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What's next for U.S. human spaceflight?

Indigenous fighters make a comeback

ISS: Dawn of a new era

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The international space station has turned the corner into its next phase, its stay in orbit having been extended by the president to at least 2020. In government, scientific, and industry circles, experts are planning myriad uses for the orbiting complex. Some even envision applications beyond its predicted life, including the possibility that it could serve as a base camp for future deep space exploration missions.

ISS
Dawn of a new era

by Leonard David
Contributing writer

Circling the Earth, the international space station is a technological tour de force, a global enterprise that is also the most politically complex space exploration program ever undertaken. Now it has entered a new phase of utilization, with planners envisioning myriad applications that might even extend beyond its predicted life.

The size and weight statistics of the station are striking. With its large solar arrays, it spans the area of a football field, including the end zones, and weighs some 400 tons. It is also the longest continuously inhabited spacecraft. Fifteen nations have provided modules and equipment over the years, with the U.S., Russia, Europe, Japan, and Canada the principal contributors. To date, more than 200 explorers have visited, lived in, and worked at the facility.

Now the station is set for an extended lifetime. President Obama's National Space Policy, issued in June 2010, calls for continuing the operation of the ISS—in cooperation with its international partners—"likely to 2020 or beyond," and for expanding efforts to "utilize the ISS for scientific, technological, commercial, diplomatic, and educational purposes; support activities requiring the unique attributes of humans in space; serve as a continuous human presence in Earth orbit; and support future objectives in human space exploration."

Even for a facility hundreds of miles high, this is a tall order. Nevertheless, the station is becoming a sort of space-based Rorschach test: Scientists, technologists, engineers, managers, commercial groups, and others envision it as a future wellspring of research, discovery, and innovation—and even as a way station to worlds beyond.

Study groups around the world are now assessing postassembly utilization possibilities for the ISS, which could include serving as a testbed platform or as a base camp to augment deep space exploration by humans. The station, including its solar arrays, spans the area of a U.S. football field including the end zones and weighs 861,804 lb. The complex now has more livable room than a five-bedroom house, with two bathrooms, a gym, and a 360° bay window. All images courtesy NASA.

The investment

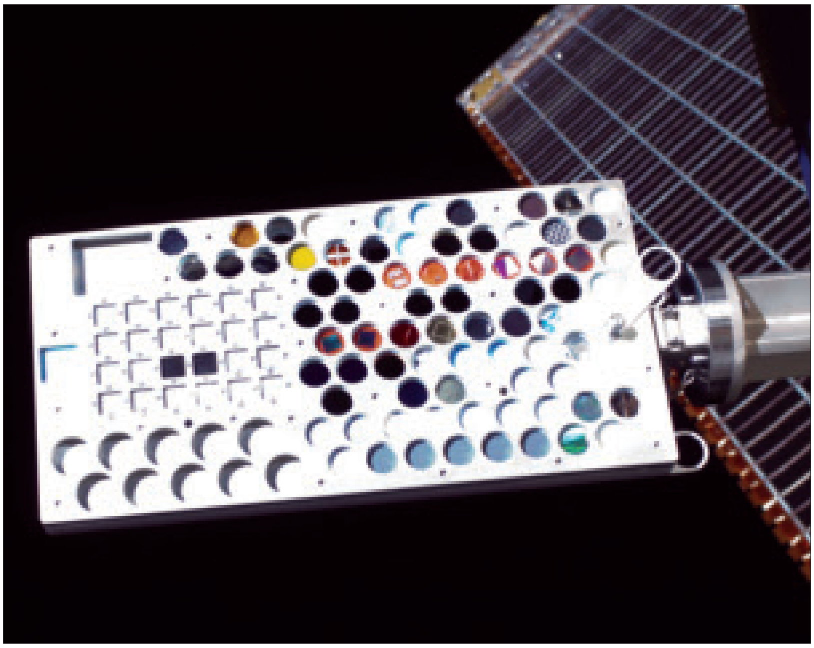
Former NASA Administrator Mike Griffin says that when he headed the agency, the best estimate of ISS costs was about $75 billion (in mid-2000 dollars), of which about $20 billion came from the project's partners.

"Some like to characterize the ISS as 'a $100-billion investment'…but I couldn't quite get to that level. Whatever the number, it is quite a large investment, as befits the completion of the most complex engineering project in human history. To fail to utilize that investment, for as long as we can reasonably do so, would be childishly short-sighted," Griffin says.

But putting more miles on the station, while keeping it safe for crews, is not an easy goal. "There are two ways you predict the age of a facility, or the age of its various components," says Mark Uhran, assistant associate administrator for ISS at NASA Headquarters. One is analytically, through engineering estimates. The other is through operational experience, he says.

As the ISS program accrues operating know-how, two key parameters are MTBF (mean time between failures) and MTTR (mean time to repair). "Originally we developed engineering estimates on MTBFs and MTTRs…and now we're trying to validate those estimates through actual operating experience," Uhran says. Engineers typically are conservative, as they should be, during the engineering estimates phase, he says, so MTBFs and MTTRs are turning out to be longer than originally projected.

"It's an extremely healthy, robust facility that in general is exceeding our predicted MTBFs and MTTRs," Uhran tells *Aerospace America*. Still, given the size and complexity of the station, he says, there are exceptions, statistically speaking.



The station has already enabled in-space evaluation of new materials and computing elements. MISSE-8, for example, is loaded with experiments to assess the effects of atomic oxygen, ultraviolet rays, direct sunlight, radiation, and extremes of heat and cold. MISSE results, which provide a better understanding of the durability of various materials and computing elements when they are exposed to the space environment, aid the design of future spacecraft.

For instance, there are troublesome control moment gyros. Then there is the facility's alpha rotary joint, which allows the solar arrays to track the Sun. And to a lesser degree, there are issues with the station's thermal radiator rotary joints. Accurately predicting lifetime is hardest for rotating mechanisms, notes Uhran, but operating these components "more gently" and using improved lubrication methods can extend life. Software changes also can change the limits and ranges at which components are energized, he adds.

Uhran says that any component necessary for making it to the 2020 milestone will be recertified. "We have high confidence we can do 2020. Then the question becomes, if there's a reasonable benefit-to-cost ratio, should we extend the operation even further…to 2028? It's too early to answer that question today. But we have formally checked with all of our partners…and the answer across the board is that we see no showstoppers to extending beyond 2020."

Safe passage

One set of experts, however, has weighed in on a host of concerns regarding the station's safe passage into the future.

The Aerospace Safety Advisory Panel, created in 1968, evaluates NASA's safety performance and advises the agency on ways to improve it. The panel's annual report for 2010 states that, as the ISS enters its second decade, lessons learned could carry human exploration to Mars and beyond—but there are challenges; for example:

- Until commercial cargo service is available, NASA must rely on a combination of vehicles from the international partners—Russia, ESA, and Japan. Cargo up-mass and volume capacity will be much more limited.
- Pending the availability of commercial crew services, NASA must rely solely on the Russian Soyuz vehicles to transport crews.
- During operations over the next decade, the nature of the safety risks is expected to change because of failures resulting from extended equipment usage in an extreme environment; hazards associated with unplanned repair, disconnect, and replacement procedures; longer exposure of the crews to space; and the 'new' environment created by termination of the shuttle.
- The biggest safety threat to the crew is from micrometeoroid and orbital debris—factors that grow worse every year.

Cost-benefit ratio

A fitting maxim for the ISS, suggests NASA's Uhran is, "We go up into space to learn what we can't learn on the ground."

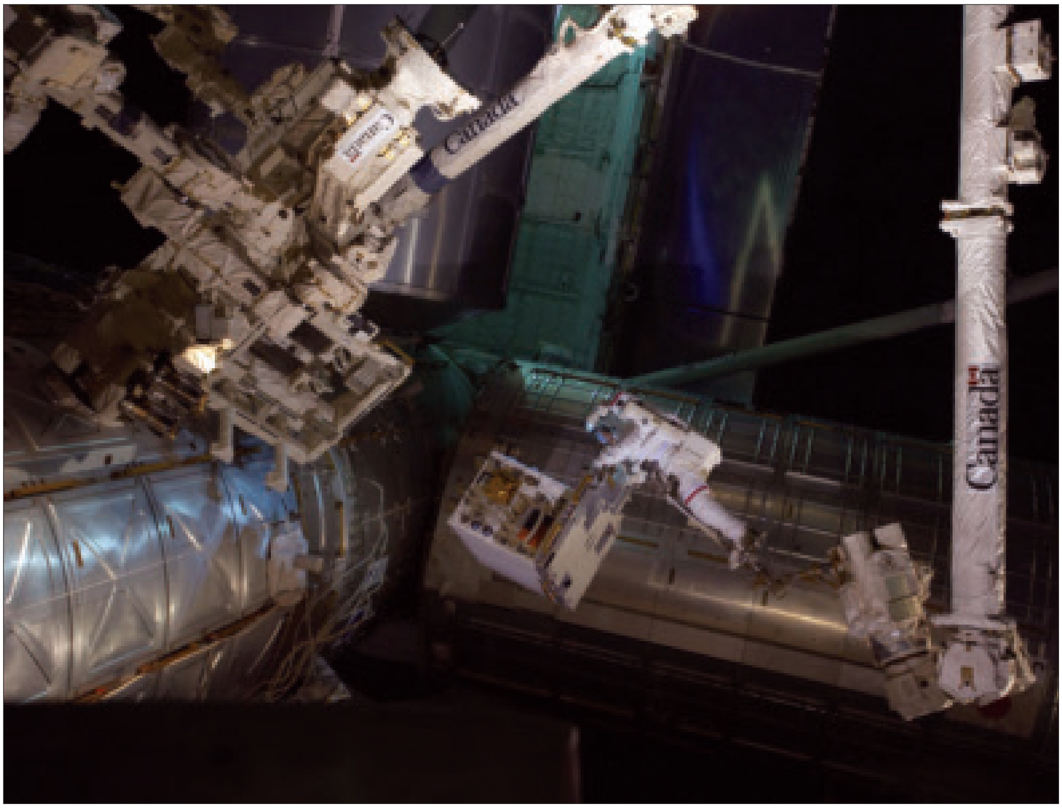
But just how ephemeral is any true ISS cost-benefit ratio? Without question, the station is a colossal engineering success story. Yet there are critics who have viewed the orbiting laboratory as a white elephant and questioned its output.

"Cost is cost, and you can audit that. Benefit is the hard one…as it comes in two flavors," Uhran responds. There are intangible benefits such as international cooperation, or stimulating young people's interest in science, technology, engineering, and math (STEM), as well as the human drive to explore, he says. These are all hard to measure but cannot be ignored.

The second category, tangible benefits, can be measured by accounting standards, says Uhran. For instance, what technologies can be developed to lower the costs of future missions? Then there are products of research such as equity agreements, licensing agreements, or patents that result from the research—all having auditable values.

"The important point is that we're just ending the assembly phase now. Everybody is trying to estimate the benefit. Well, the benefit is in the future," Uhran advises. "That's the work that's in front of us."

Uhran says he is very sensitive to people's continuing desire to know what has been discovered using the ISS. "My answer is that we've discovered how to assemble a very complex structure. Now our attention is focusing on the transition to utilization.



With his feet secured on a restraint on Canadarm2, astronaut Mike Fossum holds the robotics refueling mission (RRM) payload, the focus of a primary task accomplished on a 6.5-hr spacewalk. RRM is designed to demonstrate that robots can perform refueling tasks in orbit via ground commands. The first on-orbit attempt to test robotic refueling techniques for spacecraft not designed for on-orbit servicing, RRM is expected to reduce risks and lay the foundation for future robotic servicing missions.

It's the future of research that's going to be interesting as we turn this corner."

Technology testbed

Now that the ISS can support a full-time crew of six, a new era of utilization is beginning. While the station was being assembled, NASA officials contend, the potential benefits of space-based R&D were demonstrated—including advancement of scientific knowledge based on experiments conducted in space, development and testing of new technologies, and Earth applications derived from new understanding.

In the arena of technology testbed missions, Uhran teased out a number of ISS investigations: more work focusing on closed life-support systems, advancing humanoid robotics, and the use and deployment of next-generation structures like inflatables.

Other testbed items on the to-do list include:

•A kick-start for satellite servicing, already under way following installation of the RRM (robotics refueling mission) payload on the station. That hardware is designed to showcase the ability of remote-controlled robots to perform refueling tasks in orbit via ground command.

•Expanded use of the MIT Space Systems Lab's SPHERES (synchronized position hold, engage, reorient, experimental satellites) to provide DARPA, NASA, and other researchers with a long-term replenishable and upgradable testbed for validating high-risk metrology, control, and autonomy technologies. Such competence is crucial in formation flight and autonomous docking and rendezvous, and in developing reconfiguration algorithms.

•Enabling the communications, navigation, and networking reconfigurable testbed, or CoNNeCT, project to provide an on-orbit, adaptable, software-defined radio (SDR) facility on the ISS, along with the corresponding ground and operational systems. The growth of SDRs offers an oppor-

SPHERES, stowed inside the Destiny lab, were designed to test control algorithms for spacecraft by performing autonomous rendezvous and docking maneuvers inside the station. Their progressively more complex two- and three-body maneuvers include docking—to fixed, moving, and tumbling targets—as well as evaluating formation flying and prospective searching for lost satellites.

ISS: Abandon ship?

The reliance of the ISS on support crews was spotlighted in August when Russia's space freighter, Progress M-12M, suffered a launch failure. A Soyuz-U booster experienced an upper stage malfunction a little over 5 min into flight. The result was the loss of nearly 3 tons of cargo bound for the station—equipment, water, food, oxygen, and propellant. Progress nose-dived into South Siberia's Altai mountains.

"The cargo lost, although important, can be replaced. All of us are focused on determining the cause of the Soyuz booster anomaly so we can resolve it and get back to flying crew safely to the ISS," said NASA Administrator Charles Bolden. The third stage is common between the Soyuz U booster used for Progress cargo flights and the Soyuz F/G booster used for crew launches, he added.

A consequence of that commonality was that ISS might have to start operating without a crew this month if Russian engineers could not identify exactly what caused the rocket failure.

"The Russians will not launch another Soyuz booster until their investigation is complete and the rocket is revalidated," said Bolden. "The incident does remind us of the urgency of bringing on line U.S. transportation capabilities for both crew and cargo," the NASA chief stated. "Redundancy of systems has always been a fundamental consideration in sound spacecraft design. Redundancy is an equally important consideration at the vehicle level as we continue to operate and maintain the ISS, and as we take on increasingly complex exploration missions involving international cooperation."

However, on September 15 it was announced that a plan had evolved to assure that human operations aboard the ISS would continue uninterrupted. Russian space authorities were able to determine the root cause of the Progress failure, one that would allow for the booster's safe return to flight.

Then, on October 30, a Progress 45 lifted off from the Baikonur Cosmodrome for the ISS. Bill Gerstenmaier, associate administrator for Human Exploration and Operations, said, "We congratulate our Russian colleagues on Sunday's successful launch. ...Pending the outcome of a series of flight readiness meetings in the coming weeks, this successful flight sets the stage for the next Soyuz launch, planned for mid-November. The December Soyuz mission will restore the space station crew size to six and continue normal crew rotations."

tunity to improve the way missions develop and to operate space transceivers for communications, networking, and navigation.

•Continuation of the MISSE (materials ISS experiment) program, which allows for the placement of experiments externally on the station. This enables investigations of how long-term exposure to the harsh space environment affects materials and devices. MISSE evaluates the performance, stability, and long-term survivability of the systems that NASA, commercial companies, and the DOD plan to use on future space missions.

Use of the ISS for research and education has been a hallmark of the SPHERES effort, says David Miller, principal investigator of the venture and director of MIT's Space Systems Laboratory in Cambridge, Massachusetts.

"The SPHERES facility is analogous to a wind tunnel," Miller explains, "where technology, still in its formative stage, can be tested under operational conditions—microgravity—without incurring the cost and risk of actual flight if the technology fails."

Thanks to reconfigurable software, he adds, SPHERES is broadening its portfolio from formation flight to satellite inspection, robotic assembly, vision-based navigation, magnetic control, wireless power transfer, and even an international robotics STEM competition for middle- and high-school students, called Zero Robotics.

National lab

"Personally, I am absolutely convinced that the microgravity environment is unique, just as the vacuum environment was at the end of the 19th century," says Uhran. "We certainly have the capabilities on space station…and it's now time to ramp up the biology, chemistry, and physics research to demonstrate what kind of applications we can drive out of this unique environment."

Uhran says one new approach NASA is taking is to maximize use of the national lab portion of the ISS. The intention is to make it available to a cross section of the U.S. scientific, technological, and industrial communities.

In September NASA finalized a cooperative agreement with the Center for the Advancement of Science in Space (CASIS). This document authorizes the center to serve as the independent nonprofit entity for running the U.S. element of the ISS that will be operated as a national lab.

"It's intended to manage uses of the station, not just by commercial groups, but by other government agencies. It will be managing a mix of basic and applied research," Uhran says.

The NASA Authorization Act of 2010 directed NASA to establish this type of organization. The agreement initially will have a value of up to $15 million a year.

CASIS is located in the Space Life Sciences Laboratory at NASA Kennedy in Florida. Its national lab activities will entail developing and managing a diversified R&D portfolio based on U.S. needs for basic and applied research; establishing a marketplace to facilitate matching research pathways with qualified funding sources; and stimulating interest in using the national lab for research and technology demonstrations and for advancing education in science, technology, engineering, and mathematics.

Structural backbone

In both industry and NASA engineering circles, there is another emerging theme: turning the ISS into a departure point for deep space expeditions.

Uhran notes that the station "ultimately is going to reach an end of life, regardless of when it is. That is far enough in the future that any decision to scavenge pressurized elements or other portions of the station...is kind of over the horizon. We don't spend a lot of time looking at it. I think it's the kind of thing you would evaluate when you get closer in."

Caris Hatfield, manager of the Docking Systems Project at NASA Johnson, is assessing new ways to reuse existing equipment at ISS. These internal studies are not officially approved for implementation; but conceptually, the use of such hardware can help prepare for exploration beyond Earth, he explains. For example, residual components from the shuttle and ISS could house technology demonstration hardware. There is also a possibility they could be retasked and assembled into a spacecraft for operations beyond LEO.

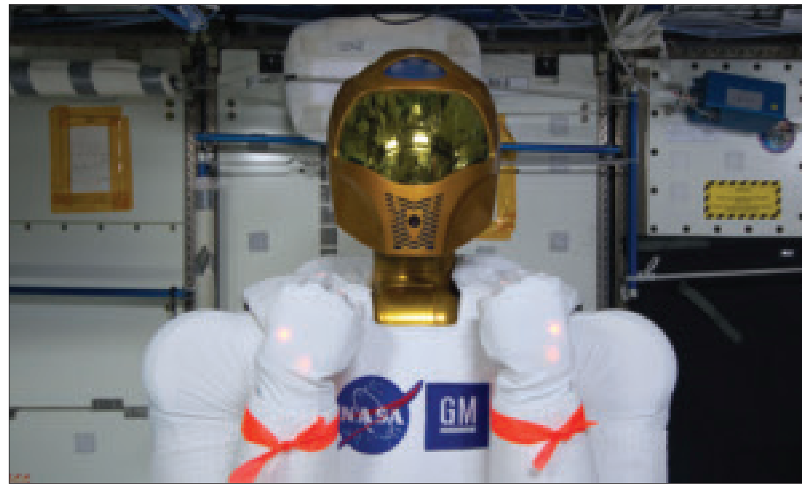
"Use of these elements is one of many options being considered as NASA develops a technology road map for future missions," says Hatfield. Using existing hardware could provide a means to save time and money in building new capabilities; a fully assembled, flight-proven pressure shell provides a foundation for building human habitation systems, he notes.

In the 'available hardware' department is the node structural test article (STA), originally built to be Node 2. In 2010, NASA inspected the STA and determined that it could be returned to flight status.

The STA could be used much as the ISS nodes are today, Hatfield says, as a central assembly point for additional test articles or modules. With a total of six port openings that can be configured for either common berthing mechanisms or NASA docking systems, a wide variety of attached systems are possible. The STA could host technology demonstrations within its pressurized volume, he adds.

Hatfield also notes that NASA has two multipurpose logistics modules in storage at Kennedy Space Center. These could be used as the shell of a habitation or lab module; each has a large interior volume that can accommodate a diverse array of equipment.

Lastly, Hatfield says that NASA has two external airlocks from the space shuttle. These are potentially very useful, since they have a docking interface on one end that could host a NASA docking system. They would also provide a structural backbone that was originally used for installation in the shuttle orbiters and could accommodate additional elements such as solar arrays and attitude control equipment.



Robonaut 2, tucked in the Destiny lab, is powered up for the first time in space by ground controllers.

Base camp

There are many ways in which the station could contribute to an international exploration program, said Michael Raftery, Boeing ISS deputy program manager, during a telecon hosted by NASA's Future In-Space Operations Working Group. This is a panel of senior engineers from within and outside the agency, scientists from NASA centers and academia, and space policy people.

"It's kind of a big idea," says Raftery, who envisions ISS as a physical platform for development and demonstration of the systems needed for missions beyond LEO. Such elements can be aggregated and thoroughly tested at ISS before departure. The station is a "logical location" for this activity, he adds, as it is accessible from all of the major launch sites around the globe.

Raftery says ISS could serve as a base camp, enabling a smaller 'high camp' fuel depot to be established at the L1 Earth-Moon Lagrange point. This depot could be built and tested first at the station, and then

Leftover hardware from the shuttle and space station programs could find new life to augment the ISS, enabling future deep space missions. This node structural test article was originally built to be Node 2 for the ISS. Photo courtesy Caris Hatfield/NASA.

boosted to its final location using either chemical or solar electric propulsion. Fuel depots at ISS and L1, he says, would dramatically reduce Earth-to-orbit boost mass requirements and enable a less costly approach to beyond-Earth destinations—a concept that reuses expensive human spaceflight-qualified hardware.

Sending humans into deep space also raises physiological questions. Here, again, the ISS might play a role.

"Artificial gravity is an idea whose time has come around...and around and around," says MIT's Larry Young, Apollo Program professor of astronautics and health sciences and technology. Decades of research studies show that space-made artificial gravity has the potential to be a single countermeasure for all physiological systems. Furthermore, he says, "the ISS affords a unique opportunity to test artificial gravity in orbit."

JAXA, the Japan Aerospace Exploration Agency, has proposed a centrifuge concept for studying human exposure to artificial gravity. However, there are implementation issues, such as what volume is available, the centrifuge radius, how to power the device, and gauging the transmission of vibration through the ISS.

"We should be able to use the ISS for the purposes we always had in mind—to lay the groundwork for long-duration space exploration," Young tells *Aerospace America*. "To protect astronauts against the debilitating effects of long-duration spaceflight, we need the unique capacity of the ISS to develop and test countermeasures."

Only by installing a human centrifuge on the ISS will we be able to check the feasibility of centrifuging astronauts for brief periods while in orbit, he says. And only then "will we be able to explore the physiological 'terra incognita' between 0 and 1*g*."

Perishable element

While there are those who view ISS as a 'torch passing' of technological know-how, there are others who see NASA as late, very late, in developing whatever will follow the station. Development of any major space facility is a 20-30-year task, so how likely is it that space agencies will have a follow-on ready, say, in the mid-to-late 2020s, when ISS will be getting pretty creaky?

A case can be made for building a long-duration (up to a few months) habitation system within a decade, drawing on the experience and capabilities developed in the ISS program and in terrestrial experiments. That is the belief of Harley Thronson, senior scientist for advanced concepts at the Astrophysics Science Division of NASA Goddard's Science and Exploration Directorate. He also leads the Future In-Space Operations Working Group.

Says Thronson, "Personnel and their experience, whether in management or engineering, are a perishable element of major successful human endeavors, perhaps nowhere more than in space exploration." He asks, "Will the next major 'stepping stone' into space after ISS be undertaken in time to use the hard-won talent of the ISS?"

Thronson says that, although important capabilities can be developed on ISS or in terrestrial labs, there is no duplicate for actual on-orbit experience with early versions of the types of habitats needed to carry humans deeper into space.

"The sooner a habitat is launched that is capable of operating beyond low Earth orbit for up to a few months," he says, "the sooner the lessons that can be learned only by doing in space can be incorporated by the designers of even longer duration human missions."

Holding a similar view is Dan Lester from the Dept. of Astronomy at the University of Texas in Austin. He stresses that one

Bringing down the house

It is a weighty proposition: How best to deorbit the massive International Space Station? It would be a fiery follow-on to the controlled reentries of the Skylab experimental facility in 1979 and Russia's Mir space station in 2001. NASA planners have begun studying this task as part of the agency's environmental impact responsibilities.

An ISS End-of-Life Disposal Plan has been prepared and briefed to the Aerospace Safety Advisory Panel (ASAP), an independent group of experts that evaluates NASA's safety performance.

As the plan takes shape, discussions have been initiated with ESA about a dedicated deorbit craft to help nudge the ISS into a selected watery grave. NASA has also begun conversations with Russian space program officials to assess the feasibility of modifying the current Progress supply craft to be part of the ISS deorbit plan. The vehicle is viewed as necessary for propulsive attitude control or additional thrust. On the table too is use of a combination of ESA's automated transfer vehicle and Russia's Progress.

Early looks at bringing down the ISS note that an estimated 9 tons of propellant would be needed. 'Optimal placement' of the ISS is targeted within a huge and remote stretch of ocean waters.

Another scenario for early termination has been scripted—to be set in motion only if this chain of events were to occur: A catastrophic event causes an early evacuation of the ISS, the ISS cannot still maintain control, and the event is also preventing additional vehicles to dock to ISS.

The first response to an early evacuation scenario would be to boost ISS to a higher altitude to allow time for addressing the problem. Additional vehicles can also be flown there, either to supply more propellant so that a plan to recrew it can proceed, or to execute the nominal end-of-life deorbit plan.

In reviewing the ISS deorbit plan, the panel responded early this year by stating, "NASA needs to move forward to determine the best option for performing the deorbit and to plan now for its implementation. The ASAP plans to increase its focus on the ISS topic in the coming year and will be examining the challenges the ISS will face in the coming decade."

Crews aboard the ISS are afforded spectacular views that enable them to monitor Earth's atmosphere. With the Moon at the center, the limb of Earth near the bottom transitions into the orange-colored troposphere (the lowest and densest portion of the Earth's atmosphere). It ends abruptly at the tropopause, which appears as the sharp boundary between the orange- and blue-colored areas. The silvery-blue noctilucent clouds extend far above the Earth's troposphere.

of the big uses of ISS is as a technology testbed for future deep space habitats. One concern, however, is that although loss of the station is not likely to occur any time soon, "what we *are* about to lose, now that ISS is complete, is the systems design engineering for such space habs."

"There will be lots of work doing upgrades and repairs, but no more work on new, complete system design and architecture for habs. In fact, that's one very good reason for near-term efforts on deep space habs," Lester says. "So while ISS is far from dying, it is entering an exciting new life. But the old life, as a system development platform, is indeed going away, and the skills that bear on that kind of work may well do the same."