Center for Environmental & Applied Fluid Mechanics

"Enhancing Wind-Farm Performance via Unsteady Fluid Mechanics"

Prof. Nathaniel J. Wei
University of Pennsylvania
Mechanical Engineering

Abstract: Modern wind turbines, like aircraft and other aerodynamic structures, are typically designed with the assumption that the flows they encounter will be uniform and steady. However, atmospheric flows are highly unsteady, and systems operating within them must contend with gust disturbances that can lead to performance losses and structural damage. In this talk, we describe experimental and analytical efforts to account for and even leverage these unsteady flow phenomena to enhance the power generation of wind turbines and wind farms. We focus on periodic oscillations in the inflow velocity and turbine thrust, problems that are particularly relevant for traditional ground-fixed turbines in axial gusts and floating offshore turbines undergoing rocking motions in the streamwise direction. Wind-tunnel experiments with a periodically surging wind turbine show that power-production gains above 6% over the stationary case may be realized in practice. Further experiments in an optical towing tank demonstrate that the same unsteady flow conditions can decrease the downstream extent of the wake by over 40%, thereby increasing the power available for downstream turbines in an array. Physics-based models of the power generation and wake dynamics help clarify the mechanisms responsible for these behaviors. Finally, these mechanisms are explored at utility-scale Reynolds numbers through experiments with a turbine undergoing periodic rotation-rate oscillations in a pressurized-air wind tunnel. Our investigations provide theoretical and experimental foundations for the design of next-generation wind-energy systems that make use of naturally occurring unsteady flows for enhanced performance and reliability.

Fall 2024 CEAFM Seminar Series

December 6, 2024 ✦ 3:00 PM ✦ Gilman 132