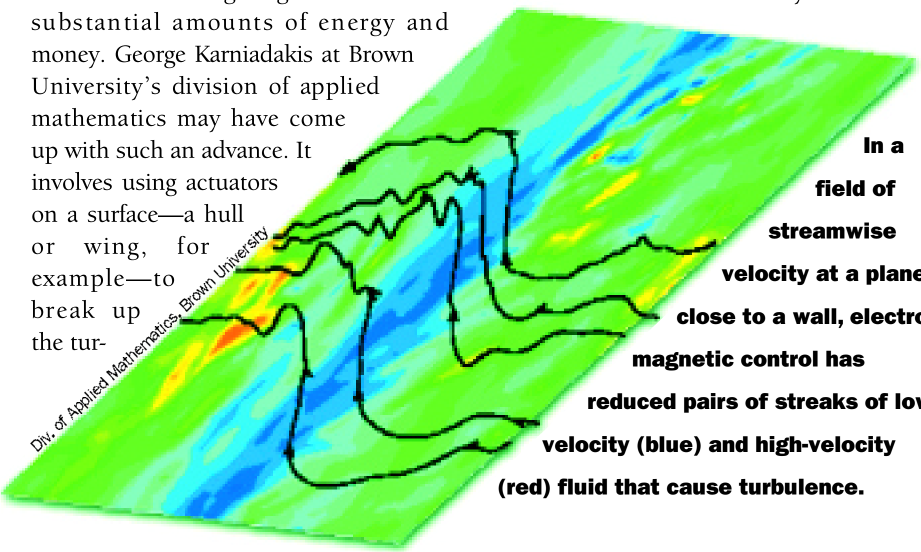
by Eric J. Lerner

Smoothing turbulence electromagnetically

Turbulent flow over surfaces is the main cause of drag, whether the fluid is air flowing over an aircraft, water past a ship or submarine, or oil in a pipeline. So any method of reducing drag is bound to save substantial amounts of energy and money. George Karniadakis at Brown University's division of applied mathematics may have come up with such an advance. It involves using actuators on a surface—a hull or wing, for example—to break up the turbulence before it forms. In a device that Karniadakis is developing, the actuators are electromagnetic tiles that create tiny waves in salt water. Simulations indicate that this approach could cut drag by as much as 50% (*Science* **2000**, *28*, 1230).



In a field of streamwise velocity at a plane close to a wall, electromagnetic control has reduced pairs of streaks of low-velocity (blue) and high-velocity (red) fluid that cause turbulence.

Researchers know how turbulence develops as a fluid flows past a surface. First, pairs of high-speed and low-speed streaks of fluid develop, and then vortices between them stretch into hairpin-shaped structures that burst, liberating energy and creating a drag force. Small metal ribs on the surface are sometimes used to try to break up the streaks, but they only reduce them, cutting drag by perhaps 5%. Using theoretical analysis and simulations, Karniadakis and his student, Yiquing Du, found that a more effective method was to set up traveling waves perpendicular to the direction of flow and parallel to the surface the fluid is passing. Under certain conditions, the waves would prevent formation of the streaks and the hairpins to which they give rise, and dramatically cut drag.

For nonconducting fluids such as air, the waves would have to be created by mechanical actuators. However, in salt water, a weak electrical conductor, the forces creating the waves can be generated electromagnetically. To do this, Karniadakis uses arrays of electromagnetic electrodes and magnets, arranged in strips. Close to the electrodes, the electric field is nearly perpendicular to the structure's surface and generates small electric currents in the salt water. Interaction of the currents with the magnetic field, which is in the direction of flow, yields a force that pushes the fluid across the flow streak. Timing the activation of each tile's electrodes sets up wave activity, which, in simulations, eliminates the high- and low-velocity streaks and cuts turbulence.

The exact conditions of the traveling waves are critical to drag reduction. The period, wavelength, and amplitude of the induced waves all affect drag and in certain combinations can even increase drag forces. However, in Karniadakis' optimal simulations, the energy spent in creating the traveling wave is only 20% of the energy saved by drag reduction.

"Right now, Ken Breuer, also at Brown, is planning laboratory experiments using half-inch tiles to test the ideas," says Karniadakis. Larger-scale tests will be conducted at the Navy Undersea Warfare Center in Newport, Rhode Island, and eventually, there will be field experiments on ships. The Defense Advanced Research Projects Agency will fund the experiments.

Single-molecule 'scope

Although many types of extremely high-resolution microscopes can observe single atoms, optical microscopy has advantages that motivate researchers to improve optical resolution. The main way of doing this has been near-field scanning microscopy. This technique takes advantage of the fact that when an illuminating aperture is very close to an object, relative to the aperture size, the illuminated spot is only the size of the aperture. (In conventional microscopy, in which the object is relatively distant from the aperture, the minimum spot illuminated, and thus the minimum resolution, has a diameter no smaller than a wavelength of light.)

But in recent years, near-field microscopy has encountered its own limits, which prevent a resolution of better than about 50 nm—about 0.1% of a wavelength of the light typically used. The problem is that it is difficult to make apertures much smaller than 50 nm, and there is a finite skin depth in every material that allows some light to pass through it. There is, therefore, an area surrounding the aperture through which light penetrates. Thus, skin depth sets a lower limit to the effective diameter of an aperture.

A team of researchers at the University of Konstanz (Konstanz, Germany) has found a possible way around this limitation—by producing a light source from a single molecule (*Nature* **2000**, *45*, 325). Because the light source still is only on the order of 1 nm across, the illuminated spot can, in theory, be that small and produce a comparable resolution.

The Konstanz team produced its single-molecule light source by starting with a standard tapered optical-fiber probe, fed by a dye laser that could be accurately tuned in frequency. They prepared *p*-terphenyl crystals doped with a dilute concentration of terrylene molecules. These molecules have an extremely sharp fluorescence resonance that can be excited only by light within 25 MHz of the resonance peak, a tuning sensitivity of 1 part in 10 million.

Each individual molecule's resonance frequency is slightly different from every other molecule's, depending on its exact location within the crystal. By tuning the laser, an individual molecule can be selected so that only it is fluorescing. By scanning this single-molecule light source over objects and collecting the reflected light with conventional optics, the German team obtained images of test samples.

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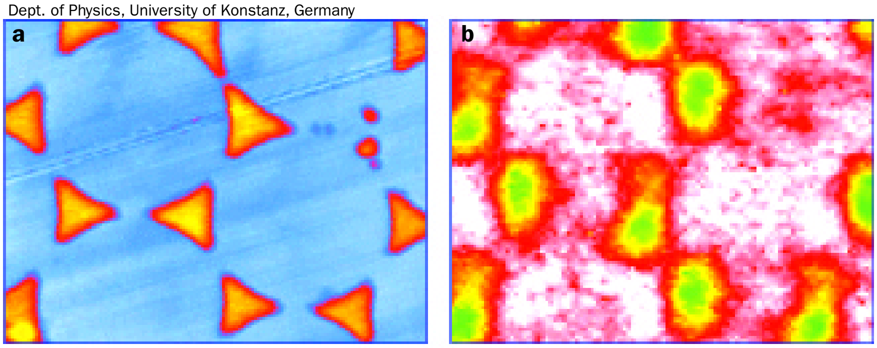


Images of 25-nm-high triangular aluminum islands in a hexagonal lattice. The topographic image was taken with an atomic force microscope (a), and the optical raster image was recorded using the fluorescence of a single terrylene molecule for illumination (b).

"Although the resolution that we were able to achieve in this first experiment was not better than the resolution demonstrated with conventional near-field microscopy, the technique has the capability of achieving molecular resolution," says Jens Michaelis, a team member. The closer the light source gets to the object, the smaller the area illuminated and, thus, the finer the resolution. However, in practice, the fluorescing molecule could not get closer than about 200 nm from the object surface, because the illuminating molecule was within the crystal and not on its surface.

In future experiments, the team will use submicrometer crystals and techniques that can identify which molecules are nearest to the surface. This should bring the technique closer to the ultimate goal of nanometer-resolution optical microscopy.

Camera in a pill

One of the more unpleasant medical procedures can be gastrointestinal (GI) endoscopy—the examination of the stomach, small intestine, or colon by fiber-optic video. A flexible catheter carrying light, power, and the return video signal is snaked down the throat or up through the colon as air is pumped in to inflate the GI tract. The procedure can be so painful that sedation is required.

Many such exams could become obsolete, thanks to a camera-in-a-pill developed by scientists at the Royal London Hospital and Given Imaging Ltd. (Yoqneam, Israel). The large pill, about 11 × 30 mm, contains a video camera, a light source, a telemetry transmitter, and a battery to power it all. Color images of the GI tract are radioed to an external recorder without the need for catheters or air inflation (*Nature* 2000, *405*, 417).

Photobit Corp.

This 11 × 30 mm pill contains a 4.3-mm-square CMOS image sensor (top right), a light-emitting diode, a telemetry transmitter, and a battery.

The capsules include several innovations that make the small unit possible. To minimize power consumption, the light-emitting diode switches on only long enough for the complementary metal oxide semiconductor (CMOS) image sensor to grab a single frame of video, and the transmitter remains on only long enough to transmit one frame at a time. Careful design of the optics eliminates the internal reflections that often occur when the illumination and the imager share the same lenses. Advances in circuit miniaturization have cut power consumption to less than 2 mW, so that 6 h of continuous transmission is possible.

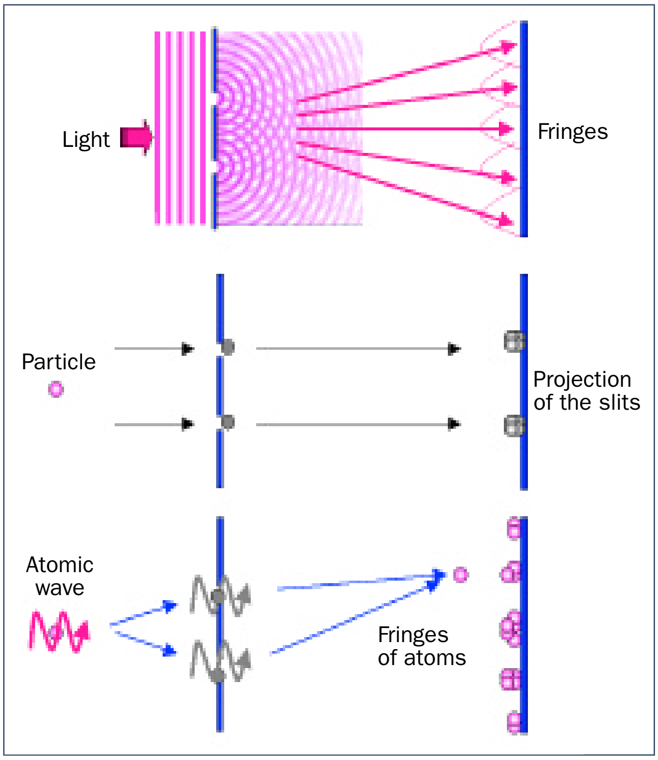
The video images are transmitted in the ultrahigh-frequency radio band to aerials taped to the patient's body and are fed to a portable recorder. Thus, the patient does not have to be at a hospital during the procedure. Peristalsis, the normal wavelike motion of the GI tract, propels the capsule on its way, and the 6-h recording time is long enough to view the stomach, the entire small intestine, and part of the colon. The ability to image the entire small intestine is of particular value, because it is generally impossible to snake a catheter all the way through it. Ten healthy volunteers who tested the capsule found it easy to swallow and reported no discomfort.

Compared with traditional endoscopy, however, wireless capsule endoscopy has some limitations. For one, the camera cannot be pointed in a desired direction, nor can it be made to linger at a site to get additional images. Nor can it be used to take biopsies or remove polyps as catheter endoscopes can. Finally, the endurance of the capsule batteries is not enough to allow imaging of the whole colon, because passage from mouth to elimination takes 10 to 48 h. Except for the lack of biopsy capacity, all of these drawbacks are associated with the inability to control the capsule. However, with rapid advances in microminiature motors, this limitation may soon be overcome, freeing many patients from the discomfort of catheter endoscopes. Ω

Holography with atoms

Computer-chip manufacturers want alternatives to conventional lithography, which becomes more difficult as circuit dimensions shrink. Both X-ray (also termed extreme UV) and electron lithography, contenders for the next generation of lithography, pose serious technical challenges. All lithography involves multiple steps as well, including first patterning a photoresist and then chemically removing the unexposed areas.

Why not lay atoms down directly onto a surface in a predetermined pattern and eliminate the lithography steps altogether? This is what Fujio Shiminimizu and S. Mitake of the University of Electro-Communication (Tokyo, Japan), and J. Fujita of the NEC Fundamental Research Laboratory (Tsukuba, Japan), are attempting to do by applying holography to atoms (*Phys. Rev. Lett.* 2000, *84*, 4027). Beams of atoms, like beams of photons, have waves that are governed by wave equations—Schrödinger's for atoms and Maxwell's for photons. Although the equations differ, many of the same phenomena occur—including interference—and so the principle of hologra-



Fundamental Research Lab., NEC Corp., Tsukuba, Japan

The principle of holography can be applied to atoms as well as to light because both are associated with waves and interference. Hence, atoms can be made to follow diffraction patterns set up by a hologram.

phy can be applied to atoms as well. As long as the beam is sufficiently dilute that interactions among the atoms are not important, atoms can be made to follow the diffraction patterns set up by a hologram.

In the Japanese device, the hologram consists of a plate with 513 platinum strips connected to electrodes. In the gaps between the strips are patterns of holes through which the atoms can pass. When the atoms pass through gaps where the electrodes have the same potential on either side, there is no change in the phase of the associated atomic wave. But when there is a potential difference, a phase change in the wave can be induced. The result is that by arranging the holes and controlling the electrodes, patterns of atomic waves can be set up, so that the atoms arriving at a surface are also patterned.

In experiments, the holograms caused the atomic beams to form English and Greek letters. By switching the way the electrodes are charged, the experimenters could rapidly switch back and forth between the letters. Such flexibility, impossible with lithography, could be of use in future circuit manufacturing and in creating complex three-dimensional structures.

The device does not produce fine-grained patterns. In fact, the mechanical plates used to detect the atomic patterns had a resolution of only 50 μm, compared with the 0.1-μm lines achieved in lithography. However, because the quantum wavelength of atoms is extremely small, even atomic-scale structures could, at least theoretically, be produced by more advanced atomic-holography techniques.

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