In the wind

By Barbara Jewett

Reducing wind turbine noise while maintaining performance is a wind industry challenge. Using NCSA's Mercury, a Georgia Tech team is contributing to the solution.

IT'S SO QUIET. That's my first thought as I stand on the road in the middle of a 240 turbine wind farm a few miles from my home, watching the blades slowly rotating in the breeze.

My family's been following the installation of the turbines. Today as we drive over to peek at the project's progress we see the giant blades are moving. We scramble from the van as soon as it stops, uncertain what to expect. As we stand in awe at the sight of hundreds of white blades slowing going round and round in the azure sky, the normal Sunday afternoon quiet of the rural road is broken only by the pinging of the van's cooling engine.

"Just because you didn't hear any sounds from the wind turbines doesn't mean they weren't generating noise," says Georgia Institute of Technology aerospace engineering associate professor Marilyn Smith. Her team is developing a tool they hope will advance wind turbine design and analysis, which includes measuring low-frequency noise—those sounds below the normal limit of human hearing.

The quiet noise

While modern versions may be quieter than their predecessors, reducing wind turbine noise while maintaining performance is still a challenge. In fact, some in the wind industry say it is the greatest challenge advocates face in gaining widespread wind turbine acceptance as the U.S. transitions from traditional carbon-based fuels such as coal and natural gas to more sustainable forms of energy like wind.

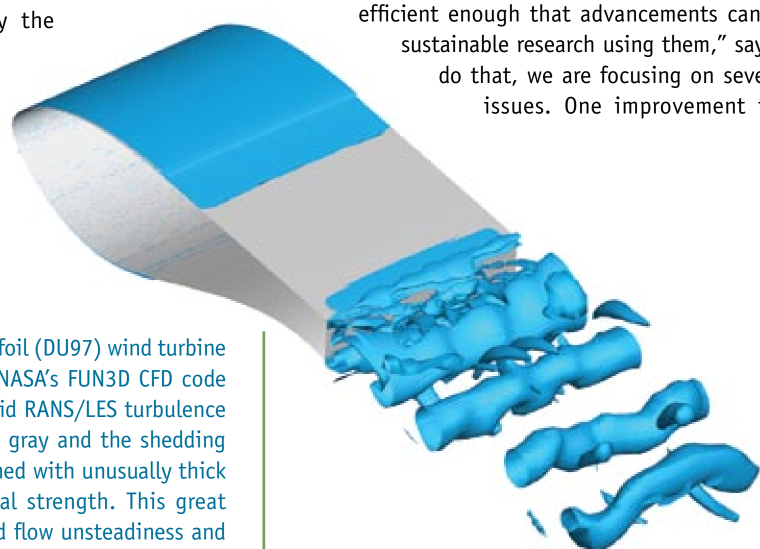
"There has been some speculation by the public that wind turbines—that is, the low frequency noise generated by their rotating blades—may be causing some health issues, such as migraines. When a wind turbine is exposed to wind, a pressure differential is created on the rotor blade, which drives the blade rotation, but is also a source of noise. An example that most people are familiar with is exiting or entering a building via revolving doors. You can feel the pressure change, and sometimes hear an accompanying noise as the pressure equalizes between the building and external atmosphere. The tools that we are developing can be used by other researchers who can use them to answer questions such as the physiological effects of wind turbine noise," says Smith.

Her team is using NCSA resources to develop methods for use in both design and analysis of wind turbines. Their tool will allow wind turbine manufacturers and researchers to examine not only turbine blades but also entire wind turbine structures and potentially wind farms.

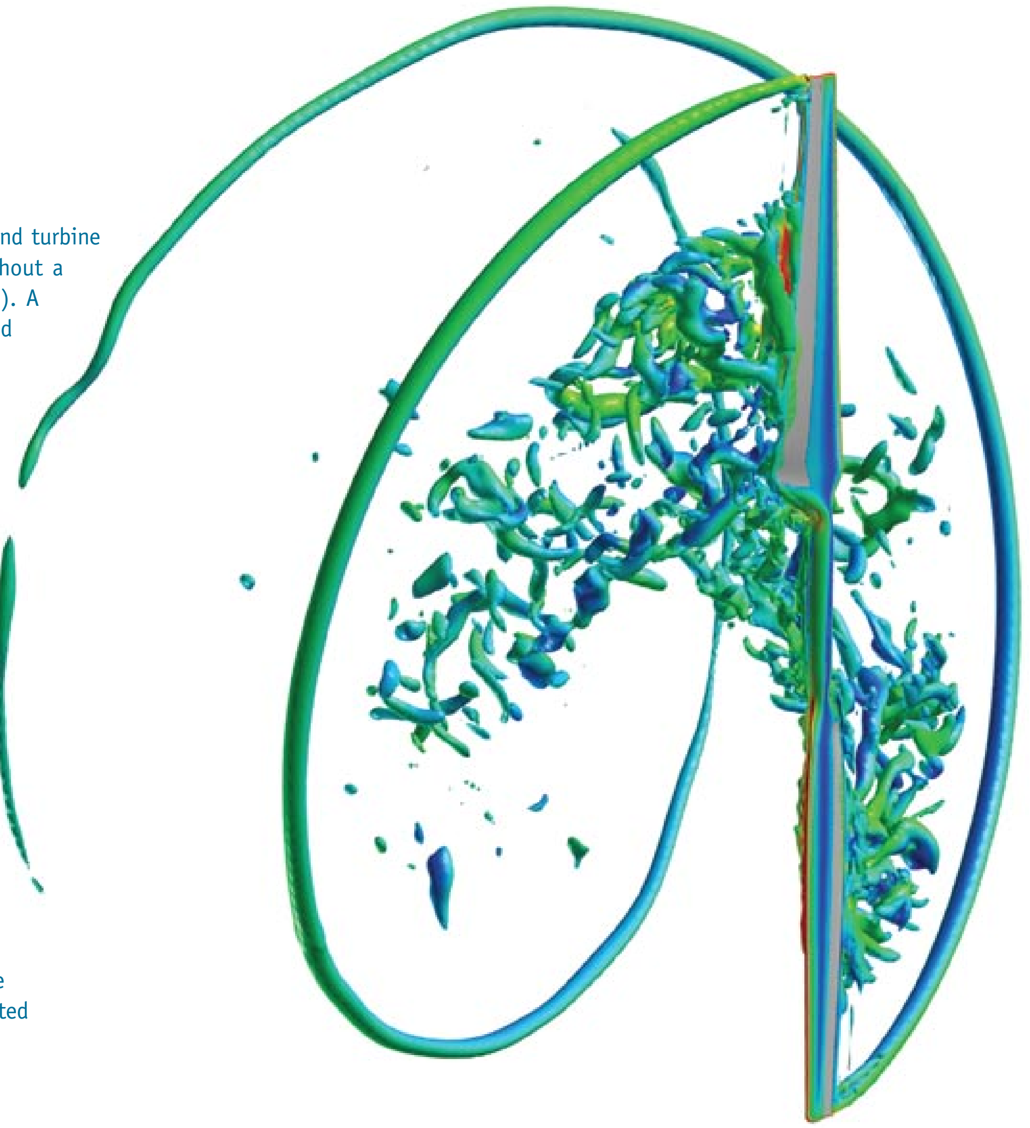
Aerodynamic factors

The primary source of noise is the aerodynamic effects—that pressure differential Smith spoke of—and is known as aeroacoustic noise. Various factors influence the strength of the aeroacoustic noise, including inflow turbulence, turbine blade elasticity, and tip speeds. The prediction of their relative effects is incredibly challenging and draws upon a multitude of engineering fields including aerodynamics, turbulence, structural dynamics, material science, and atmospheric science.

"Our focus is not so much on solving the world's problems but developing tools that have high enough fidelity yet are efficient enough that advancements can be made in sustainable research using them," says Smith. "To do that, we are focusing on several different issues. One improvement that we are



Simulation of an infinite-span "flatback" airfoil (DU97) wind turbine airfoil designed by Delft University using NASA's FUN3D CFD code modified by Georgia Tech to include a hybrid RANS/LES turbulence model. The airfoil geometry is is shown in gray and the shedding vortices in blue. Flatback airfoils are designed with unusually thick bases intended to increase their structural strength. This great stiffness comes at the expense of increased flow unsteadiness and possible increased noise.



Right: The modeling of a two-bladed wind turbine rotor using NASA's OVERFLOW code without a tower or nacelle (the gear box housing). A hybrid LES turbulence model was developed and implemented by the research team and employed here. This simulation is used to study the wake dynamics behind the rotating blades of a wind turbine. The blades can be seen in the forefront in gray; very distinct tip-vortices are seen emitting from their ends. Massive flow separation is evident inboard on the rotor.

Bottom Right: The interaction of the tower and nacelle with the rotating blades is simulated here in a "downwind" configuration, where the tower is in front of the turbine, with respect to the wind direction. The unsteady wake shed by the tower and nacelle impinges on the turbine blades causing even further unsteadiness and potentially higher noise and vibration. This simulation was conducted with the enhanced OVERFLOW code.

focusing on is implementing advanced turbulence simulation methods that actually capture some of the scales of turbulence rather than just statistically modeling it all."

Many of the techniques the team employs were originally developed for rotorcraft but are being extended to wind turbines. Rotorcraft is a term that includes a broad spectrum of rotating blade concepts, says Smith, and includes helicopters, tiltrotors, and ducted fans, to name a few.

"Wind turbines have their own set of uncertainties beyond helicopter applications. The blades rotate at tip Mach numbers that are much lower than what are encountered in conventional rotorcraft applications. Wind turbines are also more susceptible to crosswinds and atmospheric turbulence. In addition, their overall operational emphasis is not completely comparable to a helicopter rotor," she says.

Conquering the problem

The team is placing large eddy simulation (LES) methods into classic computational fluid dynamics (CFD) Reynolds-averaged Navier–Stokes (RANS) codes to see if they can more accurately model the physics than what is currently possible with the original turbulence models. The team is modifying two NASA simulation platforms currently used by the wind and rotorcraft industries, OVERFLOW and FUN3D, in order to better account for some of the dominant sources of aeroacoustically generated noise, such as turbulence-induced and blade-vortex-induced noise.

"Whereas the RANS models usually can pick up the gross features, if there is a lot of turbulence involved—a lot of flow separation—then they miss a lot of the secondary and tertiary features that can be important for performance, for vibration, and also for noise," Smith explains.

The team is also investigating the efficiency and accuracy of combining LES and adaptive mesh refinement (AMR) methods in the turbine wakes. Blades rotating against the stationary tower and nacelle—the housing for the gears and dynamo—generate a very dynamic and turbulent wake dominated by powerful tip vortices and separated flow closer to the center. This dynamic nature often means there are regions of the wake with either too much or too little grid resolution just for an instant, increasing the computation time or degrading the results. Linking LES with adaptive meshing, refining, and coarsening focuses computational power where and when it is needed. This task won't be easy; adaptive meshing presents many complications, such as feature detection and load-balancing. But, once these difficulties are overcome, the outcome will be a better result at a lower price, according to Christopher Stone, a local small-business subcontractor of Computational Science and Engineering (LLC) and member of Smith's Georgia Tech team.

OVERFLOW is a structured grid methodology, whereas FUN3D is unstructured. The research and development involving the structured grid methodology is being performed by Stone while the unstructured research is being carried out by Smith and Eric Lynch, an aerospace engineering graduate student. Lynch's work with the unstructured methodologies will be the basis for his Ph.D. dissertation.

The team is running their simulations on NCSA's Mercury cluster. They tested on Cobalt and briefly on Abe, looking at porting performance, but given the structure of the codes the best throughput is obtained using Mercury at this time. The team is also investigating program optimizations and possible restructuring needed to efficiently port to the newer, more powerful systems and will be assisted by the NCSA Advanced Support Program this year.

Other factors

The rotor wake plays an important role, so the team is also looking at how well the CFD models are capturing the wake because the importance of the wake on the loads, as well as the noise, is well known. The team is also moving from just modeling the rotor blades to modeling the wind turbine *in situ*, which includes the rotor blades, the tower, and if necessary, the near-field terrain.

"If you are going to look at the physics in depth you need to be able to model all components of the wind turbine. The rotor blades move with respect to the stationary components, and that's a very expensive simulation," says Smith. "So we are also looking at applying actuator disks and actuating blades, where we model just the blades' impact as a source field and not the actual blades. We couple the CFD code with a structural dynamics code that tells us where these blades are moving in space using the aerodynamic loads from the CFD model. This process is iterated until the loading and blade motion is periodic. These reduced rotor models, I think, are going to be useful when you're trying to get a gross approximation of the interaction of the wind turbine wakes with other features, such as a farm building or a mountain or in a wind farm. This concept will take a lot less time to analyze, and I think it's important that we have that capability."

Finishing touches

The final step for the team is examining the acoustics. By taking the methodology they developed and coupling it with known rotorcraft acoustic prediction methods, they believe they can determine what the acoustics are, both the higher-frequency noise that they can easily see in the models, and also the lower-frequency noise.

Smith and Stone say they are about midway through their processing cycles and tool development. But their results so far, which include improved turbulence modeling and unsteady low Mach number preconditioning (improving numerical accuracy and efficiency for low Mach number flows), are already garnering attention from other researchers, manufacturers, and government agencies. When completed, their tool will allow manufacturers and others working with wind turbines and wind farms to develop machines and installations that have improved aeroacoustics as well as increased operating efficiencies. ◻

Project at a glance

Team members

Marilyn Smith
Christopher Stone
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Funding

National Science Foundation

More information

www.ae.gatech.edu/~msmith
www.computational-science.com

Access online

www.ncsa.illinois.edu/News/Stories/Windturbines