IT'S A BIRD, IT'S A PLANE: FLOW PATTERNS AROUND AN OSCILLATING PIEZOELECTRIC FAN BLADE

Engineers at Nokia Bell Labs use multiphysics simulation to capture the interplay between an oscillating piezoelectric fan and the surrounding airflow in the pursuit of a quiet, reliable, and low-energy cooling solution.

By **SARAH FIELDS**

FROM A SNAKE'S MOVEMENT, TO A GECKO'S CLIMBING GRIP, to a cheetah's running stride, bio-inspired design is making its way into robotics, electronics, and medical device innovations. Among the creatures that have influenced recent tech developments, the motion of a bird's wings has inspired the creation of an oscillating piezoelectric fan blade.

As electronics grow smaller and smaller, and are used for extended periods of time, their internal heat loads become greater, demanding new, compact cooling methods. Piezoelectric fans include a piezoelectric

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material that expands and contracts as voltage is applied to it, triggering movement of a cantilever blade and consequent airflow. They are reliable, low power, and quiet, making them promising in this application.
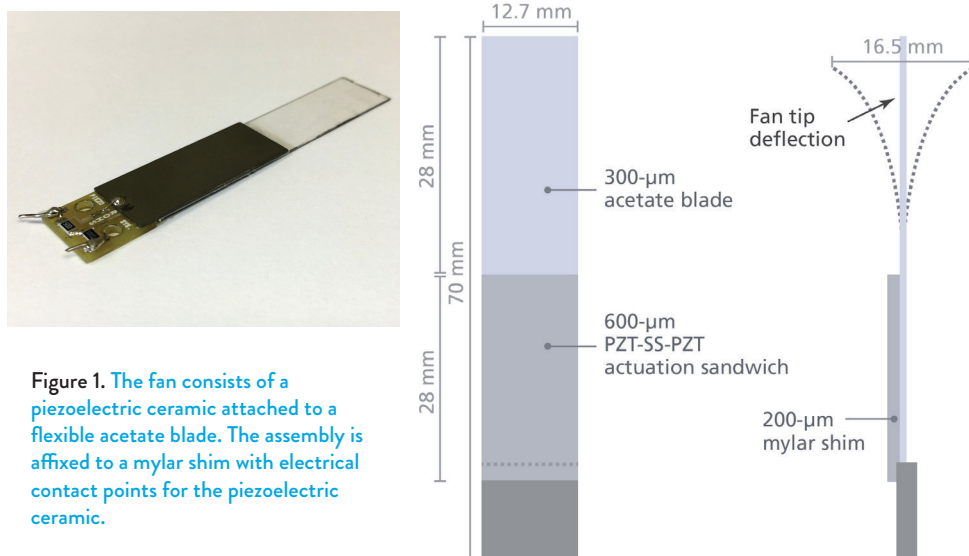
Among those furthering the science behind this concept is Akshat Agarwal of Nokia Bell Labs, who worked to characterize airflow around the fans. The insight into the airflow patterns around an oscillating blade has relevance in unexpected applications with similar airflow pattern as well.

❱❱ A STEPPING STONE BETWEEN NATURAL AND FORCED CONVECTION

DESIGNERS OF ELECTRONIC DEVICES used for extensive amounts of time usually rely on either natural convection or forced convection by way of powered fans to manage heat generation. However, forced convection requires a significant amount of power and doesn't scale down well to the small scale needed for today's generation of electronics.

Halfway between natural and forced convection, a piezoelectric material provides heat handling ability by expanding and contracting when a voltage is applied, resulting in an oscillating movement of the attached fan blade that initiates airflow. As Agarwal explained, "A piezoelectric fan is a stepping stone. Natural convection is preferred when possible, but in certain cases, it makes sense to incorporate
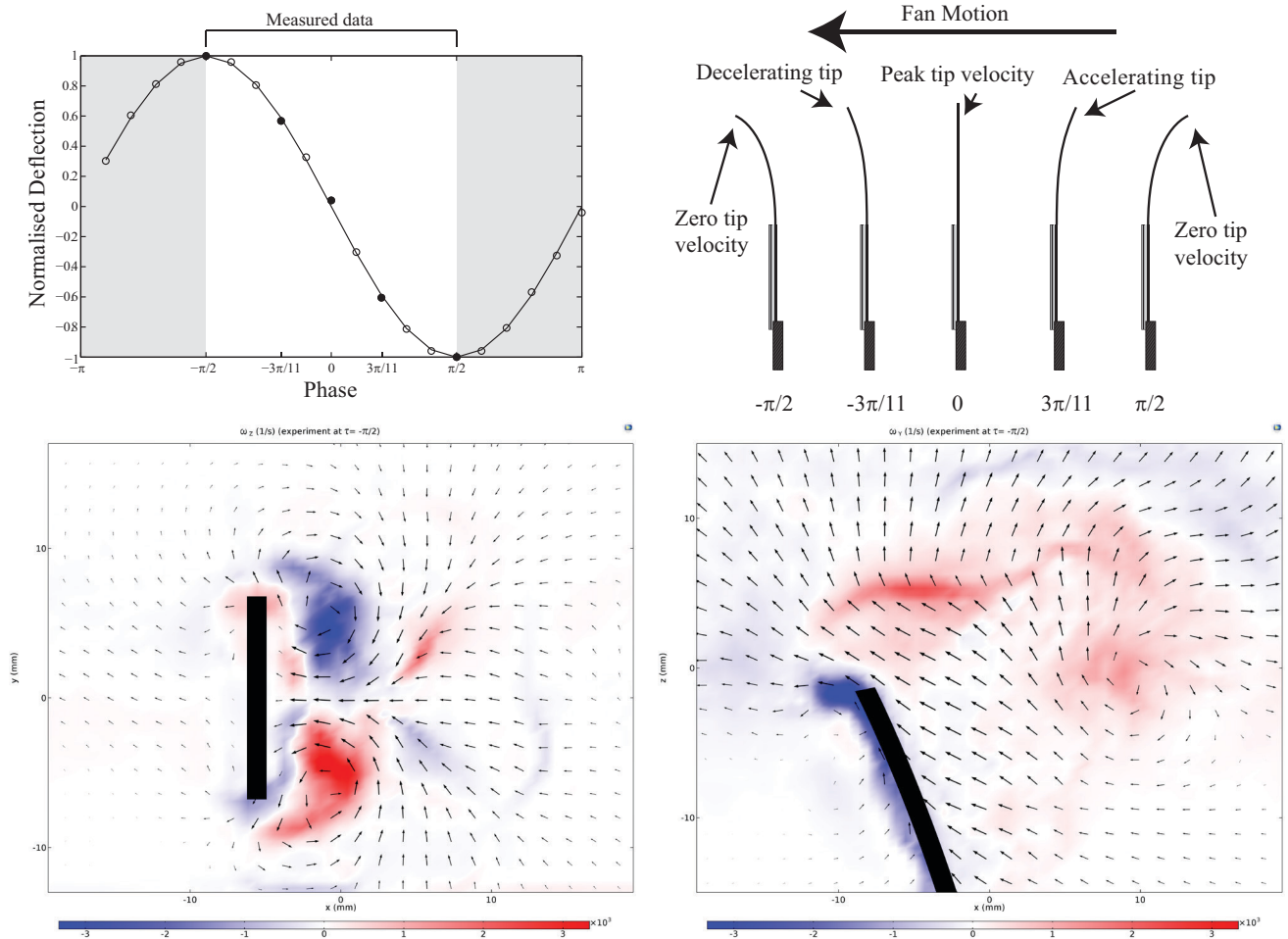

Figure 1. The fan consists of a piezoelectric ceramic attached to a flexible acetate blade. The assembly is affixed to a mylar shim with electrical contact points for the piezoelectric ceramic.

12.7 mm
28 mm
70 mm
28 mm
300-µm acetate blade
600-µm PZT-SS-PZT actuation sandwich
16.5 mm
Fan tip deflection
200-µm mylar shim

Figure 2. Top left: Plot of the phase-locked measurements showing displacement of the normalized fan tip. Top right: Illustration showing the deflection of the fan for half a time period. Bottom: Phase-locked PIV measurements for the vorticity (colored contour map) and the in-plane velocity (vector field) of an unconfined fan.

an active part to move the air." The fan blade used in the research at Nokia consists of a piezoelectric material bonded to an acetate strip and a mylar shim (Figure 1).

With a dynamic system on a small scale, understanding the fluid dynamics can be tricky. In order to truly capture the airflow around the oscillating beam, the engineers at Nokia needed to expand upon work that had been done in two dimensions to three-dimensional simulations and physical testing.

⟫ DETERMINING THE AIRFLOW PATTERN

ENGINEERS AT NOKIA BELL LABS first characterized the system experimentally using phase-locked particle image velocimetry (PIV), which allowed them to determine the vorticity and in-plane velocity of an unconfined fan in free space (Figure 2), for a total of 11 positions of the oscillating beam. For each position, data was acquired along five x-y planes and five x-z planes to obtain a 3D field.

The next step was to model the beam-air interaction to gain further insight into the

system. When it came to determining a strategy for the simulation, speed and accuracy were key considerations.

"It was important for us to be able to accurately model fluid flow around the blade as fast as possible," Agarwal said. "This would let us virtually perform design iterations and investigate how these blades would behave in many different situations."

The engineers first looked at modeling methods used in literature, but the computational demands of such approaches led them to consider another approach.

The COMSOL® software would demand fewer computational resources and included the arbitrary Lagrangian-Eulerian method, the preferred method for simulating the physics of this system. This method combines fluid flow formulated using an Eulerian description with solid mechanics formulated using a Lagrangian description.

Agarwal used COMSOL to perform a 3D bidirectional fluid-structure interaction (FSI) analysis of the forces and fluid behavior in and around the oscillating blade. This
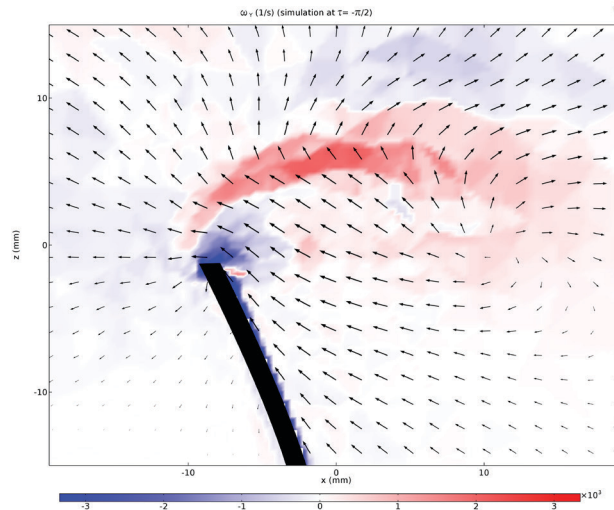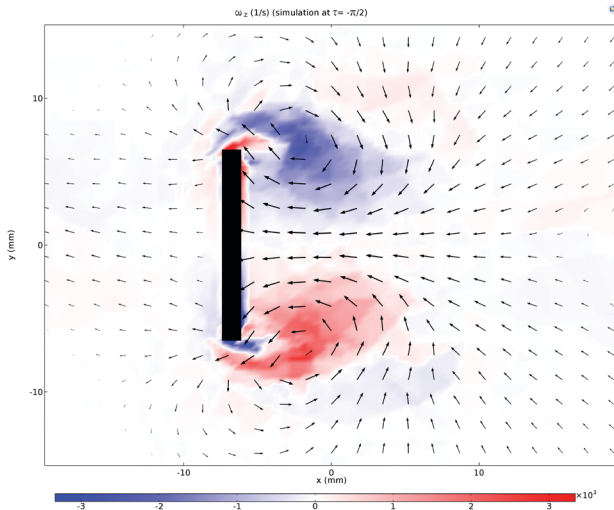
Figure 3. The COMSOL simulation shows the vorticity and the velocity field at two positions during oscillation.

analysis allowed him to accurately capture the physics of the system. Thanks to the flexibility of COMSOL, Agarwal was able to simplify the design in some of his simulations to select the best approach in each aspect of the simulation.

To simplify the study for computational efficiency, the engineers modeled the shear force and fluid pressure during the movement instead of studying the fan actuation itself. The simulation results revealed the fluid velocity (Figure 3), as well as the structures of the vortices and their movement around the fan blade (Figure 4).

"We obtained a picture of the airflow close to the blade, with a better resolution than what we could get from experimental results. At the edge of the blade is where most flow occurs and momentum is greatest. From our experiments, we were able to look at the velocimetry image and capture planes of motion. Then we stitched those

planes together to obtain the shape of the vortices. But the resolution is limited because you can only get a certain number of planes during an experiment," Agarwal added. "When you do a full 3D simulation of such a problem, you can study velocity close to the fan and far away, and you can plot many different variables."

"The software also provides a way to extract data evaluated on the mesh or grid defined by the user. That data can then be used however needed, for example, in another software, or processed with a script," Agarwal explained, referring to the postprocessing he performed to generate representations of the vorticity in the airflow around the blade.

》 ANALYSIS AND EXPERIMENT: A POWERFUL COMBINATION
THE NOKIA BELL LABS TEAM FOUND that their

simulations captured all the details and dynamics of the system and the simulations analyzed airflow and movement near the blade in more detail than physical experimentation alone. Their study resulted in a validated model that they expect to use as a benchmark in future designs. Knowledge from their results can even be used for applications in other fields, such as flapping wing unmanned aerial vehicles (UAVs).

"The power of COMSOL is that we can implement new geometries and optimize the design much more quickly. I was able to play with the design and take the best of the design features that I was after," Agarwal concluded. Future studies may examine the airflow and fluid dynamics around more than one oscillating blade, to understand how multiple fans used together might impact the cooling effect. ◎

From left to right: Nicholas Jeffers, Kevin Nolan, Diarmuid O'Connell, and Akshat Agarwal.