Reducing Jet Noise by Controlling Turbulence

Researchers use Ranger to understand and minimize jet noise generation

Daniel Bodony, an assistant professor of aerospace engineering at The University of Illinois

On the surface, sound is a relatively simple phenomenon. It is a mechanical wave that travels through a compressible medium, such as air, and reaches our eardrums to be converted into an electric signal and interpreted by the brain. It doesn't matter whether the sound came from our vocal cords, an explosion, or a commercial jet.

But within the simplicity is a mystery. Scientists are still struggling to understand how sound is generated by a compressible turbulent flow, such as by a jet engine. The challenge is due a crisis of identity: there is not a way to separate the turbulent flow from the sound it generates; they're one in the same, and no one knows precisely what they look like separately. Only far away from a jet engine do scientists know what sound is.

Scientists are using what they do know about turbulent flow to address a growing number of practical problems in our world, from blood pressure monitoring to noise-cancelling headphones for soldiers.

For Daniel Bodony, an assistant professor of aerospace engineering at The University of Illinois at Urbana-Champaign (UIUC), the practical problem is how to make commercial aircraft less noisy. Working with Professor Jon Freund, of UIUC, and Jeonglae Kim, a graduate student, Bodony is part of a NASA-funded effort trying to lessen jet engine sound by controlling the turbulence, thus altering the motions of the flow and the resulting noise.

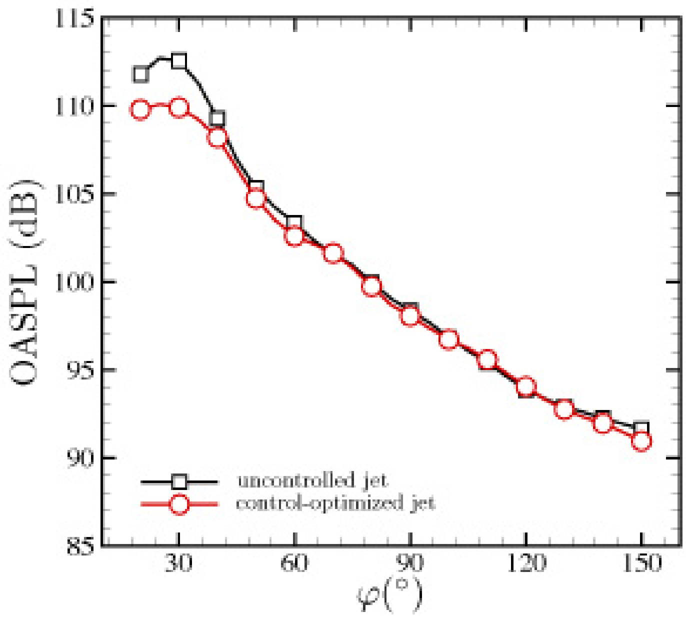
Airlines and aircraft manufacturers are under increasing pressure to keep the noise levels low for airport personnel and for those in the neighborhoods that surround airports. Approximately every 10 years, an international organization reduces the maximum noise an airplane can produce before it can be certified and sold to commercial airlines. Aircraft are barely able to meet the current levels. When the noise levels drop again in a few years, no one has a ready-made solution.

Bodony and his team believe their supercomputer simulations, which show the evolution of turbulence-generated sound waves from the jet engine exhaust, will help explain how sound is generated on the most basic level, and how it can be actively controlled with a new device.

"We're studying the controlled jet and the uncontrolled jet to understand what changes between them," said Bodony. "That's the thing that experiments can not currently do and is missing from our understanding of the science."

Because of the range of scales and complexity of these phenomena, jet turbulence cannot be examined at a fundamental level in the laboratory in the level of detail required for studying noise generation. Instead, Bodony, Freund, and Kim simulate the motion of the air around the jet using a numerical technique called large eddy simulation on the Ranger supercomputer at the Texas Advanced Computing Center (TACC), one of the largest in the world.

By leveraging the resources from TACC, the researchers are solving complex physical problems to reduce the noise from commercial aircraft. The simulations reveal the amount of turbulence flowing



A quantitative assessment of the radiated sound reduction due to control, as a function of angle from the downstream jet axis.

around the jet but, more importantly, the amount of sound that this turbulence produces.

"Unfortunately, the noise is not generated where you can control it, so you have to put a control someplace else, like on the nozzle, and tickle the flow at the nozzle exit in such a way that the sound is reduced at a later spot in the jet," Bodony explained.

He determines the precise form of the control by solving directly the unsteady equations of motion for a compressible turbulent flow expressing conservation of mass, momentum, and energy, and their adjoint (or dual). The adjoint equations tell him where and how to control the flow without having to use trial-and-error.

After conducting four years of research, Bodony and his collaborators have developed a novel technique to determine the optimal controller required to reduce jet noise. The plan involves using a plasma actuator, developed by his colleagues at Ohio State, to alter the turbulent flow causing the sound field using heat.

"We can't squash the turbulence," Bodony said. "Our controllers aren't that strong and it may not even be possible or desirable. So we add additional perturbations to reorganize the pre-existing disturbances such that the unsteady forces and stresses within the fluid are less."

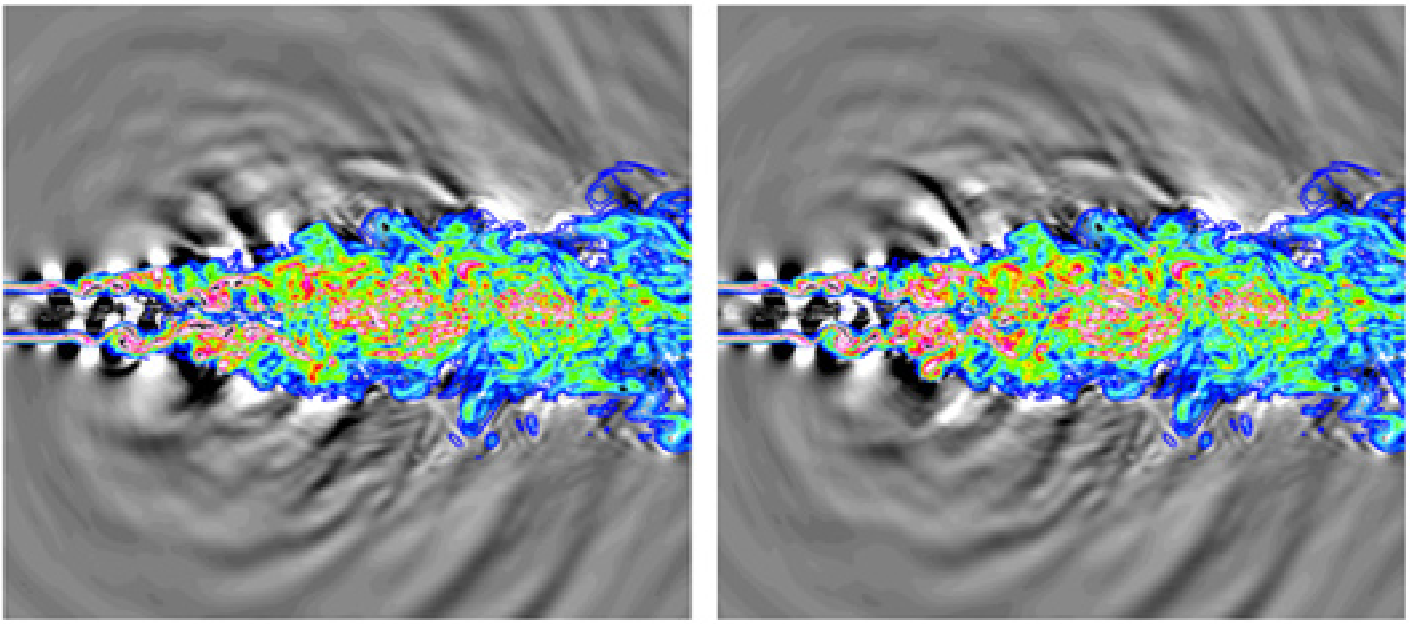
The actuator acts much like an automotive spark plug, creating a very intense electrical current that flows through the air, causing perturbations that can be introduced into the jet.

By solving equations to optimize the controller, the simulations determine the ideal timing and strength of the perturbations to reduce the engine's radiated sound without significantly altering its thrust. They are developing an active flow control device, with the ability to turn on or off, or change the strength of the control, based on continuously assessed conditions.

"We can reduce the noise from these jets as well as the absolute best that has been found experimentally by trial and error," said Bodony.

Bodony's first round of improvements showed the potential to reduce jet noise by three decibels, or the equivalent of 30 percent. Bodony is confident that with further refinements, his group will be able to reduce the noise level even further.

The design insights that Bodony uncovered are expected to reduce the sound levels of "N+3" generation aircraft: NASA's shorthand for aircraft fielded three generations in the future. Bodony expects



Small, well-timed disturbances added to an uncontrolled Mach 1.3 turbulent jet (left) result in the quieter, controlled jet (right). Though only subtly different, the controlled jet is producing 30% less noise as visualized by the black-and-white contours of dilatation, a measure of air's compression rate. The sound-generating turbulence, as indicated by the vorticity, is shown as color.

such a device, if successful, to come to market in 10 to 15 years.

If that sounds long, consider that the newly released Boeing 787, the first commercial airliner equipped with noise-controlling devices, called chevrons, contains elements designed 15 years ago.

Results of the group's theoretical, experimental, and simulation work have been published in several AIAA conference proceedings, in the Journal of Sound and Vibration, and is currently being reviewed by several leading journals. [For a full listing of Bodony's publications, visit his webpage.]

There's no guarantee that the simulations will determine the best possible design, but a lot of science, a lot of understanding, and a lot of computer muscle went into them – and, through extensive validation, the group's simulations have proven accurate.

"Bodony and Freund are exploring the question of how the flow should be changed or altered so as to reduce its radiated noise significantly while maintaining the propulsive performance," said Sanjiva Lele, professor of mechanical engineering and aeronautics and astronautics at Stanford University, who is not involved in the research. "This is computationally and intellectually demanding, but if systematic methods to reduce noise can found, the benefit to the aviation community would be tremendous."

The question of why sound behaves the way it does is still in play, so Bodony has also been using the simulations to isolate some of the leading hypotheses related to jet noise to see whether they fit with the computed results.

"One hypothesis is whenever you want to make a jet quieter, you have to add a disturbance of a particular orientation, called streamwise vorticity," said Bodony. "We are in the process of evaluating the difference in the controlled and uncontrolled flows to see if this is true."

They are also examining how the "coherent motions" of the jet – subtle movements up and down and from side to side – relate to sound generation.

"Our intuition with turbulent flows is very poor, so we need more advanced techniques," said Bodony. "With the simulations, there's no guessing involved. But that also puts the burden on us to understand the data that we get."

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