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Turbulence and Fluid Mechanics Fundamentals applied to Wind Energy

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ABSTRACT:

In this presentation we provide various illustrative examples of how fundamental fluid mechanics knowledge has had profound effects on our understanding of wind energy and wind farm performance. We discuss the fundamental concept of the logarithmic law for turbulent boundary layers and its extension to a double-logarithmic mean velocity distribution for the horizontally averaged velocity in large wind farms. We discuss fundamental understanding of axisymmetric wakes and how these led to the development of wave superposition models that are then coupled to models of the atmospheric boundary layer structure. Focusing on individual wake structures, we then discuss the technique of yawing wind turbines for wake steering, wherein turbine wakes can be redirected to reduce interactions with downstream turbines. The wake deflection is associated with the generation of counter-rotating streamwise vortices of very large size (macro-vortices), whose magnitude can be predicted using classical lifting line theory. Finally, we show how models of wave-number frequency spectra of turbulent boundary layers can be used to predict frequency spectra of fluctuating power generation of entire wind farms, of direct relevance to understanding and predicting wind power variability.

BIOGRAPHY:

Charles Meneveau is the Louis M. Sardella Professor in the Department of Mechanical Engineering, is Associate Director of the Institute for Data Intensive Engineering and Science (IDIES) and is jointly appointed as Professor in the Departments of Physics and Astronomy and of Environmental Health Engineering at Johns Hopkins University. He received his B.S. degree in Mechanical Engineering from the Universidad Técnica Federico Santa María in Valparaíso, Chile, in 1985 and M.S, M.Phil. and Ph.D. degrees from Yale University in 1987, 1988 and 1989, respectively. During 1989-1990 he was a postdoctoral fellow at the Center for Turbulence Research at Stanford. He has been on the Johns Hopkins faculty since 1990. His area of research is focused on understanding and modeling hydrodynamic turbulence, and complexity in fluid mechanics in general. The insights that have emerged from Professor Meneveau's work have led to new numerical models for Large Eddy Simulations (LES) and applications in engineering and environmental flows, including wind farms. He also focuses on developing methods to share the very large data sets that arise in computational fluid dynamics. He is Deputy Editor of the Journal of Fluid Mechanics and has served as the Editor-in-Chief of the Journal of Turbulence. Professor Meneveau is a member of the US National Academy of Engineering, a foreign corresponding member of the Chilean Academy of Sciences, a Fellow of APS, ASME, AMS and recipient of the Stanley Corrsin Award from the APS, the JHU Alumni Association's Excellence in Teaching Award, the APS' François N. Frenkiel Award for Fluid Mechanics, and the 2024 Batchelor Prize.