researchers, says Martin Glicksman, a materials scientist at Rensselaer Polytechnic Institute who has pioneered 'telescience' during Spacelab missions. But continuous high-bandwidth communications is required.

NASA promises that high-capacity data transmission will be available by 2002 (both Russian and US data relay satellites are planned), and talks about switching to commercial satellite networks to supply greater capacity in the future. In a cautionary move, Japan and Europe reserve the right to provide their own data relay systems.

Perhaps the greatest worry among microgravity researchers is not knowing how free of vibration the station will turn out to be — a critical question for delicate fluid physics and crystal growth studies. Researchers have been promised that acceleration forces won't interfere with their work. But equipment designed to damp out vibrations from myriad sources on the station — whirring fans, motors, astronauts exercising on treadmills — worked only partially on its space shuttle test flight and may not be tested again before being installed in experiment racks in NASA's lab module in 2000.

US investigators can only hope that this Active Rack Isolation System — and other untested hardware — works, or that NASA has enough money to fix it. European and Japanese researchers may go with an alternative Canadian design for damping out vibration. Japan's space agency NASDA has been especially concerned that the station may not be as "quiet" as advertised.

Worry no. 3: Money

European users cannot be certain how many space station experiments their sponsoring governments will be able to afford. The two main ESA players in the project, Germany and France, are already having difficulty finding 'utilization' funds.

The German-led Fire Detection Infrared Sensor System was one of six experiments selected by an ESA review board for a coveted place on the station's exterior. But the experiment has been rejected for funding by the German space agency DLR, and the principal investigator has been asked to submit a scaled-down version. The DLR has had funding for German (as opposed to ESA) space research cut by 21 per cent over the past four years, with microgravity science bearing a disproportionate reduction.

The situation in France is even more drastic. One of the first acts of the new research minister, Claude Allègre, last October was to cut the 1998 budget for microgravity research to zero, as part of his bid to find more money for research posts. He has since restored some of the money, but the final amount is in question. Only Italy has reallocated money to pay for station experiments. But Giovanni Bignami, science director for the Italian space agency ASI, admits that this will strain funding for other space activities in coming years.

Worry no. 4: Manpower

Astronauts will have only limited time to run science experiments during the five years of station assembly. Ironically, the situation will get worse as more research equipment arrives, because the crew will have more assembly tasks and spacewalks to do. John-David Bartoe, research manager for the station at NASA's Johnson Space Center in Houston, estimates that the total time the initial crew of three US astronauts and Russian cosmonauts will devote to research will

Commercial labs to rent: good views, priority booking

Government officials on both sides of the Atlantic are optimistic that private industry will pay to use the space station for its own research projects. And a generous portion of onboard resources — laboratory space, electrical power, crew time, and the like — has been set aside for this purpose; now all that is needed is customers.

European station resources reserved for industrial use are expected to amount to between 20 and 30 per cent. The US reserve will be between 30 and 40 per cent — compared with 30 percent each for basic life science and microgravity research. NASA chief Dan Goldin would like to see this proportion climb eventually to 60 per cent.

German research minister Jürgen Rüttgers goes one better than Goldin — he would like commercial users to pay as much as possible for the station. And Claude Allègre, the French research minister who has complained loudly about the costs of station use, would be happy to see no government-funded basic research at all, letting industry take all the laboratory space.

This kind of talk may warm the heart of politicians who hope the private sector will help foot the station's enormous bill. But it frightens government-funded academic researchers, who expect to be rudely bumped whenever a paying customer comes along.

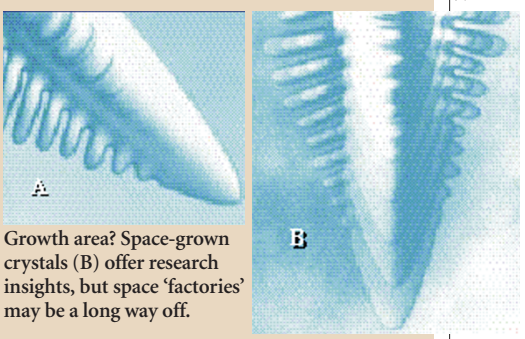
Perhaps they have no need to worry. Despite years of government efforts to enlist commercial partners, industry has so far shown little interest in spending real money on space experiments. NASA alone has spent about $40 million a year for the past decade trying to prime the pump of private space investment primarily through a network of Commercial Space Centers (CSC) affiliated with universities or private companies, which offer free rides into space for CSC-sponsored research.

As of last year, NASA could claim some 150 private US firms as partners in this commercial space network. But their investments have mostly been limited to small, in-kind payments, such as donating a researcher's time and laboratory facilities, or contributing a few tissue samples or crystals to be launched into orbit.

Some projects flown on the space shuttle by 'name' companies like Merck and Genentech have been "advertising, let's face it", says one senior NASA science official. In an advisory committee meeting last year, Edward Gabris, who oversees commercial payloads for NASA's office of microgravity and life sciences, admitted that "nobody beats a path to my door" to send privately funded experiments into orbit.

Hartmut Ripken, director of space station activities at the German space agency DLR, says European industry's lack of interest is understandable, given the past lack of flight opportunities on the space shuttle, and the inadequate facilities for industrial research on Mir. The space station will be different, he believes, and will draw private sector interest once the research results start coming back.

The bad news for would-be space entrepreneurs is that any commercial operation in orbit has to compete with far cheaper ground-based alternatives. Commercial protein crystal growth (PCG) in space is often touted as a likely money-maker. Crystals tend to grow larger in microgravity, yielding more suitable material for X-ray diffraction analysis.



NASA

Growth area? Space-grown crystals (B) offer research insights, but space 'factories' may be a long way off.

Pharmaceutical companies will pay good money for such crystals, say advocates of PCG, because it will help them design more effective drugs. But even on the ground, protein structure analysis is no longer a preferred method of drug design, which currently focuses more on high-throughput testing of candidates generated through combinatorial chemistry and gene libraries.

"Commercial payloads are getting far more space than is justified," complains one materials scientist, who questions whether a space manufacturing boom will ever materialize when the cost of reaching orbit is so high. He quips: "If Rumpelstiltskin took straw into space and spun it into gold, he'd still lose money."