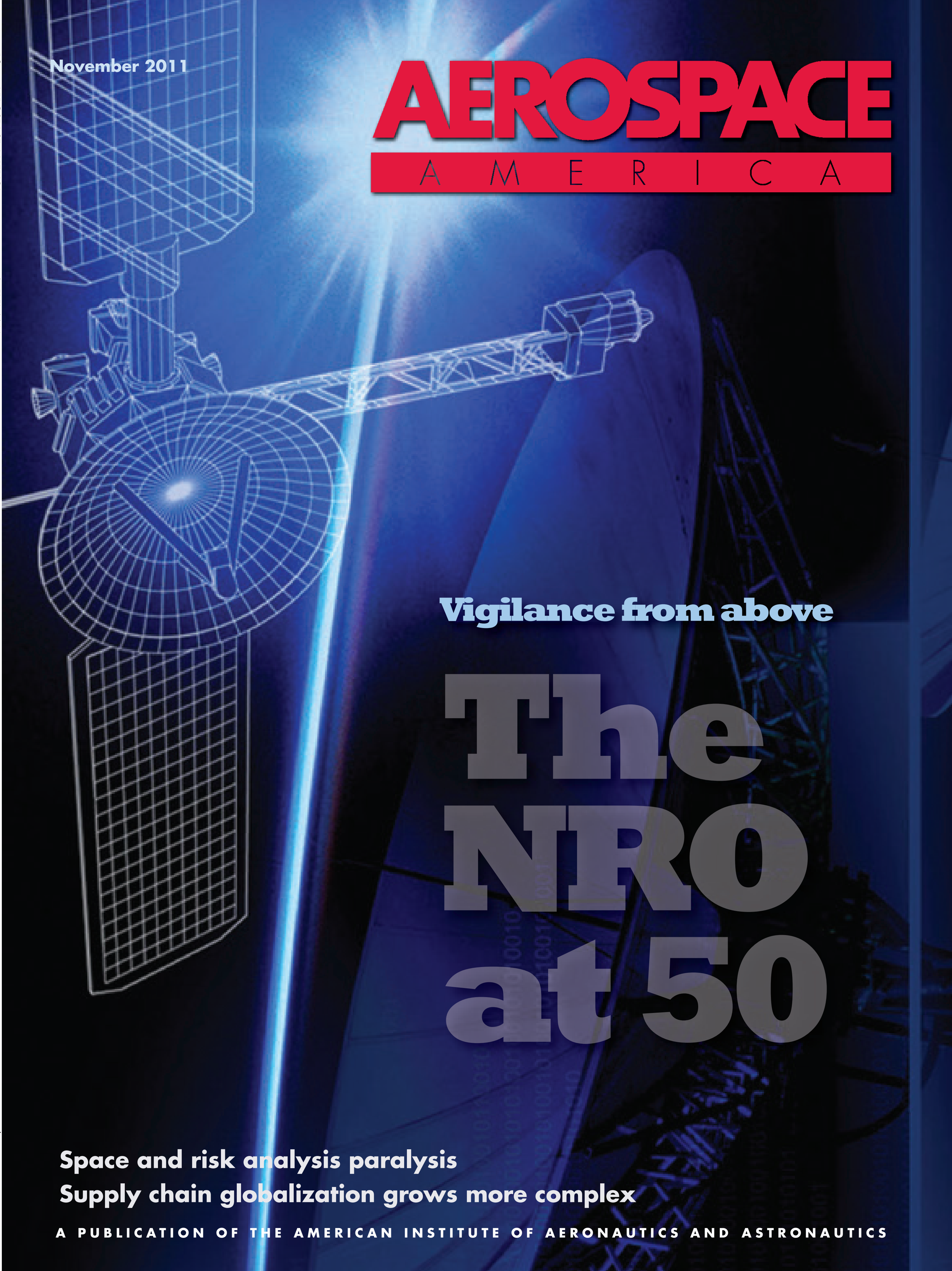

November 2011

AEROSPACE AMERICA

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10 AEROSPACE AMERICA NOVEBER 2011

Preparing NASA's astronauts for the High Frontier

In the predawn darkness, double sonic booms sent a shiver up my spine: A spaceship was coming home. Scant minutes later, the xenon searchlights flickered at the approach end of Runway 15, Kennedy Space Center. Atlantis, back on Earth, streaked past us at midfield, drag chute filling at the end of her final voyage.

But STS-135's landing was *not*—no matter how many times the media said it—'the end of America's space program.' This oft-repeated hyperbole ignores the two NASA astronauts and their four international crewmates who were living and working aboard the international space station.

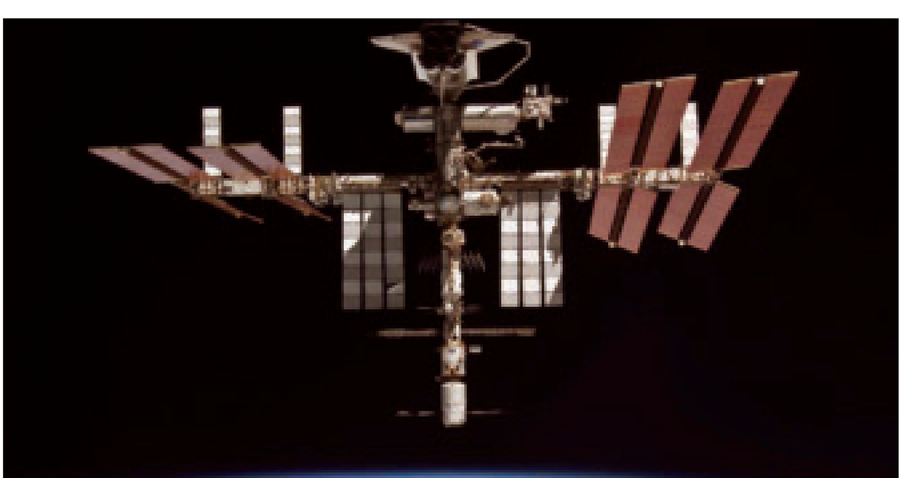
For the next decade or more, the ISS will be the focus of the U.S. human spaceflight program. Shifts of astronauts will supervise an array of experiments at the national laboratory and conduct tests of next-generation systems and operations techniques to prepare for expeditions into deep space.

Now that the station is substantially complete, crews are deeply involved not only in systems operations and maintenance, but in interactive science operations conducted in the Destiny, Columbus, and Kibo laboratories. Focused for three decades on short-duration shuttle flights, will NASA's Astronaut Corps be prepared to meet the demands of steady-state ISS operations (and anomalies) through 2020 and beyond?

Corps questions for astronauts

That question prompted NASA to ask the National Research Council of the National Academies to examine the future roles and size of the corps, and the proper training facilities needed to preserve U.S. human spaceflight excellence. Early this year, the NRC commissioned a study panel to address these topics. The 13-member panel was cochaired by Joe Rothenberg, former NASA associate administrator for spaceflight, and Fred Gregory, former astronaut and NASA deputy administrator. Dwayne Day, NRC senior program officer, directed the study.

In early September, the panel issued its final report, entitled "Preparing for the High Frontier: The Role and Training of NASA Astronauts in the Post-Space Shuttle Era" [http://www.nap.edu/catalog.php?record_id=13227].



The ISS and the docked space shuttle Endeavour, flying at an altitude of 220 mi., were captured by Expedition 27 crewmember Paolo Nespoli from the Soyuz TMA-20 following its undocking on May 23. ISS and Soyuz training are the current focus for NASA's Astronaut Corps.

NASA asked our panel to address three major questions:

- How should the role and size of the activities managed by the NASA Johnson Flight Crew Operations Directorate change following shuttle retirement and completion of the assembly of the ISS?
- What are the requirements for crew-related ground-based facilities after the shuttle program ends?
- Is the fleet of aircraft used for training the Astronaut Corps a cost-effective means of preparing astronauts to meet the requirements of NASA's human spaceflight program? Are there more cost-effective means of meeting these training requirements?

We'll discuss only the first and third of these questions here. The reader can find a full discussion of the second within the report itself.

Post-shuttle roles

For the past three decades, NASA's astronauts have prepared mainly for space shuttle operations. In this ISS and Soyuz era, what should be the central roles and responsibilities of the Astronaut Corps?

Based on NASA information and our own research, the panel found that the Astronaut Office (the Astronaut Corps is the subset of people within that office eligible to fly in space) should support six tasks in priority order:

- Provide well-trained spaceflight operators to support the NASA flight manifest.
- Supply ground support personnel for unique tasks required to support the NASA flight manifest.
- Provide support for new program development, ranging from relatively small payloads and equipment to whole new spaceflight designs.
- Be a source of operational knowledge and corporate memory of human spaceflight.
- Provide for collaboration with other governmental and private organizations

as needed and directed by NASA.

• Provide support for public and educational outreach to society.

Flying is why astronauts sign up for this hazardous job. Once Soyuz crew launches resume, probably this month, NASA's astronauts will continue serving space station tours lasting an average of six months. They will also serve as flight engineers during Soyuz launch and reentry (commanded by a Russian cosmonaut). These fundamental tasks drive most of the training requirements for ISS crewmembers.

Flying is an obvious and core priority, but even when not actively training for a mission, astronauts directly support their colleagues in space. In Mission Control, they work as capcoms (capsule communicators), help flight controllers develop procedures for on-orbit research or maintenance, and verify proposed workarounds for in-flight anomalies by executing them in simulators or in the Neutral Buoyancy Laboratory at Johnson.

NASA also assigns astronauts to assist future spaceflight programs. They track the work of commercial spacecraft developers and provide operational input to designers of NASA's Orion multipurpose crew vehicle, new heavy-lift Space Launch System, and advanced concepts for asteroid, lunar, and Mars exploration.

Heat damage is evident on the Soyuz TMA-11 descent module after landing on April 19, 2008. Astronauts will have to respond to similar in-flight emergencies in the era of ISS, Soyuz, and commercial crew spacecraft. (Photo: Novosti/Aleksandr Pantyukhin)

As an invaluable national reservoir of knowledge and corporate memory on effective operations practices, the Astronaut Office fosters the spread of a vigorous safety culture within NASA.

Astronauts also work with U.S. government departments and international space agencies, providing technical expertise and coordination of common human spaceflight activities.

Finally, they are often the highly visible public face of NASA. Speaking with everyone from David Letterman to thousands of eager students, astronauts between flight assignments spend several days each month crossing the country to represent NASA and its mission to taxpayers.

Progress 44 launched from Baikonur on August 24 on a Soyuz U rocket, bound for the ISS. The Soyuz experienced a third-stage engine shutdown due to a faulty gas generator. (Photo: RSC Energia.)

Sizing up the Right Stuff

In contrast to the 40 or more astronauts who crewed shuttle launches every year, steady-state ISS operations require the launch of roughly a dozen crewmembers each year: six Russian and six U.S. and international partner astronauts. That manifest drives the overall size of the Astronaut Corps and the need for new hires.

As the end of the shuttle program neared, Johnson's Flight Crew Operations Directorate shrank the corps size through attrition and reduced hiring. From a high of nearly 150 in 2000, by early 2011 NASA had just 61 astronauts. That total may drop further as some shuttle astronauts depart and others are disqualified by medical problems. NASA says it needs a corps, through 2016, of 55 to 60 astronauts.

That number, based on the directorate's model of the so-called 'minimum manifest requirement,' includes a managers' margin above the corps size required to meet the six or so crewmembers flying each year. FCOD has recently dropped this margin from 50% to 25%. But that cushion may still not be enough to enable the Astronaut Office chief to deal with real-world factors affecting astronaut supply and demand.

For example, each ISS crew slot has a specific skill requirement, such as EVA and robotics qualifications, Russian language skills, scientific research experience, or flight experience required to serve as an ISS commander

The 2009 class of NASA, JAXA, and CSA astronauts never flew on the shuttle, but will fill the ISS flight manifest for the coming decade. They are Jeremy Hansen, Scott D. Tingle, Michael S. Hopkins, Gregory R. Wiseman, Mark T. Vande Hei (front row); Jack D. Fischer, Serena M. Auñón, Kathleen Rubins, Jeanette J. Epps (middle row); and David Saint-Jacques, Takuya Onishi, Norishige Kanai, Kimiya Yui, and Kjell N. Lindgren.

or Soyuz flight engineer. But astronauts are not interchangeable; they have different strengths, and levels of proficiency vary as they move through their careers. Some may not be eligible for long-duration flight due to medical factors: cumulative radiation exposure, recovery from injury, or temporary health problems. (Recently, some ISS astronauts have experienced inflight vision degradation from swelling of the eye's optic disc.)

The result is that the office chief has in the past year had trouble finding the right astronauts. Of 60 or more eligible astronauts on the books, only six were actually qualified to step into a pair of pending ISS assignments. That's too shallow a talent pool.

Providing qualified crewmembers is vital to the safe and successful operation of the ISS. Our panel found that a corps size of just 55-60 poses a risk to U.S. human spaceflight capability. Future attrition is difficult to predict, but some returning station crewmembers will decide that the family stresses of another two to three years of intense training, followed by a six-month deployment, preclude another expedition assignment.

New hiring is not a magic bullet either, given the long lead times necessary to train astronauts for flight (two years from hiring to flight eligibility). For example, an inexperienced astronaut will be unable to help NASA mount a surge of missions responding to a serious ISS orbital emergency.

We recommended that NASA management increase corps size to comfortably exceed the calculated minimum needed for flight requirements. We think NASA should increase the managers' margin, hiring more astronauts to protect against unexpected attrition or renewed spaceflight development tasking in the coming decade.

Astronaut wings

Since 1959, NASA has used high-performance jet aircraft to help prepare its astronauts for spaceflight. The Mercury Seven flew F-102s, F-106s, T-33s, and other jet trainers. By the mid-1960s, NASA had acquired a small fleet of T-38 Talon trainers from the Air Force, and astronauts have honed their physical and mental skills in these sleek, two-seat, twin-engine jets for nearly 50 years. But given that the Soyuz is highly automated and lands under a parachute after a near-ballistic reentry profile, are high-performance jets really an effective way to train for ISS and the Soyuz flight regime?

Ground-based mission simulators, in facilities at Russia's Star City, NASA Johnson, and international partner facilities in Europe, Japan, and Canada, provide approximately 90% of ISS and Soyuz task training. NASA also requires crewmembers to fly the T-38N for what it calls 'spaceflight readiness training,' or SFRT.

Although jet flying amounts to just 10% of the training activity for unassigned astronauts, shrinking to 5% for those assigned to an ISS expedition, it does expose crewmembers to a fast-paced operational environment that parallels the dynamic, stressful, and always dangerous spaceflight environment. It's not just the hands-on jet flying that is important, though that has application to Soyuz flying, robotics operations, and delicate EVA tasks. Making real-time judgments in the cockpit—dealing with conflicting traffic, hazardous weather, and actual aircraft failures or emergencies—builds experience that helps astronauts react coolly and deliberately when exposed to emergency situations in orbit.

SFRT is accepted by the ISS international partners as a key element in training qualified spaceflight crews. Our panel found that ground simulators, while improving in fidelity, can-

T-38A Talons fly over NASA Dryden. NASA's upgraded T-38N trainers provide astronauts with spaceflight readiness training, a close analog to the dynamic, high-stress, and risky environment of spaceflight.

not provide the full spectrum of physical and psychological stresses seen in an actual aircraft cockpit.

One example of SFRT's value came from Astronaut Office Chief Peggy Whitson, who related her own experience on April 19, 2008, when returning on Soyuz TMA-11 from Expedition 16. The station commander and a Ph.D. biochemist, Whitson was serving as Soyuz flight engineer during reentry; both she and Soyuz commander Yuri Malenchenko had extensive aviation experience. Failure of the Soyuz instrument section to separate fully from the descent module led to a sustained 7-*g* ballistic reentry, with heat damage to the crew hatch and radio antennas. During descent, smoke penetrated the crew cabin and the crew promptly executed the emergency checklist steps for an electrical fire. After an unusually hard landing, the crew could not immediately exit the Soyuz—the landing retrorockets had started a grass fire. Whitson believes this real-world emergency might have ended less successfully if she had not trained extensively in the T-38.

During Expedition 23 in August 2010, during crew sleep, an ISS external ammonia coolant pump failed and shut down half of the solar array output. Responding to alarms, the crew executed a swift reconfiguration of the core station systems, working closely with ground teams to reach a stable power and cooling configuration. They conducted three critical spacewalks in the following weeks to replace the pump with a spare, restoring full cooling and power. The initial stages of the emergency required high situational awareness, crisp communications, timely response, and proper crew resource management, all skills exercised during NASA's high-performance aircraft training.

In September, the Expedition 28 crew lost communications with Moscow just before Soyuz reentry yet made a safe and successful landing. I've had similar experiences, from last-second launch pad aborts to jammed EVA hatches to time-critical external coolant leaks on the station. In each case, thanks to piloting experiences in the Air Force and in NASA's T-38s, I had a strong sense that "I've been here before." I was able to think clearly yet react quickly.

Simulators augmented that experience, but did not provide the instinctive ability to react rapidly and appropriately in a dynamic emergency. Particularly for those astronauts who come to NASA without professional flight experience, SFRT brings potential crewmates up to a similar, confident level of operational skill—high assurance to NASA that they are ready to meet and exceed the mission's safety and mission requirements.

High flight

That astronauts have dealt successfully with hundreds of similar anomalies on the shuttle and the station—all having had SFRT—made the case to our panel that high-performance aviation contributes to preparing certified crews who can get the job done in the demanding, unforgiving, and hazardous spaceflight environment.

Our panel recommended that NASA retain its T-38N fleet for use in spaceflight readiness training, and ensure that the fleet size (projected to shrink to 16 aircraft in 2013) matches corps training requirements. More modern aircraft could also serve NASA in the SFRT role, but it is very unlikely the agency will be able to afford a new fleet of high-performance jets in the coming decade. The T-38s have undergone cockpit, safety, and performance upgrades in the last decade, and are poised to provide another 10 years or more of reliable service.

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With $100 billion in hardware and operational effort having gone into the space station's construction and activation, and given its importance to the agency's research and human exploration plans, continuing astronaut high-performance aviation training will assure NASA and its partners that their orbital investment will always be in capable hands.

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