Microgravity Materials Science Strives to Stay in Orbit

Imagine a world where temperature or pressure or some other condition never changed. Entire vistas of phenomena, perhaps as basic as melting and boiling, might remain out of view on this world, and probably also out of mind. When it comes to the condition of gravity, this world has been Earth.

That's why 1992 will be a memorable year for materials scientists eager to see what happens as liquids, solids, and gases crystallize, mix, flow, and otherwise cavort in orbit where the earthly value of gravity falls toward zero. With at least five space shuttle missions scheduled to haul hundreds of experiments into space, "this is by far the biggest year for microgravity research," says Robert Snyder, chief of microgravity research and applications at NASA's Marshall Space Flight Center in Huntsville, Alabama. All this activity in support of science in orbit can't hurt NASA in its battle with Congress (most recently, with the House of Representatives) to sustain funding for the Space Station Freedom.

But for the station's supporters, this year's surge of microgravity research holds an unpleasant irony. Although Congress understandably prefers to fund science that has obvious applications—new drugs, alloys, and semiconductors were just some of the wonders promised from microgravity experiments—increasing numbers of prominent materials scientists are coming around to the view voiced by Earl L. Cook, who has coordinated space research for 3M: The commercial potential of microgravity "was grossly oversold."

What the field needs right now, several committees of microgravity researchers have agreed this year, is to turn away from the current thrust of experimentation in orbit—into materials and processes that could quickly be commercialized—and dive unashamedly into good, old-fashioned basic research. The problem has been that while the program so far has yielded hints of concrete payoffs such as semiconductor crystals of exquisite quality and tiny latex spheres uniform enough to be sold as reference standards of size, too often the experiments have been at best inefficient. Why? Because researchers don't know enough about basic microgravity physics to predict how materials and processes will respond to microgravity.

Even the growth of protein crystals—"the area that seems to have the most immediate potential for commercial payoff," according to William Wilcox of Clarkson University—doesn't always proceed as planned. Perfect protein crystals are the starting point for x-ray structural studies, which, the argument goes, could lead to new drugs, among other things. But, says Charles Bugg, director of the Center for Macromolecular Crystallography at the University of Alabama, "there are cases where the [space-grown] crystals turn out to be less usable than ones grown on the ground."

NASA

Microgravity rides high. The crew of IML-1 poses during the January mission, which kicked off microgravity research's busiest year.

Liya Regel, former head of materials science at the Space Research Institute in Russia and now director of the newly formed International Center for Gravity Materials Science and Applications at Clarkson University, puts the problem this way: "Almost every flight experiment has given unpredicted results."

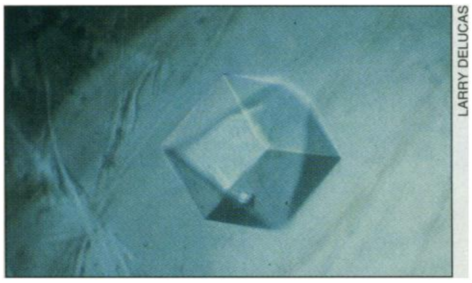
For basic researchers, of course, that's no drawback. The lure of microgravity lies in the surprising phenomena that emerge when the gravity-driven effects that roil gases and liquids on Earth are stilled, says Simon Ostrach, a long-time microgravity scientist at Case Western Reserve University in Cleveland. Buoyancy-driven convective motion, for example, in which gravity drags down cold, more dense regions of a fluid while warm, less dense regions of a fluid rise, can wreak havoc on materials solidifying or crystallizing from the gaseous or liquid phase. It can easily overpower the weak intermolecular forces that might otherwise assemble a nearly perfect protein crystal, for example, and jumble the distribution of current-carrying dopants in a semiconductor crystal. But in orbit, where microgravity quells this kind of convection, the way should be open for crystals of exceptional size and quality to form.

At the same time, microgravity opens a view of fluid motions that are obscured on Earth, such as surface tension-driven convection. Driven by slight temperature variations across a liquid's surface, it produces so-called thermocapillary flows, which resemble minuscule hot streams worming through cooler surrounding liquid. Largely invisible on Earth, thermocapillary flows can introduce their own brand of disorder into materials solidifying in space, says Ostrach.

All of this is well and good on a theoretical plane, but in selling the idea of a space station to Congress and the public, NASA said little about thermocapillary flows; instead, say critics, it advertised the possibility of growing crystals or creating entirely new materials in the absence of gravity. "NASA was saying, 'Hey! There's all sorts of gold to be harvested in space,'" recalls 3M's Cook. The publicity was certainly effective; in a recent press conference, notes Ostrach, "everyone wanted to know what my experiment will do for the homeless and people with AIDS."

Belying the hype, though, is how scanty researchers' experience of microgravity has actually been. Many investigators have made do with the few seconds to few minutes of microgravity available when experiments are released down drop tubes, flown in planes that take stomach-turning freefalls, or launched on suborbital sounding rockets. And even though researchers have for years flown experiments on orbiting platforms including Skylab, the Russian Mir space station, shuttles, and unmanned "free-flyers," access has been woefully intermittent.

This lack of access has already driven some players hoping for commercial gains out of the picture. 3M, which has flown automated polymer and crystal experiments on six shuttle missions, became one casualty when it put its space research on hold last year. The slow pace of research convinced executives there was no prospect of a payback within an acceptable time scale, says Cook. What would it take to regain the company's interest? "We should be able to get an experiment up and back in a reasonable time [from its conception], in 6 months or less," he says. Genentech Inc., which flew a biotech experiment on an October 1990 shuttle flight, has also put its



Clear-cut advantage? A crystal of malic enzyme, grown aboard USML-1.

space plans on hold.

This year, at least, the glacial pace picked up. The International Microgravity Laboratory-1 (IML-1) kicked off the year of microgravity in January, when it flew in the belly of the Space Shuttle with dozens of materials and life science experiments aboard. In June, the same modular laboratory flew again, refitted with a new battery of experiments and apparatus and redubbed the United States Microgravity Laboratory-1 (USML-1). Two weeks ago, the shuttle launched an unmanned laboratory, the European Retrievable Carrier (Eureca), due to remain in orbit until April 1993. And before the year is out two more shuttle-borne materials labs should fly: Spacelab J, a Japanese version of IML-1 and USML-1, and the United States Microgravity Payload-1, an unmanned pallet of experiments that will be bolted inside the shuttle's cargo bay.

Results from the scores of investigations that have flown so far are now trickling in, bringing glimpses of microgravity's effects on, for instance, the formation of zeolites (pivotal industrial catalysts), the growth of complex radiation-sensing semiconductor crystals, and how flames spread over solid fuels in the absence of convection. But none of that is convincing researchers that manufacturing in space is about to become a profitable venture.

Indeed, some investigators think that microgravity's potential might be better understood if it had not been for the rush toward applications. Because of it, says Taylor Wang of Vanderbilt University, whose most recent experiment in the physics of acoustically levitated drops flew on the USML-1, basic research has often been neglected and projects said to be proprietary have eluded proper peer review. The upshot: "There are some very crappy experiments being flown," he charges.

What is really needed, says William Sirignano of the University of California, Irvine, and a member of the National Research Council's (NRC) Space Studies Board, is less attention to what microgravity does to specific materials or processes and more to basic mechanisms. Whether it be the crystallization of proteins, the physics of flames, or the formation of alloys, that means running many more experiments under systematically varied conditions of temperature, chemical concentration, and other parameters. Only through these extensive space studies, together with control experiments carried out on Earth, says Case Western's Ostrach, will investigators get a clear picture of just what materials and processes would benefit most from the microgravity environment.

Sirignano and other researchers uneasy with the direction of their field have now gathered some official support. Under the auspices of the Universities Space Research Association, Ostrach convened a distinguished panel from the microgravity research community, which has circulated a white paper to NASA officials, the White House, and Congress, among others. The document's aim is to help bury the expectation that space will be industry's best friend and to resurrect the notion that it is an essentially untested condition for fundamental research.

The NRC, too, is trying to provide a reality check. In a report titled "Toward a Microgravity Research Strategy," released late last month, the Committee on Microgravity Research of NRC's Space Studies Board concluded that "to date, no examples have been found of materials that are worthy of manufacture in space." The main rationale for microgravity research, the committee concludes, is "to improve our fundamental scientific and technological knowledge base." If that exercise can guide improvements in materials and processes for use in space or—a long shot—yield valuable insights for Earth-bound industry, all the better. But to make sure that unrealistic expectations aren't undermining the science, the NRC report recommends that NASA's 17 Centers for the Commercial Development of Space—set up to foster industrial interest in the microgravity environment—get a thorough eyeballing to see if they are meeting scientific standards.

All of which leaves the microgravity community in a peculiar bind when it comes to the Space Station Freedom. Even at this year's pace, researchers can't hope to build a base of fundamental knowledge anytime soon. "Each of these flights is just chipping away at an experimental science where the laboratory is mostly inaccessible," says Alabama's Bugg. "It's a helluva way to do science." As a result, Bugg and many other microgravity scientists would just as soon cast their lot with advocates of the space station.

But these scientists have to acknowledge that for them, the station's mammoth price tag—five times that of the embattled Superconducting Super Collider—is one huge investment in basic research, with no guarantee of payoff. In the end, says Ostrach, "society will [have to] decide if it is worth it."

–Ivan Amato

A Vote for Man in Space

No, microgravity scientists by and large won't claim that payoffs from their studies of materials made under low gravity can justify the enormous price tag of the Space Station Freedom (see main text). But that doesn't mean they aren't boosters: Indeed, if the thing is built, these researchers would be more than happy to set up their experiments aboard. But look for no hosannahs about the glories of working on such a platform.

For one thing, measurements of crystal growth, fluid flow, and other such delicate processes won't coexist easily with the lurching, thumping presence of human beings and the whir and buzz of the life support, propulsion, and safety systems needed for manned spaceflight. Indeed, opponents of the space station argue that microgravity research is far better conducted aboard robotic unmanned platforms like the Eureca lab, recently launched from the Space Shuttle for a 9-month stint in orbit. Even NASA's Roger Crouch, associate director of the Materials Science and Applications Division, acknowledges that it would probably take some time for microgravity research to pick up speed aboard the space station. "The first years may not be productive," he says.

But on balance materials scientists still favor the use of a manned platform because they can come up with counterexamples such as one from USML-1, the microgravity lab that flew aboard the space shuttle in June. Remarks Charles Bugg, director of the Center for Macromolecular Crystallography at the University of Alabama: "For the first time we had a trained crystallographer up there"—Bugg's colleague Larry DeLucas. "My being up there was important because so many conditions that people expected would be right turned out to be off target," DeLucas told *Science*. "Just extruding and drawing liquids in and out of a syringe is not what you would expect," he recalls.

DeLucas credits his experiment-saving interventions, such as swinging a syringe around to extract bubbles that had unexpectedly collected near its tip, with some of USML-1's crystal growing success. Of 34 proteins flown on USML-1—among them an immune system factor, a blood clotting protein, and a key protein from the AIDS virus—40% yielded crystals suitable for x-ray structure studies, an unprecedented success rate. For DeLucas and Bugg, the space station as conceived might have drawbacks, but at least it offers the human touch.

–I.A.