The International Space Station:

A WORK IN PROGRESS

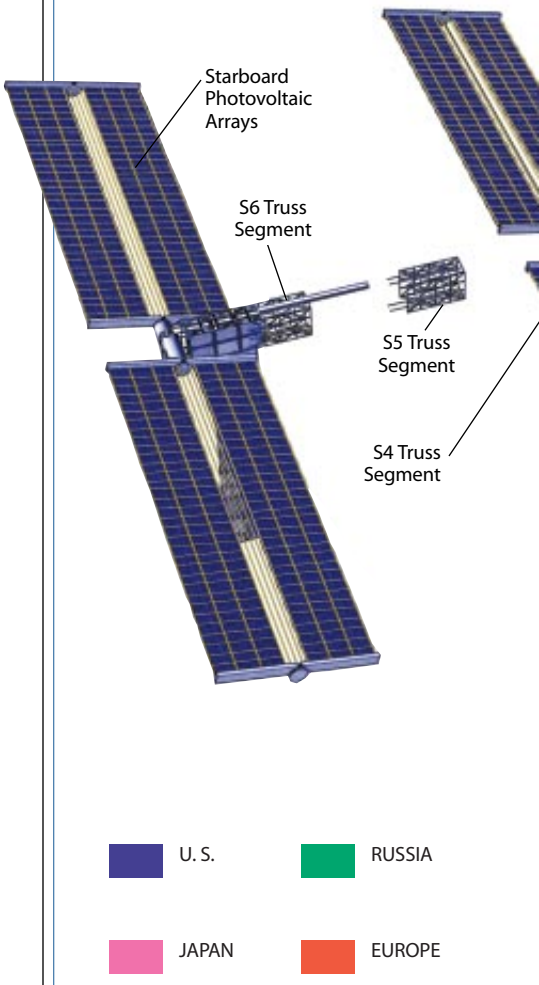
The U.S. and its international partners are finally building a space station, even as they continue to argue about the blueprints

by Tim Beardsley, *staff writer*

The construction site in space that is for the next six years the International Space Station is nothing if not ambitious. Writers have an array of superlatives they can choose from to describe the program: it is by far the most complex in-orbit project ever attempted and arguably one of the biggest engineering endeavors of any kind. More than 100 separate elements weighing 455,000 kilograms (over a million pounds) on Earth will be linked together during the assembly operation, making it the most massive thing in orbit: it will have the equivalent of two 747 jetliners' worth of laboratory and living space. The job will need 45 flights by U.S. shuttles and Russian rockets, and over 50 more launches will take up supplies, crew and fuel to maintain the station in its orbit. Contributions come from 16 countries, making it the most cosmopolitan space program. Hooking the pieces together will take at least 1,700 hours of space walks, many more than have been made during the entire history of space exploration to date. Robotic arms and hands will be required, and free-flying robotic "eyes" might be employed for inspection flights.

But one remarkable aspect of the project received little attention during the hoopla surrounding the successful launch and mating of the first two components late last year. With construction work on the station well under way in its orbit 400 kilometers (250 miles) up, the final configuration of the edifice is not yet settled. Indeed, it could look very different from current artists' impressions.

In large part, the changes are the result of pressure that Congress has put on the National Aeronautics and Space Administration to reduce the program's near-total reliance on Russia as a provider of essential station components and rocket launches.



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Science Power Platform
Progress
Service Module
Zarya (Sunrise) Control Module
Pressurized Mating Adapter 1
Universal Docking Module
Life-Support Module
Docking Compartment
Docking and Stowage Module
Soyuz
Research Module
Research Module
Soyuz
Thermal-Control Panels
Express Pallet
S0 Truss Segment
S3 Truss Segment
P1 Truss Segment
CSA Remote Manipulator System
Mobile Servicing System
S1 Truss Segment
Z1 Truss Segment
Solar-Alpha Rotary Joint
Cupola
Centrifuge Accommodation Module
Unity (Node 1)
JEM Experiment Logistics Module
JEM Remote Manipulator System
Airlock
Node 3
U.S. Lab
JEM Exposed Facility
Japanese Experiment Module (JEM)
Crew Return Vehicle
Habitation Module
Node 2
Pressurized Mating Adapter 2
Pressurized Mating Adapter 3
European Lab: Columbus Orbital Facility
Multipurpose Logistics Module
Solar-Alpha Rotary Joint
P6 Truss Segment
P5 Truss Segment
Port Photovoltaic Arrays
P3 Truss Segment
P4 Truss Segment

CANADA
BRAZIL
ITALY

INTERNATIONAL SPACE STATION will include more than 100 components from 16 countries. The U.S. will contribute a laboratory, a habitation module and the station's primary solar-power arrays. Russia had planned to provide additional laboratories, but those contributions are now in doubt. The European Space Agency and Japan will build their own research modules. When complete, the station will stretch more than 100 meters across and weigh nearly 500 tons (*inset at top*).

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Concern has focused especially on the Russian Service Module, which is scheduled to provide living quarters, life support, propulsion, navigation and communications for the station during the early years of assembly. The Service Module will, if all goes well, be the next major component in orbit after the Zarya tug and Unity Connecting Module that are now flying.

But all has not been going well with construction of the Service Module at the Khrunichev State Research and Production Space Center in Moscow. Originally scheduled for completion in April 1998, the module has been a victim of Russia's financial crisis. Work on the module, which was originally to be part of a Russian space station, started as long ago as 1985, long before Russia joined the International Space Station. Yet the unit is now not expected to be completed until this summer. Russia's failure to finish the component in time is the main reason the start of station assembly was delayed from 1997 until late 1998. Without the propulsion provided by the Service Module, the station as originally envisaged would be incapable of staying in orbit for more than 500 days. Friction with the sparse air molecules in low-Earth orbit would gradually cause it to lose altitude.

NASA has had to employ creative accounting techniques to justify sending the Russian Space Agency ever mounting sums to complete the module. Last year it gave the Russians an extra $60 million (the official explanation was that these funds would purchase additional stowage space and experiment time for the U.S. during the construction phase). But NASA has acknowledged that over the next four years it will most likely have to send a further $600 million to ensure the completion of other modules. Many Russian space workers have not been paid for months.

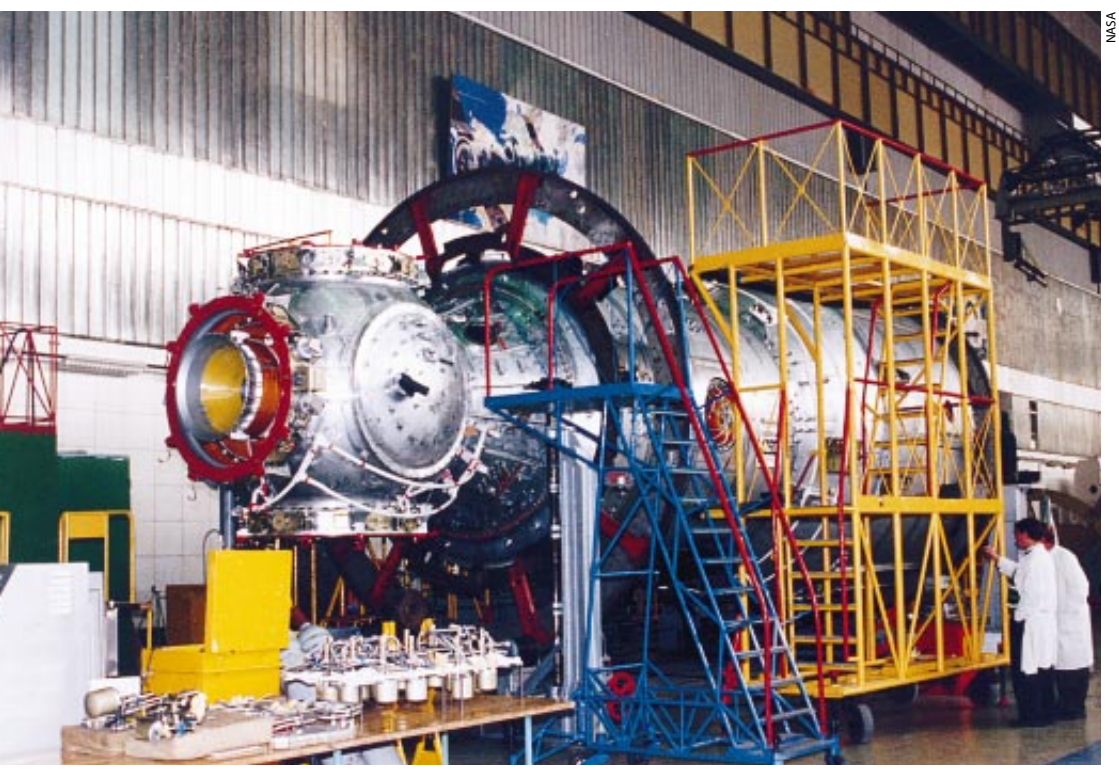
The Price of Progress

This $660-million contribution is in addition to $728 million NASA has already paid the Russians between 1994 and 1998 for space station work and the joint flights on the Russian space station Mir, according to the Congressional Research Service. Although having Russia in the program was originally intended to save money, NASA now admits that it has actually added about $1 billion to the station's cost. NASA has had to work hard to secure from the Russians an agreement that they will shut down the Mir space station this summer, despite opposition from Russian nationalists. Keeping Mir alive could drain Russian resources from the international station, NASA fears.

Not that cost overruns are restricted to Russia. NASA figures indicate that U.S. construction costs are running 30 percent over projections, and an independent commission headed by Jay Chabrow, a former TRW executive, estimated that the overrun will reach 42 percent. NASA has irked scientists who had planned to run experiments on the station by transferring some $460 million from science accounts to help meet U.S. construction costs. The station's expense, including the cost of shuttle flights, is now likely to exceed $40 billion, and it has become "an albatross around the agency's neck," in the view of space policy expert Marcia S. Smith of the Congressional Research Service. The General Accounting Office puts the total cost of the program at $95.6 billion.

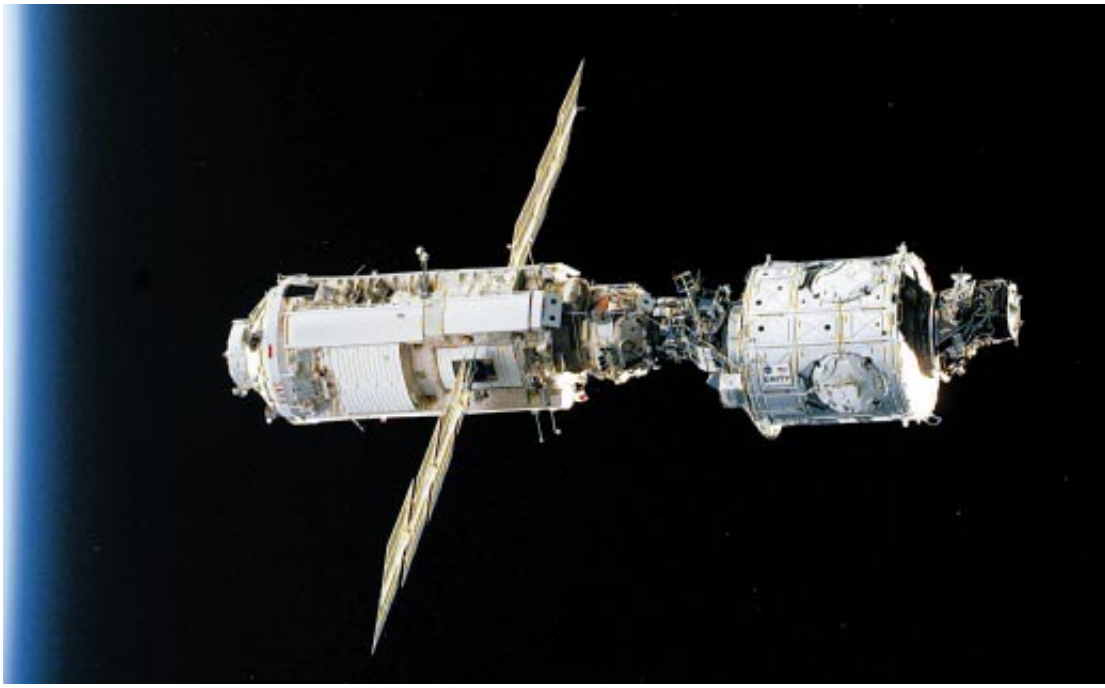
All these estimates assume nothing major goes wrong during assembly. The British magazine *New Scientist* has decided, on the basis of a statistical analysis of risks, that there is a 73.6 percent chance of at least one catastrophic failure that would result in the loss of station hardware during one of the U.S. or Russian assembly launches.

While the costs of keeping Russia as a partner have been growing, its planned contributions have declined. Russian officials have announced a "core program" on the space station that no longer includes a science power platform, two research laboratories and a life-support module. Russia is discussing constructing one laboratory with Ukraine—but "we don't see much design and development work" on the life-support module, says W. Michael Hawes, Sr., senior engineer for the space station. Hawes says the changing design has now made the Russian life-support module redundant. The status of other Russian components is unclear. Perhaps more worrying, Russia is unlikely to be able to sup-



NASA

SERVICE MODULE, designed to provide living quarters and propulsion for the International Space Station, is shown under construction at the Khrunichev State Research and Production Space Center in Moscow. Russia's failure to complete the module on schedule has delayed the assembly of the space station and prompted U.S. officials to redesign the station to reduce their reliance on Russia.



NASA

FIRST PIECES of the International Space Station—the Unity node (*far right*) built by the U.S. and the Zarya module built by Russia—were linked by the crew of the space shuttle *Endeavour* in December 1998. A total of 36 shuttle flights and nine Russian launches will be required to complete the assembly of the station by 2005.

ply the seven Progress and two Soyuz refueling and crew rotation flights each year that it had undertaken to do: congressional overseers now think five such flights each year is more realistic.

To satisfy Congress's demands for a backup plan, NASA has quietly been changing the assembly sequence and designing and modifying hardware to reduce its vulnerability. The first of these late-arriving additions is a $156-million Interim Control Module, which is now nearing completion at the Naval Research Laboratory. The module is a modified version of a previously classified upper-stage rocket, and it could by itself provide attitude control and reboost for the station for a year or two. NASA also modified Zarya (which the U.S. owns) prior to launch to improve its station boosting and control capabilities.

The European Space Agency has agreed to provide propellant for the Service Module, according to Daniel Hedin of NASA's space development office. And NASA is now also planning to modify all its space shuttles to increase their capacity to boost the station. The fix should mean the station needs only about 30 Progress refueling boosts instead of the baseline number of 53, according to Hedin. Moreover, NASA does not rule out launching the Interim Control Module sometime in 2000 even if the Service Module does launch this year, because it would provide insurance against a future shortage of Progress rockets.

The Interim Control Module will not be the only addition to the station undertaken because of Russia's crippling budget problems. NASA is now also negotiating with Boeing to build a U.S. propulsion module, at an expected cost of $350 million. It would eliminate the need for about half of the currently scheduled Progress resupply flights and offer a permanent solution in the event that the Service Module never arrives.

Other aspects of the station are almost as fluid. No final decisions have yet been made on provisions for returning crew to Earth in the event of some emergency. In the early construction phase that role will be played by a Soyuz spacecraft attached to the station. A Soyuz, however, can transport only three astronauts, and the station's final scheduled crew numbers seven. The U.S. is planning to build a larger Crew Return Vehicle capable of bringing home all the permanent crew, but it will most likely not be ready until 2003 at the earliest, and the station will probably have a crew of more than three before then. NASA is considering buying one or more Soyuz vehicles to provide an interim emergency return capability.

In any event, the U.S. crew return vehicle's final form is still undecided. The current design, based on the X-38 experimental craft, offers only nine hours of life support. NASA and the European Space Agency are discussing modifications to the design that would turn it into a transfer vehicle that could be launched on an Ariane rocket.

Even the basic design of the main American habitation module is still up for grabs. Engineers at the NASA Johnson Space Center have proposed an inflatable structure known as TransHab as a substitute for the aluminum habitation module in the present design. TransHab would have a hard composite core surrounded by Kevlar and foam layers for micrometeorite protection. Its main selling point is that it might serve to test a mode of construction that could, because of its low mass, be advantageous in future crewed moon or Mars expeditions.

But the station's value as a test bed for a future crewed mission to Mars can be questioned. The most important physical hazards facing such a crew are likely to be loss of bone mass, which seems to be a common result of prolonged weightlessness, and radiation from solar storms. Yet a vehicle designed to go to Mars could easily be furnished with artificial gravity, by separating it into two connected sections and slowly spinning them, says Ivan Bekey, a former head of advanced concepts at NASA. Furthermore, the station's orbit is too low to experience the full fury of solar storms. An earlier design would have tested five innovative space technologies, including a high-voltage power transmission system and solar-thermal power generation. They, however, were dropped from the final scheme, Bekey notes.

The International Space Station is principally a foreign-policy enterprise. And as such it may be a success. Thousands of Russian scientists and engineers who without the American bailout might have gone to well-paying jobs designing weapons for rogue states are now still at work on peaceful systems. Politicians and officials and technical experts in countries throughout the world have had the opportunity to collaborate and link their destinies in an organizationally demanding endeavor. Perhaps the value of that return cannot be measured in dollars. SA