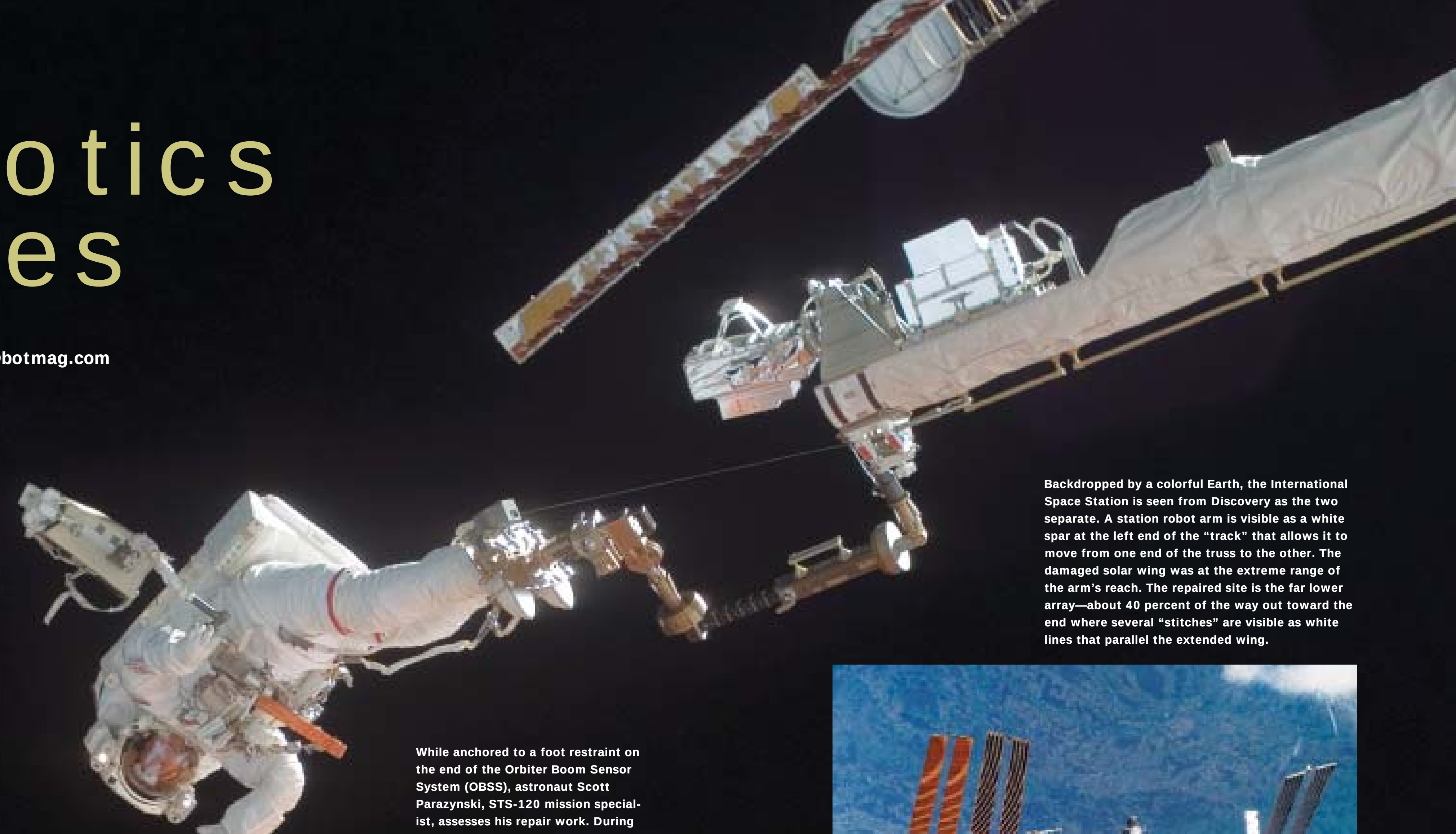
Human-Robotics Alliance Saves the Day

by Jim Oberg jimo@botmag.com

Robot arms facilitate emergency space station repair

In a field of endeavor as unpredictable and as "free form" as space exploration, being bound by the classic engineering principle that "form follows function" is an intolerable restriction on spacecraft design. And when you add into the mix the systemic dynamics of human-robotics synergy, the question becomes why did anybody think that principle *ever* applied?

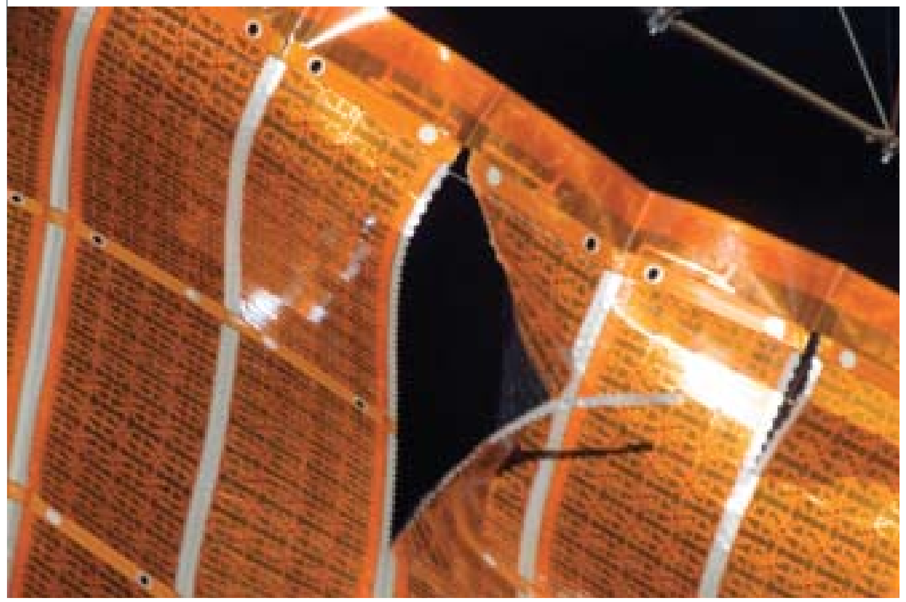
A perfect example is the November 2007 space station solar array repair spacewalk. This was the most severe engineering crisis in the entire history of the International Space Station (ISS). It was overcome by a human/robotics alliance that saw equipment used in configurations and applications for which it had never been designed. But lashed together in hitherto inconceivable ways, their symbiosis proved just barely capable of saving the day.



While anchored to a foot restraint on the end of the Orbiter Boom Sensor System (OBSS), astronaut Scott Parazynski, STS-120 mission specialist, assesses his repair work. During the 7-hour, 19-minute spacewalk, Parazynski cut a snagged wire and installed homemade stabilizers designed to strengthen the damaged solar array's structure and stability. The solar array was fully deployed during the mission's fourth session of extravehicular activity (EVA).

Backdropped by a colorful Earth, the International Space Station is seen from Discovery as the two separate. A station robot arm is visible as a white spar at the left end of the "track" that allows it to move from one end of the truss to the other. The damaged solar wing was at the extreme range of the arm's reach. The repaired site is the far lower array—about 40 percent of the way out toward the end where several "stitches" are visible as white lines that parallel the extended wing.

PHOTOS COURTESY OF NASA



Here, a two-foot tear is evident in the solar array material. This image was downlinked by the STS-120 crew members a few hours before a scheduled two-person spacewalk to repair the damaged area.

The repaired solar array was photographed by an STS-120 crew member aboard the space shuttle Discovery as it moved away from the International Space Station. The repair is in the foreground.

Fortunately, the equipment had been built not just to perform all imaginable tasks but also to be available for some unimaginable utilization strategies that might only later be discovered to be necessary. This flexibility—this strategy to plan and design for the unexpected, to add more "margin" than you can justify based on known needs—is the design principle that needs to supplant form follows function in the imaginations of space designers for both human and robotic systems.

The crisis developed during the STS-120 mission with shuttle Discovery docked to the station. A complex strategy of station assembly and expansion was threatened when one solar-power wing tore during redeployment. Only partially extended and not rigidized, the wing was not generating enough electrical power and was unsafe for further dockings to the station.

SOLAR ARRAY TEARS

The wing, the so-called "P6 Array," had just been emplaced by the station's robot arm at the far left end of the transverse "truss" backbone. It was actually the first of the planned four arrays that will power the fully assembled station, and it had been docked in a "temporary" position on the roof of an American "node" module in December 2000. There were difficulties in unfurling the arrays the first time, and help from spacewalking astronauts was needed.

In the following years, the truss was assembled, segment by segment, and then new arrays were added at each end. When it was time to move "P6" to the outboard left end, its arrays were retracted, although they were so persnickety that they needed spacewalking astronauts to poke and tug at them with the equivalent of "space rakes." Safely strapped down for the transfer, they were supposed to unfurl easily, but this proved to be a vain hope. A snag led to a sudden tear between two adjacent panels, and the deployment stalled 80 percent out.

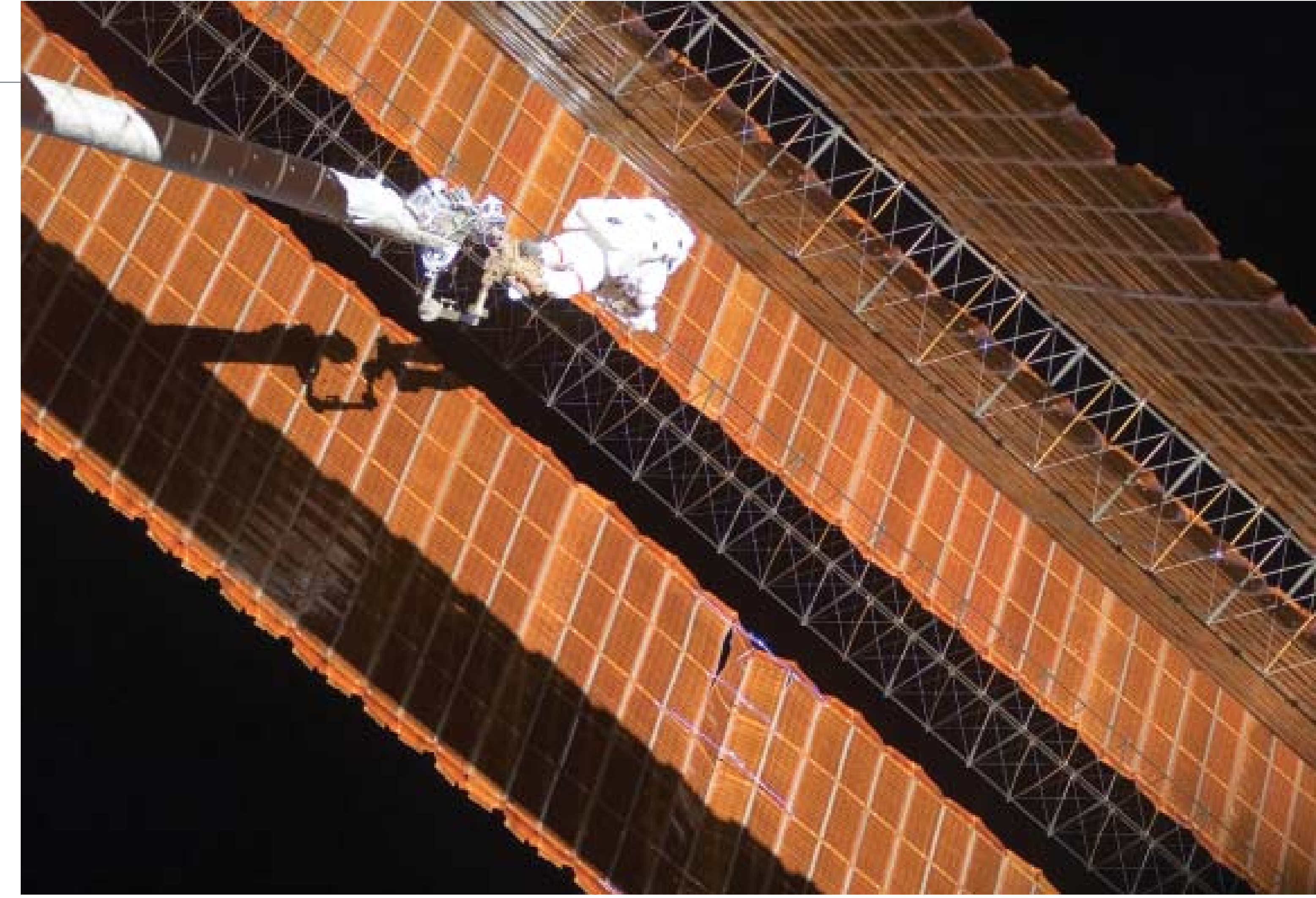
Already on the station was the awesome Canadarm-2 [see the Fall 2007 *Robot*, issue 8]—the two-handed gadget that could crawl from point to point or, if needed, be attached to a trolley that could run from one end of the station's backbone to the other (it had just moved P6 from the center module's roof to the far end of the truss). The shuttle also had its own smaller arm (Canadarm-1) along with an instrumented boom that had been added after the Columbia disaster to allow the inspection of the shuttle's underside for heat shield damage.

As part of the plans to repair possibly damaged heat shield areas, NASA had also tested a work platform that could be held by the shuttle arm and would carry an astronaut and a tool kit to the damaged area. If the shuttle's arm turned out not to be long enough to reach a repair site, NASA worked out—and, last summer, tested—a way to attach the work platform to the end of the sensor boom and then grab the other end of the boom with the robot arm and move the astronaut (at the end of the boom) to the more remote corners of the shuttle's belly. The spacewalk test had shown that the boom-arm combination was still rigid enough for the astronaut on the far end not to be swayed back and forth too much and hit the heat shield under repair.

ROBOTICS SOLUTION

So far, since the addition of this capability, no heat shield repair has been needed. But at the end of October, the capability was suddenly needed for an entirely different kind of repair on an entirely different system of an entirely different spacecraft. The only surprise should have been that anybody was surprised by the "unplanned" need for the space tools.

Fixing the tear turned out to be the easier part of the challenge; getting close enough to do it, but not too close, was the hard part. And that's where robotics really came in.



Waving the astronaut out at the end of the arm-held boom involved commanding multiple joints—both bending and rotation joints—in the Canadarm-2. And since the arm/boom combination would be at nearly its maximum extension, the end position was very sensitive to joint motions.

"We like to design joint motion sequences in advance and test them in our lab," a NASA robotics expert had told newsmen before the spacewalk. "But in the rush to build this procedure, there's been no time to optimize the motion"—that is, to design the joint command sequence to minimize the swings and turns of the astronaut at the end of the boom during the 45-minute ride to the site. He called the quick-draw plan workable but "painful"—that is, not elegant.

COMPLEX ARM MANEUVERS

Equally inelegant was the complex sequence of using both robot arms to join the boom to the station arm. Parked at the far left end of the station's truss, Canadarm-2 could not reach the boom where it lay along the right edge of the shuttle's payload bay. The shuttle arm (installed along the left side of the payload bay) picked it up, but it couldn't use the more convenient (of two) grapple fixtures on the boom because the center of the payload bay was blocked by the space station's docking port where the shuttle was attached. As a result, the station arm had to take the boom from the shuttle arm at a point some distance from its end, thus wasting some of its length. Still, the combined length was just barely enough.

On November 3, Scott Parazynski, a veteran astro-

Astronaut Stephanie Wilson, STS-120 mission specialist, works the controls of the Space Station Remote Manipulator System (SSRMS), or Canadarm-2, in the Destiny laboratory of the ISS during flight-day-12 activities while the space shuttle Discovery is docked with the station.

Astronaut Steve Robinson on Canadarm-2 is poised for observation or repair work.

naut and emergency room surgeon, took the robot ride—describing the awesome sight the whole way—and arrived at the orbital "operating room." There, he literally stitched the tear together with sutures called "'cuff links" because they passed through existing holes and then locked in place. The station was saved, thanks to an ingenious alliance of preexisting space capabilities that had been made available for entirely different purposes.

An astronaut perches on the end of a boom held by the ISS robot arm. This configuration was used on the repair EUA.

MEETING FUTURE CHALLENGES

The lesson of this success for space robotics is profound. Far from being mindless automata with tightly constrained scenarios, the space robotic systems showed unplanned flexibility in response to a blindsiding anomaly, and they did so with only a few days of emergency planning. Future systems designers must always remember that it is not merely good enough to build a system that's capable of handling all imaginable requirements. Somehow—and here's where true genius and artistry are essential—the system must have even more skills in reserve for the future demands that nobody ever expected.

Editor's note: see an animation of the solar array repair at www.botmag.com/issue 10, [http://mfile.akamai.com/18566/wmv/etouchsyst2.download.akamai.com/18355/wm.nasa-global/STS-120/eva4animation.asx]