing faster inflow conditions for a well-placed neighboring turbine. Since the power produced by a VAWT typically scales as the cube of the incoming wind speed, even a modest acceleration of the flow can have a significant impact on the overall turbine array performance.

Still, a major challenge that persists is to understand the dynamics of the fluid interactions among closely spaced VAWTs. This fundamental knowledge could aid in optimizing array performance by, e.g., giving insight into manipulating fluid energy transport, or controlling the fluid stresses that lead to fatigue of turbine blades. A reasonable approach is to first decouple the problem and develop an understanding of the flow around an individual VAWT. Much of the recent experimental work related to VAWTs has focused on blade-level aerodynamics, such as dynamic stall and tip vortex shedding,[5–7] as well as near wake analysis of the mean flow and Reynolds stresses.[6,8]

Motivated by a desire to develop intuition about the spatio-temporal evolution of the VAWT wake, we constructed a qualitative flow visualization experiment using a miniature, 3-bladed VAWT in a gravity-driven soap film tunnel (Fig. 1). We observe a broad range of scales present in the VAWT wake, from small-scale periodic blade shedding to the development of large-scale vortical structures in the far wake. These large structures are thought to be the result of the developing shear-layer instability in the wake and appear to dominate the dynamics of the flow in the far wake of the turbine. These qualitative observations are in agreement with further analysis of the velocity spectra from particle image velocimetry (PIV) measurements in a larger scale ($Re \approx 10^4$) VAWT experiment.[9] In addition to providing qualitative insight about the flow, the vastly lower Reynolds number and essentially two-dimensional soap film flow could lend support to a tractable theoretical development of VAWT wake dynamics.

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