Soapy swirls. A cylinder in a rapidly flowing soap film sheds a "vortex street" in its wake. Similar 2D turbulence may occur in the atmosphere and the oceans.

eral micrometers thick in the center and lasts for hours as pumps return the fluid to the nozzles at the top. Small cylinders inserted in the flow create vortices that look like mushrooms, spiral galaxies, and other graceful forms. These shapes are highlighted by microscopic spheres of titanium dioxide or polystyrene in the film, which catch the light of probe lasers or stroboscopic lamps.

This system let Rutgers probe one of the key differences between 2D and 3D turbulence. In a 3D fluid, swirls can intensify in a process called "vortex stretching," in which particles go faster and faster as they plunge toward the throat of the vortex. This happens to water gurgling down a drain or winds sucked into a tornado: The conservation of angular momentum amplifies motions as the whirling tube gets stretched thinner. However, this stretching and amplification can't happen in a 2D fluid, because the swirling particles are confined to a plane. Instead, according to theories proposed in the 1960s by physicists George Batchelor and Robert Kraichnan, some vortices should merge into progressively larger ones, a process called the inverse energy cascade. At the same time, smaller swirls should stretch and fold into the seething fluid like candy on a taffy puller—an effect known as the forward enstrophy cascade.

To test these predictions, Rutgers placed two vertical combs of cylinders along the edges of his soap film flow to generate constant trains of interacting vortices as the film streamed past. He saw evidence for both processes. If the vortices exceeded a certain size, they merged into larger whorls. However, smaller vortices sheared and vanished, like thin ribbons of cream in a mug of coffee. "This was a key theoretical prediction, but [the two energy cascades] had never been observed simultaneously," says Rutgers, whose findings appeared last September in *Physical Review Letters*.

Ongoing work by Rutgers and by Goldburg and Wu suggests that 2D turbulence doesn't always conform to theory, however. Theory predicts that 2D vortices should grow and dissipate gradually, because they cannot interact as chaotically as they do in 3D. Instead, says Goldburg, "we are finding that 2D flows can depart violently from the mean in rare bursts"—a hallmark of turbulence called "intermittency" that scientists had assumed was the sole province of the 3D world. The 3D phenomenon is familiar to airline passengers as "violent excursions"—unexpected jolts that leave your stomach in the lurch. In 2D flows, the excursions appear as occasional spiky transfers of energy among vortices.

Some experts wonder whether the soap film results are too squeaky clean. "The experiments are very nicely done, but they are not an exact analogy [to 2D turbulence] by a long shot," says fluid mechanician John Lumley of Cornell University in Ithaca, New York. The main problem, he says, is that the films vary in thickness by up to 30%. Such bulges could be compressed or squished, especially in a fast-moving film, he says. To Lumley, that invalidates the assumption that the turbulence traces a purely planar flow, because compression introduces a 3D component of motion to the film. Experimentalists acknowledge that the bulges are a concern. But in a report last August in *Physical Review Letters*, Ecke and two colleagues described a study of a tilted film that flows more slowly than the vertical ones. They found that the behavior of their film, bumps and all, hewed closely to predictions for an ideal 2D sheet.

Even so, Lumley wonders about the real-world relevance of soap films. "There is one important case where turbulence in nature is approximately 2D, and that is in the atmosphere on large scales," he says. "Beyond that, my feeling is that almost all turbulence in the universe is three-dimensional." Such views, however, shouldn't burst the bubbles of soap film researchers, says fluid dynamicist Katepalli Sreenivasan of Yale University in New Haven, Connecticut. "Finally, after 30 years, we see a convergence of theory, simulation, and experiment," he says. "Anything that cleans up our understanding of one area of turbulence is most valuable."

–ROBERT IRION

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SCIENCE EDUCATION

Reinventing the Science Master's Degree

The Sloan Foundation is backing an experiment at five universities to offer science undergrads an alternative to the Ph.D.

Meet Jarrell Pair, science professional. Fresh out of grad school, Pair is spending the next few months in Santiago de Compostela, Spain, creating a virtual driving tour of the 1200-year-old city's narrow cobblestone byways and bustling cafe-lined plazas. When the project is finished, people will be able to sit in a fake car surrounded by movie screens and take a virtual spin through Santiago, "experiencing all the sights and sounds of being in the actual city," Pair says. The exhibit, part of the Santiago 2000 celebration, will also tour computer graphics conferences in Europe, serving as a showcase, Pair says, for luring high-tech companies to the Santiago region.

Sim city. With a new master's under his belt, Jarrell Pair is helping design a virtual tour of Santiago, Spain.

Pair didn't have to tough out a Ph.D. for graduate training in his specialty, human-computer interaction. Instead, the 26-year-old with eclectic interests—he earned bachelor's degrees in computer engineering and international affairs, and certificates in music, drama, and film—last year completed a professional master of science degree at the Georgia Institute of Technology in Atlanta. The university is one of five in an experimental program, funded by the Alfred P. Sloan Foundation in New York, to test the academic waters by of-

CREDITS: (TOP TO BOTTOM) PETER VOROBIEFF AND ROBERT ECKE, LOS ALAMOS NATIONAL LABORATORY; UNIVERSIDAD DE SANTIAGO DE COMPOSTELA fering a graduate science degree that is tailored toward careers in business and industry rather than academe—an alternative to the long journey to a Ph.D.

"I see this as an altogether new degree comparable to the creation of the MBA in 1908," says Sheila Tobias, a science education consultant in Tucson, Arizona, who is advising Sloan. "No one will be able to manage anything without a firm grounding in science and mathematics," says Tobias, who coauthored the book *Rethinking Science as a Career*. She envisions a cadre of technically trained, highly paid "science-trained professionals." People in industry are gung-ho for the program. "There is a major demand for people with some practical experience other than the pure science," says Jack Samiarias, senior vice president for ABN AMRO, an international bank in Chicago.

But the new breed of science salaryperson must overcome several hurdles, including the disdain U.S. academic scientists generally shower on master's degrees. "Faculty in the sciences are mostly accustomed to thinking their students will get doctorates, and their students will get jobs in academia," says Sloan program director Jesse Ausubel. Although a master's has long been a respectable pursuit in engineering, computer science, or geology, for example, it doesn't carry much weight in the basic sciences. Master's degrees in the life sciences, for instance, have evolved into "a consolation prize or booby prize for people who did not make it through qualifying exams," says Shirley Tilghman, a Princeton University molecular biologist who chaired a panel on graduate education for the National Research Council (NRC). The situation is a bit different in other countries, particularly in Europe, where science students often earn a 6-year degree similar to a combined U.S. bachelor's and master's.

In many fields, the master's used to be a required milestone on the road to a Ph.D., says John Vaughn, executive vice president for the Association of American Universities in Washington, D.C. Realizing that stopping at a master's "wasn't a real good deal," he says, many departments eliminated it to streamline doctoral programs. Any university that starts a professional master's, Tilghman says, must "make this a distinct and different and new program." Indeed, warns Vaughn, "programs like this will encounter resistance on some campuses that see it as resurrecting some second-class degree to pursue a third-class career objective."

But Tilghman and others say the time is ripe to renovate the science master's, particularly as many new Ph.D.s flounder in today's job market. By now, most scientists have disabused themselves of the notion that academia offers ample opportunities to freshly minted Ph.D.s. And some Ph.D.s who embark on careers outside academia find, to their dismay, that they didn't even need the years of grinding doctoral studies and late nights in the lab to succeed.

As people began to grapple with this trend in the early 1990s, the idea of revitalizing the master of science started making the rounds. Georgia Tech got into the game early, conceiving the human-computer interaction program in 1995. Officials saw the new master's as "an interdisciplinary, industry-oriented, stand-by-itself degree—an alternative to the academic Ph.D.," says Anderson Smith, Georgia Tech's associate dean for the College of Sciences. Sloan officials also were exploring alternatives. "This was an idea that was in the air, and the time seemed right to do it," says Ausubel. In early 1997 Sloan invited Georgia Tech and other universities to submit proposals for professional master of science programs.

Georgia Tech won its Sloan award before launching its human-computer interaction program in fall 1997. Sloan has handed out four more $400,000 grants to universities to start degree programs that combine graduate science education with training in business-related fields such as finance, computation, and information sciences. So far 19 Sloan-funded programs, spanning fields from computational linguistics to integrated pest management, are up and running or in the works (see table). Other universities, not funded by Sloan, have started or are contemplating similar programs. All are designed to appeal to students who don't want to become steeped in the esoterica of subdisciplines.

The Sloan-funded programs last up to 2 years and focus on coursework rather than basic research. Like MBA programs, the science master's emphasizes hands-on experience through internships in industry. Tuition and fees per semester range from $1132 to $11,099; the fledgling programs are providing some financial support to lure students. But in the long run, officials say, students in these professional M.S. programs will be expected to foot the bill themselves, unlike Ph.D. students, who generally receive training grants or stipends to cover tuition.

NEW MASTER'S OF SCIENCE
(Sloan-funded programs)

University and degree programs	Expected start date
Georgia Institute of Technology	
Human-Computer Interaction	Fall 1997
Bioinformatics	Fall 1999
Computational Quantitative Finance	Fall 2000
Michigan State University	
Industrial Mathematics	Fall 1999
Integrated Pest Management	Fall 1999
Industrial Microbiology	Fall 2000
Computational Chemistry	Fall 2000
Operational Statistics	Fall 2000
Physics Applications: Modeling and Simulations	Fall 2000
University of Arizona	
Applied Biosciences	Fall 2000
Applied and Industrial Physics	Fall 2000
Mathematical Science	Fall 2000
University of Southern California	
Computational Linguistics	Fall 1999
Physics for Business Applications	Fall 1999
Computational Molecular Biology	Fall 2000
Environmental Science and Technology	Fall 2000
University of Wisconsin, Madison	
Environmental Monitoring: Remote Sensing and Spatial Information Management	Fall 1999
Biomedical Informatics	Fall 2000
Computational Sciences	Fall 2000

Industry experts say they are thrilled with what the new programs are aiming to do. Ph.D.s, they say, often are too specialized and have trouble adapting to nonacademic work. Robert Arnott, managing partner for First Quadrant, an investment management firm in Pasadena, California, hires Ph.D. physicists as financial analysts. However, he says, most recruits "start out not knowing what to do. We wind up spending the first year, or sometimes two, helping them get out of blind alleys." He's curious how the science master's students will fare and is eager to bring some aboard as interns.

Educators, too, are keen to see the effort blossom. "There is a niche for professional master's degrees," says Wyn Jennings of the National Science Foundation's Division of Graduate Education. But first, he says, academics must discard their disciplinary blinders. "You will have to divorce yourself from traditional disciplines," he says, because the professional master's programs are driven by the needs of the market, not specific fields.

If the programs earn respectability and take root, they "would save a lot of young people a lot of angst," says the NRC's Charlotte Kuh. Pair certainly seems angst-free: He says he has received many "unsolicited inquiries as to my availability" after his return to the United States in August. –**MARI N. JENSEN**

Mari N. Jensen is a science writer based in Tucson, AZ.