


National Wind Technology Center

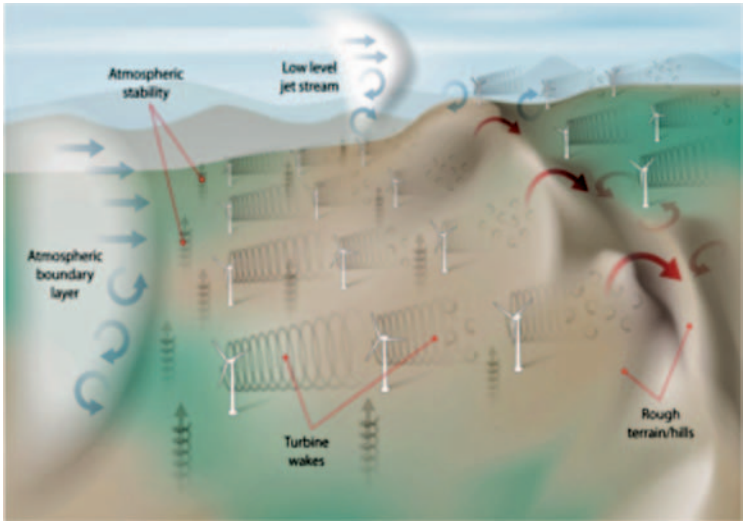
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind Energy Aerodynamics/Aeroacoustics

Overview

Wind turbine aerodynamic research has grown from blade and rotor aerodynamics, and now includes wind plant and atmospheric inflow effects. The energy capture of wind farms is dependent on all aerodynamic interactions. Research is crucial to understanding how wind turbines function in large, multiple row wind farms. Such work is important because these conditions impact the cumulative fatigue damage of turbine structural components that ultimately effect the useful lifetime of wind turbines. This work also is essential for understanding and maximizing turbine and wind farm energy production. Both turbine lifetime and wind farm energy production are key determinants of the cost of wind generated electricity.

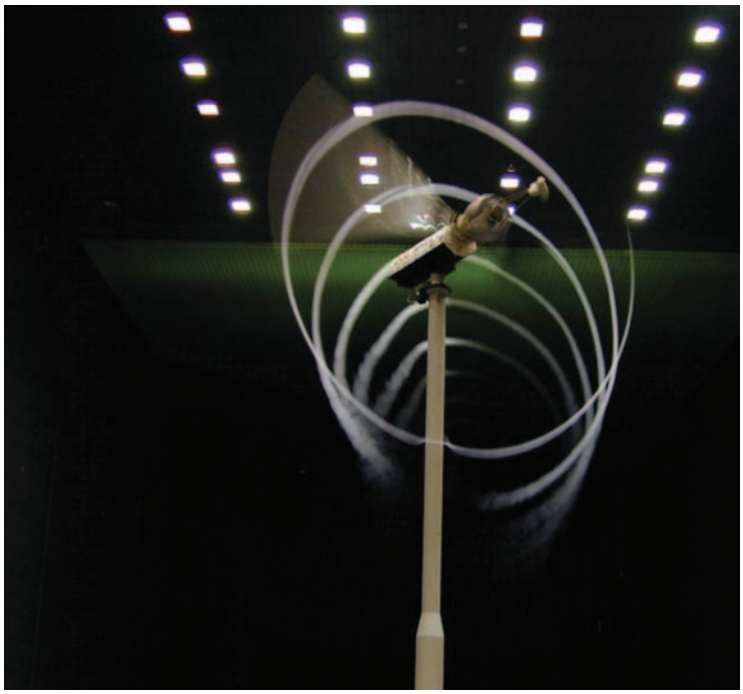
Another consideration in wind energy is the sound wind turbines emit. Researching where the sound originates and what causes it will lead to design methods to reduce it.



Schematic of wind farm interactions with atmospheric boundary layer, terrain, and vegetation.

Aerodynamics

Understanding wind turbine blade aerodynamics can enhance the accuracy and reliability of aerodynamic force predictions in engineering models used to design wind turbines. These advances improve machine operability, life span, energy capture, and power quality, all of which ultimately enable continued reductions to the cost of wind generated electricity.


Wind turbine smoke test in the NASA Ames 80 ft x 120 ft wind tunnel.

Wind tunnel experiments in the NASA Ames 80 ft x 120 ft wind tunnel allowed researchers to measure and understand turbine blade rotational augmentation and dynamic stall, which occur frequently during routine turbine operation. This research fostered a more complete understanding of rotationally augmented blade flows and dynamic stall, and thus facilitated more accurate predictions and improved turbine design.

Another key objective for NREL's research has been the development of a stochastic inflow turbulence simulator that can reliably reproduce important flow conditions such as low-level jets and site-specific turbulent conditions. These simulations then can be used as the input to engineering models used to develop new turbine designs.

In addition, ongoing research on the atmospheric conditions created by, and impacting, wind turbines is critical for continued deployment of wind energy. Specifically, when turbines are grouped together in a large multiple row array wind farms, interactions between the wind farm and the local atmosphere, as well as interactions between individual turbines complicate turbine structural loading and energy capture, thus requiring further study.

Research and development challenges for wind farms include:

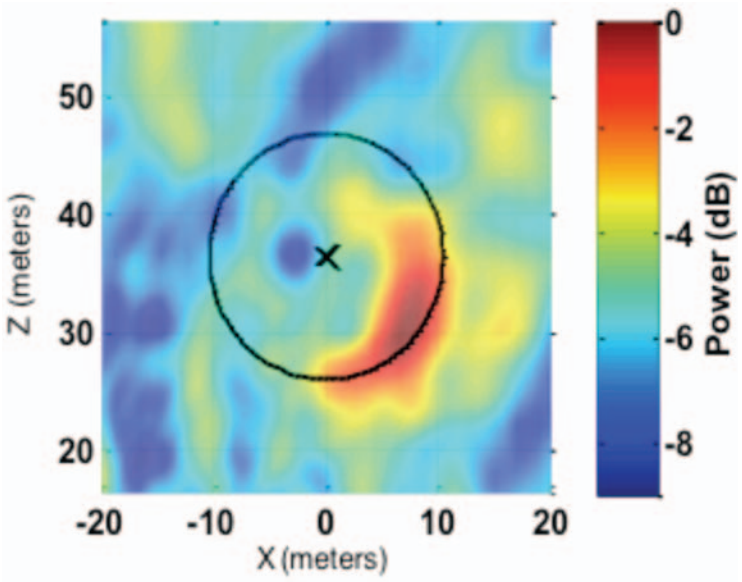
- The behavior of the atmospheric boundary layer within which the array of turbines resides can have a large impact on their performance and turbine loads.
- Researchers believe the major cause of lower energy capture and increased failure rates in wind farms is turbine wake interaction. Turbines in wind farms are in close proximity to one another, causing many of them to operate in the wake of upstream turbines. Operation within a wake causes a decrease in power output, and an increase in mechanical loading, translating to less energy and greater maintenance costs.
- The impact of terrain and vegetation are other areas of uncertainty. It is well known that wind speeds increase at the tops of ridge lines, which is why wind turbines are often placed in these locations. But the downwind impacts of terrain or of vegetation on potential wind sites remain unknown, and could be significant.

Recently, the National Wind Technology Center (NWTC) received a Laboratory Directed Research and Development (LDRD) program award to conduct research on a new project, "Wind Turbine Array Fluid Dynamic and Aero-Elastic Simulations."

Expected outcomes include a tool to accurately simulate wind turbine array flows in a variety of atmospheric conditions and a model to accurately predict the loading wind turbines encounter in an array environment. These models will allow researchers to address local and regional climate impacts from wind turbine arrays.

Aeroacoustics

Aeroacoustic emissions are the sounds made by air interacting with wind turbine blades. In addition to improving aerodynamics, the National Wind Technology Center (NWTC) is engaged in comprehensive research efforts to improve the understanding of wind turbine aeroacoustics. For decades, engineers have been researching methods to reduce the sounds emitted by wind turbines. Efforts that reduce mechanical sound sources associated with gearboxes, bearings, and other turbine elements have been successful. However, other aeroacoustic emissions are not well understood or controlled.



This radar-like picture of the sounds a 100kW wind turbine blade creates shows the loudest region at the apex of the blade rotation in a half-moon shape.

NWTC engineers are conducting aeroacoustic tests to identify the physical causes of wind turbine sound.

In the acoustic array project, turbine sounds recorded through multiple microphones surrounding a wind turbine are pictorially represented and plotted based on their location. Visual hotspots appear. Analysis on this data allows for more accurate pinpointing of sound sources and their relative amplitudes. Locating the source of the sound assists researchers in determining the physical cause and therefore, how best to reduce it. This research could lead to the design of quieter wind turbines. Designing for sound reduction requires analyses, wind tunnel tests, and field verification. The acoustic array is the latest tool NWTC is using in this process.

National Renewable Energy Laboratory

1617 Cole Boulevard, Golden, Colorado 80401 • 303-275-3000 • www.nrel.gov

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