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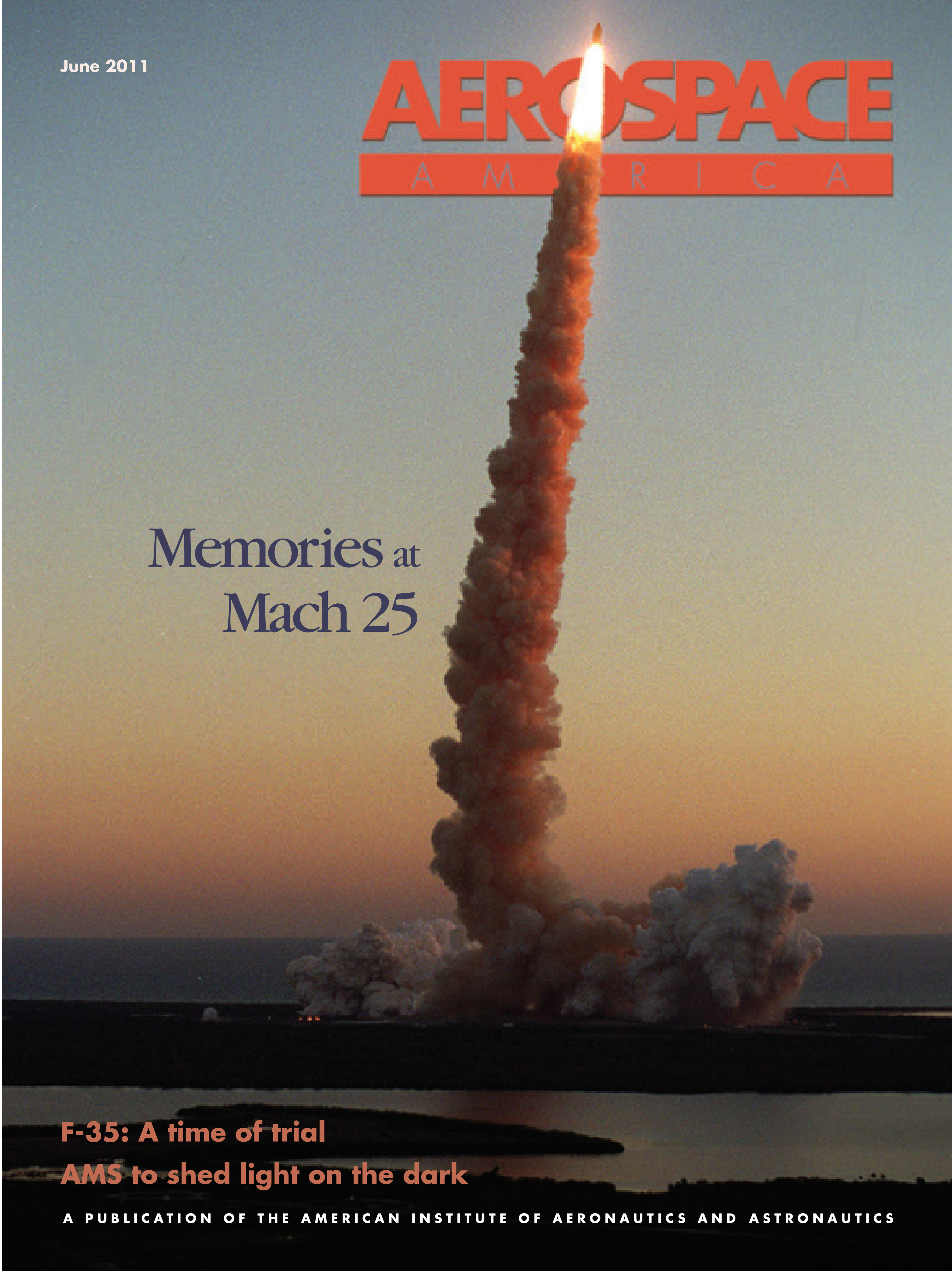

Memories at Mach 25

F-35: A time of trial

AMS to shed light on the dark

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Space shuttle: Memories at Mach 25

Endeavour lifts off from launch Pad 39A on April 9, 1994, at 7:05 a.m. on STS-59.

The 30-year flight history of the space shuttle culminates this month in one grand finale, a microcosm of its 134 previous missions. On STS-135, Atlantis and her crew will deliver the Raffaello multipurpose logistics module, laden with supplies, logistics, and spare parts, to the ISS. The vehicle will also fly a system to investigate the possibility of robotically refueling existing spacecraft. In addition, Atlantis will return a failed ammonia pump module to help NASA diagnose the failure mechanism and improve future pump designs.

The space shuttle's flight history can be summarized neatly with eye-popping facts and figures about satellites launched, cargo upmass hoisted to orbit, and modules delivered to the ISS. But Atlantis' last flight should also remind us of the uniquely human achievements of hundreds of thousands of shuttle engineers, technicians, scientists, managers, and support staff, offered willingly to sustain this amazing fleet of spaceships. This dedicated team—in mission control, at NASA centers, at industries and labs across the nation, as well as in the cockpit—propelled the space shuttle to its successes. On the eve of the shuttle's final mission, here are some personal memories of their contributions.

Vaya con Dios!

Endeavour was my first shuttle, carrying five veteran crewmates and one rookie—me. At T-2 minutes during the STS-59 count, the last call to the crew from the orbiter test conductor was: "Endeavour, close and lock your visors, initiate O_2 flow, and 'Vaya con Dios!'" Commander Sid Gutierrez replied crisply with, "Thanks a lot, Mark, and we'll see you in about 10 days." On the flight deck, pilot Kevin Chilton jokingly asked Sid, a favorite son of Albuquerque, if he could translate Mark's Spanish sendoff.

"Nope, I think I got that one. The real translation is 'God be with you as you go.'"

God is who I wanted lying next to me 90 seconds later, when Endeavour's three main engines coughed fire and shivered their way up to full power. My middeck seat rattled and shook along with every fitting in the cabin, until six seconds later booster ignition hit us with a massive crash-bang wallop. Explosives split the eight hold-down nuts clamping the SRBs to the pad, and the shuttle leaped clear of Earth under 7 million lb of thrust. The brutal ride on the solids was like hurtling down a dirt road in a pickup truck at about 50 mph, and Endeavour wasn't backing off the accelerator.

After two minutes of crackling and shaking, the boosters left us with a metallic *Clang!*, and we traded brute power for smoother, sustained acceleration on the main engines. Six-and-a-half minutes later, after a full, chest-squeezing minute of 3-*g* throttling, we were in orbit over the North Atlantic at just over 17,000 mph. For my first orbital experiment, I unzipped and tugged off my left glove, then released it to float and spin lazily, inches from my face. My grin could have lit up the world.

Through the Aurora

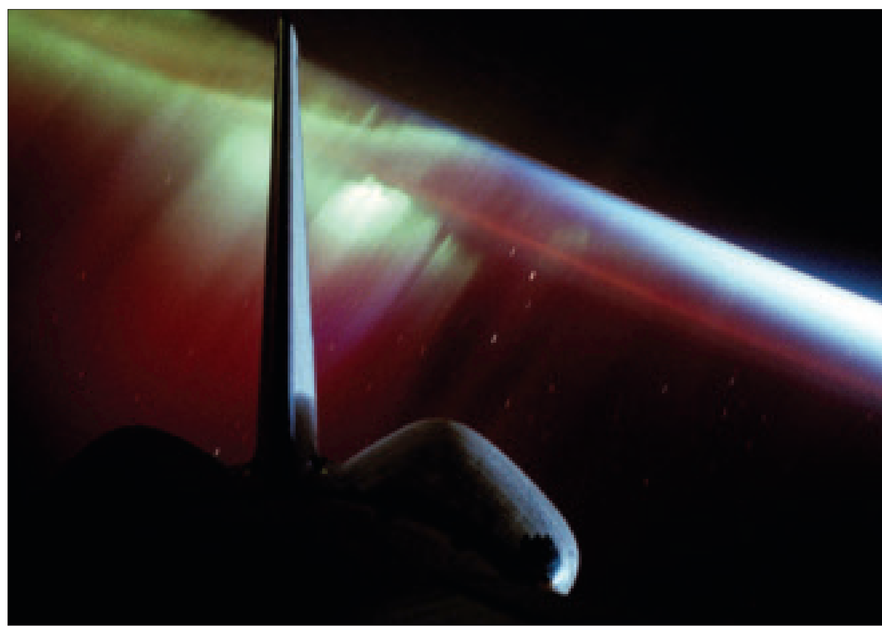
The payloads on my first two shuttle flights, in April and October 1994, were space radar labs (SRL-1 and -2), synthetic aperture imaging radars scanning Earth's changing surface with wide-ranging geological and ecological applications (see http://southport.jpl.nasa.gov/). Endeavour carried us around the globe at an altitude of 121 n.mi., at an orbital inclination of 57°. JPL scientists and Johnson flight controllers had come up with an ingenious steering technique that enabled the shuttle to pirouette delicately through each orbit, aiming the radar beam precisely and canceling out the Doppler error in the echoes caused by the Earth's rotation. The result was a nearly 24/7 swath of crisp, multifrequency radar portraits of our planet, imaged at 20-m resolution.

In April the vehicle carried us on three orbits daily through the autumn darkness, well south of Australia and New Zealand, where we sailed among the glowing curtains of ionized nitrogen and oxygen atoms called the Aurora Australis. My recorded notes reveal sightings on Flight Days 4 and 6:

At times we were flying right through the long thin streamers of the aurora, projecting straight up through the atmosphere, a very ghostly pale yellow green.…We could see these long streamers going up above us, but at times we flew right over the long shimmering arcs of the aurora. We could see the shimmering curtain below us, and when we flew over the top of it, it would become edge-on to us, and we could look straight down on this line… just a fantastic sort of ghostly sight… swirling all around the shuttle…pulsating curtains and rippling ribbons of light.

Of course, daytime held even more spectacular sights: On September 30, my STS-68 crew and I roared off the launch pad the day Russia's Kliuchevskoi volcano blew its top. Late on launch day we soared over the Kamchatka peninsula, but could see little of the twin-peaked volcano's summit, entirely shrouded in charcoal clouds of ash boiling up 50,000 ft into the stratosphere. The jet stream threw that vast eruption plume of steam and dust nearly 350 mi. out across the Pacific. Crowding Endeavour's windows, cameras in hand, we captured dramatic, down-the-throat views of this live geology lesson, as explosions from Kliuchevskoi fed the turbulent shaft of steam shot through with dirty-brown ash. The radar was able to penetrate the cloud, revealing active vents, hot lava and mud flows, and melting of the summit's icy hood.

Kliuchevskoi was just one of our 572 science targets, and Endeavour nailed them all: Flight controllers handily developed a software patch to work around a faulty steering jet and restore precise radar pointing. Later in the mission, with the help of payload and in-flight maintenance controllers, astronauts Steve Smith and Jeff Wisoff removed and replaced an oven-sized high-rate digital recorder on the flight deck, restoring full data flow from SRL-2. After 11 days STS-68 glided home with 13,000 still photos of Earth, and enough radar imagery to fill a stack of CDs more than 65 ft high.



STS-68, orbiting just 120 n.mi. up for its SRL-2 mission, cruises through the Aurora Australis in October 1994.

In total, the NASA/JPL, German, and Italian radars imaged 150 million km² of the Earth's surface, observing about 15% of the globe. That's over 100 terabits of data—an imagery collection that would fill a 45,000-volume encyclopedia. We tested radar interferometry (stereo imaging) techniques that in 2000 enabled the shuttle radar topographic mission to generate a precise, 30-m-resolution topographic map of 80% of the world's landmass. These three flights were typical of the shuttle's superb performance as an orbital science platform.

Are you turning the handle clockwise?

The shuttle showed off its scientific versatility again on STS-80 in November 1996. At the outset, KSC launch controllers wrestled with a hydrogen leak in Columbia's main engine compartment that held our count at T-31 seconds. On the flight deck, I was sure we had scrubbed for the day, but within a couple of minutes propulsion engineers had eyeballed the leak rate and determined it was within safety limits. With studied coolness, the console lead announced, "NTD, it appears to me that we're on the edge, but that this is an acceptable condition. My recommendation is that we continue." A few seconds later the NASA test director had approval from his launch director, and intoned, "Copy, resume on my mark: three, two, one, mark!"

My reaction? *Holy smoke, they're going ahead!* Thirty-one seconds later the twin boosters blasted us off the pad, and the five of us were soon safely in orbit. The experts on the Kennedy launch team had saved a scrub and saved our hides. I'm still grateful!

Ten days later Tammy Jernigan and I were floating at vacuum inside Columbia's airlock, ready to rehearse a toolbox full of space station assembly techniques on the first of two EVAs. With a 'GO!' from Houston, Tammy swung the outer hatch handle to crack the seals and open the door to the payload bay. But instead of describing an easy circle, her gloved hand stopped abruptly after 30 degrees of travel, hard against some mysterious resistance. Ten minutes of fruitless shoving couldn't budge the handle further; frustrated, we called in Houston for advice.

Flight controllers scrambled with the hatch schematics while walking us through troubleshooting steps. A quarter of an hour later we were still locked inside by the jammed handle. I couldn't really blame Capcom Bill McArthur for his next transmission: "Tom, uh, forgive us for asking the obvious, but could you please confirm you're turning the handle *clockwise*?" His tone was apologetic—Mission Control had to cover every possibility.

If only that *had* been the problem; after two hours of troubleshooting, we admitted defeat. Our $2-billion space shuttle's doorknob was broken. The jammed mechanism was on the far side of a sealed cover, impossible to reach from the airlock. We were stumped, and our Thanksgiving night spacewalk was scrubbed.

It was a crushing blow to Tammy and me, but my disappointment was salved somewhat by membership in a team that could exercise such cool and thorough decision-making. I later learned that Houston and cape engineers had meticulously examined every branch of the hatch mechanism failure tree, zeroing in on where the failure must be—in the hub gearing.

We could bypass the faulty mechanism only by applying a hammer and chisel. Punching through the hatch might leave us stranded in the airlock with no way to repressurize and get back inside, forcing an emergency landing and abandoning our free-flying ORFEUS-SPAS astronomical satellite. The shuttle team made the right call in canceling: Spacewalks could be (and were) rescheduled. Our disappointed crew took satisfaction in hauling in and berthing a successful ORFEUS-SPAS, its recorder packed with two weeks of high-quality astronomical observations. We also logged the longest shuttle mission ever, including a weightless Thanksgiving dinner I'll never forget.

Columbia's five astronauts launched and retrieved ORFEUS-SPAStelescope as well as the Wake Shield Facility materials processing satellite during STS-80. Mission duration was a record at nearly 18 days.

Destiny in space

Atlantis was our ship for the STS-98 mission, which delivered the U.S. Destiny Laboratory to the ISS in February 2001. On Flight Day 4, Marsha Ivins expertly flew the Canadian robot arm to swing Destiny out of the cargo bay and nestle it permanently into its berth at Unity's forward hatch.

Meanwhile, pilot Mark Polansky had suited up Bob 'Beamer' Curbeam and me, and propelled us out of the airlock for our first EVA—this time, I managed to rotate the hatch handle all the way 'round. We were soon clambering about the station's exterior, releasing launch locks and connecting utility lines to the new lab.

Beamer had to disconnect four ammonia coolant lines from the station's cooling loops and plug them into the new lab's heat exchangers. Within seconds of releasing the first hose from its ISS receptacle, its business end sprayed my partner with a jet of ammonia vapor and ice crystals from a cold-soaked poppet valve. My heart sank: We were venting vital coolant for the new lab.

Backdropped by Atlantis' cargo bay, spacewalker Bob Curbeam peers into the orbiter's airlock to retrieve the Destiny Lab's protective window shutter for installation on Feb. 12, 2001.

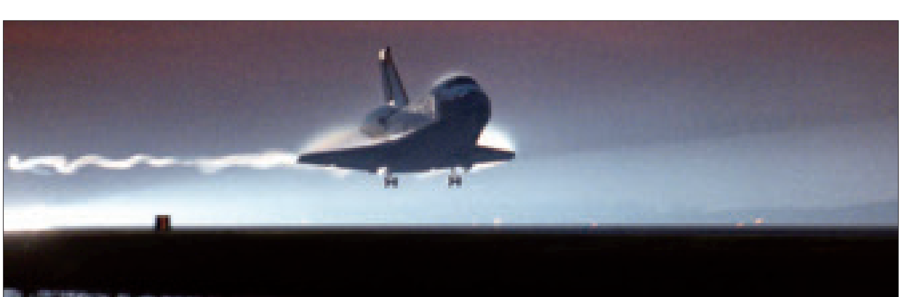
"Yeah, I know," Beamer exclaimed. "I've got ammonia…definitely ammonia coming out, and ice crystals forming all over the place." Against the empty black sky, fat ammonia snowflakes tumbled in brilliant sunlight, blasted outward by a barely visible jet of vapor.

But Curbeam had already thought through this failure—back on the ground. Just weeks before launch, station and shuttle payload flight controllers conferred with us about a possible leak. We agreed on a strategy in case one should occur: Cut off the ammonia supply, then seat the connector into the new lab fittings.

Engulfed in an ammonia snowstorm, Beamer muscled open an upstream valve, choking off the leaky connector. Within minutes of the initial leak, he had wrestled the stiff hose and its spewing connector safely into its lab receptacle. His quick thinking and execution, building on thorough contingency planning by the ground team, had preserved 95% of the coolant supply. In the end, the potentially crippling leak merely gave us a glimpse of a spectacular but transient ammonia comet tail.

Another curve ball: Inside Atlantis, Ken Cockrell and Marsha Ivins got word from flight controllers that a faulty thermostat had pushed the lab's interior temperature to over 100 F. Tapping laptop keys on the flight deck, they promptly worked with Houston to step through the module's activation procedures, taking just 45 minutes instead of the planned two-plus hours. Their quick response restored cooling and prevented heat damage to Destiny's avionics and life-support systems.

That was a tense day in orbit, inside and out, but the combined Houston/Atlantis team had dealt with every problem, inaugurating the $1.4-billion lab's operations. Ten years later, Destiny is still the hub of control and research activity at the ISS.



Mission accomplished, Columbia nears touchdown at Kennedy Space Center for a dawn landing on December 7, 1996. The next national space system will build on the accomplishments of the space shuttle team's 30-year record of excellence.

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What a privilege you've given me: representing the U.S. on four flights of its marvelous space shuttle. I've seen almost everything the shuttle can do: delivering space station modules, hauling supplies to crews in orbit, serving as a 'workbench' for complex spacewalks and robotics work, observing both Earth and the universe with cutting-edge scientific payloads, and launching and returning satellites for refurbishment and reuse.

We will miss the shuttle's ample lifting power and, even more, its flexibility and versatility. Serving as our classroom in space, the orbiter fleet has taught us invaluable skills: orbital repair, outpost construction, precision rendezvous and docking, complex EVA, and intense, round-the-clock science operations. Even its shortcomings will help us build safer and more efficient vehicles.

When the shuttle retires, what we will miss most is its human component. That superbly professional team overcame innumerable technical obstacles and recovered from devastating tragedy in compiling an unmatched record of success in Earth orbit. The nation should not surrender their talent, but rather build on their dedication and experience to capture our future in space.

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Thanks to my crewmates Jay Apt, Mike Baker, Dan Bursch, Kevin Chilton, Rich Clifford, Ken Cockrell, Bob Curbeam, Linda Godwin, Sid Gutierrez, Marsha Ivins, Tammy Jernigan, Story Musgrave, Mark Polansky, Kent Rominger, Steve Smith, Terry Wilcutt, and Jeff Wisoff; ISS crewmembers Yuri Gidzenko, Sergei Krikalev, and Bill Shepherd; and the thousands of shuttle colleagues with whom I had the privilege of working. Your record in 30 years of space exploration is second to none.