French Nobel prizewinning molecular biologists Jacques Monod and François Jacob announced their scheme for control of gene activity in bacteria, which included specific, but nonmobile, regulatory sequences. At last, McClintock's ideas had produced an echo in the halls of the molecular biology establishment. But it was an echo with limited fidelity to the original.

The *re*discovery of mobile genetic elements occurred piecemeal, starting in the mid-1960's with certain elements in bacteria, proceeding in the mid-1970's with the discovery of bacterial transposons, which can carry drug-resistance genes, and then exploding into the 1980's with many kinds of mobile elements in all kinds of organisms, including humans. "In every genome you look, they are there," comments Gerald Fink of Massachusetts Institute of Technology. In *Drosophila*, for instance, they comprise several discrete families and constitute between 5 and 10 percent of the genome.

Some mobile elements are large and complex, measuring as much as 10,000 nucleotides in length and carrying many genes, while others are simple sections of repeated DNA just a few hundred nucleotides long. Some people would classify all such elements as "junk" or "parasitic" DNA. Others strongly demur and insist that, for instance, although there is yet to be found any convincing evidence for the involvement of a limited class of elements in development in organisms other than maize, the possibility should by no means be dismissed. In any case it is clear that the mobility of certain genetic elements is essential in the generation of the huge diversity of antibodies in vertebrates and in the production of different antigenic coats in certain parasites. Jumping genes clearly represent a potentially rich source of mutation. In addition, an evolutionary link between mobile elements and retroviruses now seems incontrovertible, as does a causal relationship with certain cancers.

The list of mobile genetics elements is now long and growing fast. It is more than a catalog of interesting pieces of DNA: it is a statement that "the dogma of the constancy of the genome" has been swept away, 30 years after Barbara McClintock knew it was wrong.

—ROGER LEWIN

Spacelab: Science on the Shuttle

A new era of space science dawns with the first flight of Spacelab; but how useful will the shuttle really be for science?

On 28 November—or later if the National Aeronautics and Space Administration (NASA) cannot solve its latest problem with the space shuttle boosters in time—the space shuttle *Columbia* will lift off for the long-delayed first flight of Spacelab, the European Space Agency's (ESA's) orbital scientific laboratory. When it finally happens, it should be quite a show: to celebrate the event, ESA and NASA have given the 9-day mission at least one of everything.

On board the pressurized laboratory module, which rides in the shuttle bay like a camper in a pickup truck, and on the U-shaped pallet, which holds instruments exposed to the vacuum, there will be astronomical telescopes, solar telescopes, and an electron beam accelerator to excite the ionosphere. There will be earth observations by camera and by microwave, and motion sickness experiments on the astronauts. There will be confused sunflower seedlings trying to sprout in weightlessness. And there will be 30 experiments in materials processing, including the mixing of immiscible alloys and the convectionless growth of large, perfect crystals.

In the normal course of events, this would be the worst way conceivable to run a mission. Many of the experiments are utterly incompatible: *Columbia* will constantly be twisting down to point toward the earth, up toward the stars, and out toward the sun. No one experiment will be able to make full use of the time.

But then Spacelab 1 is not a normal mission. It is an exercise in engineering exuberance: one module, one pallet, six astronauts, three communications channels, dozens of instruments, 70 experiments, and innumerable investigators—from 14 countries—all working together for the first time.

Even more important, Spacelab 1 is a symbol—for ESA, the symbol of Europe's emerging prowess in space technology; for NASA, the symbol of a revitalized space science program, long constrained by delays and overruns on the shuttle. Indeed, the Spacelab program as a whole is seen by NASA as a major step toward the agency's most heartfelt goal, a permanent manned space station.

There is something fitting about the latter aspect, for Spacelab grew out of NASA's disappointment over its first bid for a space station in the early 1970's. *That* space station had been endorsed as a worthy successor to the Apollo moon landings by the high-level Space Task Group, chaired by then Vice President Spiro T. Agnew. A giant rotating wheel, capable of housing some 50 people full time, it would have cost some $20 billion (1970 dollars). It would have been the jumping-off point for a manned mission to Mars. And it would have been serviced by a reusable space shuttle, included in the plan almost as an afterthought as a cheap way of ferrying things up there and back.

Unfortunately for NASA, however, the euphoria of the first moon landings had proved short-lived, and Vietnam was ravaging the federal budget. Worse, the agency's attempts to lobby the skeptical Nixon White House were heavy-handed and clumsy. In the end NASA was lucky to get the shuttle.

"Once that decision was made [in 1972], a lot of us were appalled that there was nothing left in the plan for space science," recalls Robert L. Lohman, NASA's chief of Spacelab development. "So we took the idea of these RAM's [Research and Applications Modules, intended to be carried up and attached to the space station by the shuttle], and started to look at using them in the shuttle instead for 'sortie' missions."

Meanwhile, says Lohman, the Agnew commission had made a strong recommendation to internationalize the space program, and this was striking a responsive chord overseas. The Europeans were especially eager; "At one point they even wanted to build half the space shuttle orbiter in Europe," says Lohman. When the United States proved reluctant, the Europeans turned their attention to the Space Tug, a reusable booster that would ferry satellites from the low orbit of the shuttle to the 35,900-kilometer geosynchronous orbit. They spent some $30 million on studies before the U.S. Department of Defense vetoed the idea, on the grounds that not even our allies should have access to our top-of-the-line rocket technology. (This attitude is not unrelated to Europe's determination to develop an independent launch capability in the form of the Ariane.)

Fortunately, says Lohman, there was the RAM-sortie concept—Spacelab. It seemed like a relatively straightforward project, with no sensitive technologies involved. The cost (then) was estimated to be well under $1 billion, which matched what Europe wanted to spend. The interface to the shuttle seemed simple and clean. And a number of European companies already had expertise in the idea, having worked as subcontractors on studies of the RAM concept.

"It was a good match," says Lohman. In August 1973, an intergovernmental agreement was signed between the United States and nine of the member states of ESRO, one of the predecessor agencies of ESA. Europe agreed to design and build an engineering model, one complete flight unit (consisting of one full pressurized module and five pallets, which could be mixed and matched in many different ways), and associated ground support equipment. The United States agreed to buy at least one more flight unit. And that was it.

"It was a *very* generous agreement," says Lohman. "They would build Spacelab and essentially give it to us. We could do anything we wanted with it. Joint flights were encouraged, and the first flight specifically *had* to be a joint flight, but that's all that was specific."

Of course, the deal was hardly an act of altruism on Europe's part. ESRO and its member states were willing to invest a lot to build in-house skills and to advance European industries. Moreover, NASA's original plans for the shuttle—agreed to by President Nixon's Office of Management and Budget—called for a constant NASA budget through the 1980's (in constant dollars) and a correspondingly heavy schedule of shuttle flights. Optimists were talking about 20 Spacelab flights per year. Europe had every reason to believe that NASA would buy as many as three or four extra Spacelab flight units.

In practice, however, everyone has had to lower their expectations painfully. Not only did the shuttle prove far more difficult and expensive than NASA had hoped, but under Presidents Ford, Carter, and Reagan the agency's budget actually began to fall in real terms. The projected flight rate fell right along with it; NASA has purchased the second set of Spacelab hardware, as agreed, but plans to buy little more.

Meanwhile, ESA—which formally came into existence in 1975—was finding that Spacelab was not so straightforward either. The instrument pointing system, for example, essential for the fine-tuned guidance of Spacelab telescopes, has proved to be a major headache. But a worse headache was the space shuttle itself: innumerable design changes during the shuttle development process kept the European engineers scrambling to make the corresponding changes in the Spacelab interfaces. They did a superb job, by all reports—"the hardware is beautiful," says Lohman—but by the time ESA delivered the first flight unit in 1981, the development costs had climbed by 40 percent, to just under $1 billion.

Along the way, embarrassingly enough, ESA found itself virtually dropping out of Spacelab science. Five years ago there were firm plans to follow up the first joint mission with NASA with four all-European flights, two funded by ESA and two funded independently by Germany. (The Germans have put up half the money for Spacelab development as it is.) Since then, however, the projected cost of a shuttle flight dedicated entirely to Spacelab—assuming all-new instruments—has climbed to roughly $150 million. And the European effort has correspondingly dwindled to one German flight (D1 in 1985) that is about 30 percent ESA. The ESA member nations, who have to approve the agency's

A Parade of Firsts

Spacelab 1 will contain a remarkable number of firsts. Among them:

• The first flight of Spacelab's pressurized laboratory module. (The first Spacelab pallet went aloft on the second shuttle flight in 1981, bearing an Earth observations package known as OSTA-1.) Officially, the mission's prime goal will be to test this hardware. Most people, however, will be watching the experiments.

• The first flight of nonprofessional astronauts: payload specialists Ulf Merbold of the Max-Planck Institute in Stuttgart and Byron K. Lichtenberg of the Massachusetts Institute of Technology. The idea is that they will run the experiments while commander John Young and pilot Brewster Shaw fly the shuttle, and mission specialists Owen Garriott and Robert Parker—who are full-time astronauts—operate Spacelab itself and help out on the experiments. In the early days the concept of using outside payload specialists rankled the professional astronauts, some of whom had been waiting more than a decade for a flight. That controversy has died down only as shuttle flights have become more numerous.

• The first operational use of TDRSS, the Tracking and Data Relay Satellite System. TDRSS's ability to transmit data at 48 million bits per second means that principal investigators on the ground can now have real-time interaction with their experiments in orbit. "That's what Spacelab is all about," says Mary Jo Smith, program manager of Spacelab 1. "If you see something interesting, follow up on it. If your widget doesn't work, quit and go on to something else." Since NASA has delayed launching the second TDRSS because of the problems it had getting the first one into orbit last spring, Spacelab 1 will only be able to use that channel about 30 percent of the time. (With two TDRSS's the figure would have been only 56 percent; the mission requires so many maneuvers that the orbiter spends a fair amount of time blocking its own antenna.) The life sciences and plasma experiments will be hurt the most, since they are the most dependent upon real-time interaction. Otherwise, the crew will take up the slack with a lot of extra data tapes.

• The first attempt to run a flight with *two* controls centers: the venerable Mission Control Center in Building 30 at Johnson Space Center in Houston, which will be in charge of the overall mission; and the new Payload Operations Control Center (POCC) one floor down, where the scientists will communicate with the payload specialists running their experiments. The communications, by the way, will involve three separate channels: two through TDRSS and one direct to the ground. The efforts to coordinate all this should be interesting to watch.—**M.M.W.**

budget, are taking a firm wait-and-see attitude; ESA officials can only hope that a good first mission this fall will raise Spacelab's political profile enough to get the program moving again.

On this side of the Atlantic, NASA is contending with a different problem: a bitter, suspicious community of space scientists. "We're still living with the set of expectations planted in the Spacelab user community by optimists selling the shuttle," says Michael J. Sander, NASA's head of Spacelab science. "Not only did they project 20 Spacelab flights per year, but there was this vision that we would get to a 20-per-year level *rapidly*"—say by 1982, assuming a first shuttle launch in 1979.

It was on that basis that NASA issued its 1978 announcement of opportunity for scientific research on Spacelab. Some 40 instruments or investigations were ultimately approved for funding, says Sander—except that by then the shuttle had begun to slip badly. And by then also, the Carter Administration had begun to step up its budgetary pressure.

"There was no obvious end to it," says Sander. "The space science office had to absorb its share of the cuts somewhere. And with no shuttle flights in sight, the logical thing to target was Spacelab." In one year, the Spacelab budget fell from $110 million to $30 million.

"Most of the investigators were told 'Congratulations!—We'll have to fund you later,' " says Sander. "Some were given just enough money to keep the projects alive. And really only three were selected for development."

For the scientists themselves, the situation was excruciating. Not only had a lot of researchers put a lot of effort into these projects, for no visible return, but the consequences of the delay went far beyond Spacelab itself: the money that might have gone into new planetary missions, or new space plasma physics missions, or whatever, would instead be going to support big-ticket items like the Galileo probe to Jupiter while they marked time waiting for the shuttle. Even now, more than 2 years after *Columbia*'s first flight in April 1981, the bitterness still lingers. It was a major factor in the recent repudiation of NASA's space station plans by the National Academy of Science's Space Science Board (*Science*, 7 October, p. 34). As the University of Chicago's John A. Simpson points out, "You just aren't going to see the community rising in support of a space platform when NASA can't even get science on the shuttle."

The message has not been lost on NASA. "We've spent the last few years trying to get well," says Sander. "*If* the budget keeps its current momentum, then by 1986 we'll be where we wanted to be by 1980." That is, all the original 40 experiments will either be flying, in development, or in the definition stage. On the other hand, he concedes that the original vision of 20 dedicated Spacelab flights per year has given way to a more realistic nine or ten per year by the end of the decade. And of those, only one or two will involve the manned module; most of the rest will consist of pallet-borne experiments that fly along with other cargo. "It's become clear what it takes to get something into the shuttle and flying," says Sander, "and its more than just tossing something in the back."

"It would cost NASA half a million dollars to fly a pin."

The cost and complexity of that process is a major source of complaint among shuttle users, and not just the scientists. It costs three to five times as much to develop an instrument for Spacelab as for a sounding rocket or balloon, Sander estimates—although that is still about half as much as for a free-flying satellite—and NASA has been making it a point for the last year or so to find ways of getting that cost down. That may be easier said than done, however, since a fundamental cost driver is NASA's own compulsive fear of failure.

As one veteran says, only partly in jest, "It would cost NASA half a million dollars to fly a pin. Every time you turned around there'd be a review panel asking 'What is the history of this pin? How is the metal hardened? Who hardened it? Can you certify that this pin meets specifications?"

Sander agrees that the problem is real, and that it will not be easy to overcome. "Much of it is driven by NASA's conservatism on the first time through," he says. "But as we get more confidence in the shuttle, we are trying to go back to a less formal system."

The scientists, meanwhile, have a parallel fear. A common perception is that the number of flight opportunities will only go down. So researchers tend to build fail-safe instruments with all the bells and whistles, as if it were the only opportunity in their career. "We've got to give people the hope that they *can* refly," says Sander. The idea here is actually an old one, the dedicated discipline laboratory. Clusters of related instruments, mounted in a pressure module or on a pallet, will be kept together and reflown as a unit with only stepwise upgrades and refurbishment—at perhaps 20 percent of the initial costs. Examples include the International Microgravity Laboratory, a pressure module fitted out for materials and life science experiments, and Astro, a cluster of pallet-mounted ultraviolet telescopes.

Yet another potential cost saver is the Payload of Opportunity Carrier, or "hitchhiker," a simple instrument support system that could be slipped into the payload bay on a space-available basis. Sander notes that investigators would have to adapt their apparatus to the power, cooling, and data interfaces of the carrier instead of vice versa. But the payoff will be a quick, cheap ride into orbit.

"The scientists don't trust us yet, and I don't blame them," says Sander. "You have to wait till the meat's on the table." But the flight rate does look good, and NASA is trying to get the costs down. "In fact," says Sander, "we're beginning to see a wedge in the late 1980's when we might be able to request *new* experiments."

A wild card in all this is the shuttle itself. It is hardly the ideal platform for high-precision science: it vibrates, it emits vapors and exhausts, it glows ever so slightly in the dark. Ultimately, as the Spacelab series explores the shuttle's limits, it may prove desirable to move the most sensitive telescopes and materials science experiments onto unmanned orbital platforms—which NASA, as it happens, is including in its latest plans for a space station (*Science*, 10 September 1982, p. 1018).

On the other hand, NASA's associate deputy administrator Philip E. Culbertson does not see Spacelab being phased out anytime soon. "Even if we get a start on the space station now, it will be 1991 before we fly," he says. "In the meantime, Spacelab will give us a lot of information on how to *use* a manned laboratory in space. And even after the station goes up, we anticipate that for a number of years there will only be one station in one orbit. So we will continue to fly Spacelab for specialized missions in other orbits."

Yes, Spacelab will be an evolutionary step towards a space station, he says—it is entirely possible that the pallets and pressure modules could be incorporated into the station directly—"but it will also be an adjunct to the station for a long time to come."—**M. Mitchell Waldrop**