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A SLOW TRANSFORMATION

SESAR faces nontechnical hurdles

A conversation with Richard Brookes

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Space shuttle: An astronaut looks at its legacy

The shuttle countdown clock stood at "L-minus-three," three launches remaining—as engineers were able to deal with the helium isolation valve leak found in Discovery's right maneuvering system pod in time for an April launch, and President Obama had not yet announced whether an additional launch, or launches, would be scheduled.

Reports of the orbiter fleet's retirement may still be premature. I have a feeling that this year and next we'll see several "final" shuttle launches.

We are nevertheless nearing the end of the shuttle's long career, an appropriate moment to examine the craft's historic and complex legacy. Even after 30+ years of atmospheric tests and orbital missions, the shuttle's outstanding characteristics have yet to be matched by other space vehicles. The shuttle orbiters expanded our human capabilities in space a hundredfold.

But the spacecraft, built by human hands, is an imperfect creation. Compromised by tight budgets and conflicting requirements, its career has been twice marred by terrible tragedy. By recognizing how it has fallen short of its promises, and building on its many successes, we can make the next generation of spacecraft safer, more efficient and better suited to the demands of future exploration.

Born in compromise

During its 30 years in service, the shuttle has averaged about four launches per year. Its large crews (up to eight astronauts) have made it the initial route to space for about 61% of the 509 human beings who have left the planet. But at its conception in the late 1960s, its future was by no means assured.

President Richard Nixon, swayed by his budget director, Caspar Weinberger, approved the shuttle's development early in 1972. The project was underfunded from the start (a $5-billion budget target eventually swelled to nearly four times that), and NASA struggled to find a design that was both affordable and attractive to the widest spectrum of launch customers.

Carrying just two passengers, Columbia lifted off for the first time on STS-1, on April 12, 1981.

To get the Pentagon to designate the shuttle as the sole launcher for the largest national defense payloads, NASA agreed on an orbiter with a 60x15-ft cargo bay, far larger than necessary for most scientific or commercial satellites. Air Force requirements were also responsible for the orbiter's expansive delta wings. They delivered the hypersonic cross-range performance for a first-orbit, high-inclination satellite deployment from Vandenberg AFB, California, followed by an immediate reentry and landing back at the base.

Although the larger wings and payload bay required a bigger (and more vulnerable) heat shield, the orbiter could then haul impressively large payloads to orbit. The shuttle can launch 15,900 kg to the 51.6°-inclination orbit of the space station, and routinely returns 9,400 kg of cargo from the ISS in the Italian-built MPLM. By contrast, the ESA-built automated transfer vehicle delivers 7,385 kg to ISS; the JAXA HTV, 6,000 kg; the Russian Progress, 2,350 kg. The cramped Soyuz can return a mere 60 kg of cargo from ISS. Even when commercial cargo services debut in 2011, the shuttle's truck-like hauling capacity will be sorely missed.

The shuttle has been the classroom in space for two generations of NASA's engineers, scientists and managers. Its frequent flights, steadily advancing capability and long career have built a bridge that has supported the nation's space operations talent pool until the agency's path could match its long-held ambitions.

Carrying just two pilots on its first four shakedown flights, each lasting only a few days, Columbia and its companions gradually expanded NASA's experience base in LEO. Beginning with relatively simple launches of commercial communications satellites, the fleet expanded its capabilities to national defense payloads and satellite rescue and repair. Commercial cargoes were dropped from the STS manifest after Challenger's loss in 1986, but the orbiters stayed busy with a wide array of scientific missions, everything from planetary probe launches to repeated flights of ESA's long-duration Spacelab module.

Flexible, reusable science platform

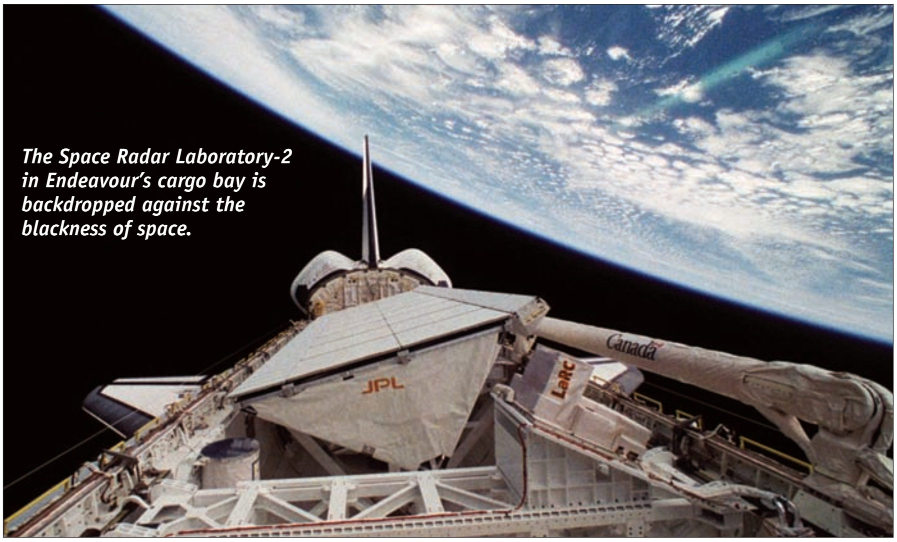
In the nearly 20 years between its debut and the start of ISS construction, the shuttle served as a versatile science platform, hosting an astounding array of experiments and major payloads, both in-cabin and in the cargo bay. With launch costs approaching half a billion dollars per liftoff, science customers could have found a cheaper route to space. But the orbiters did offer a reliable platform with robust power, pointing and communications budgets, and they could return science payloads to Earth for refurbishment and reflight. A purely robotic space science program would not hire the shuttle as a launcher. But the shuttle's expansive capabilities for meeting national security and human spaceflight priorities allowed it to be made available for science.

My two flights with the Space Radar Lab in 1994 were good examples. SRL included an advanced, multifrequency imaging radar (http://www.jpl.nasa.gov/radar/sircxsar/) to map the changing face of our planet. Its 40x12-ft antenna weighed 21,380 lb; if flown as a free-flyer it would have required a maneuverable satellite bus, 10-kW solar arrays, and a high-bandwidth communications system. On STS-59, however, Endeavour provided pointing, power and communications; the crew conducted over 400 separate target-tracking maneuvers and captured the avalanche of digital imagery on high-capacity tape cassettes.

Best of all, the shuttle enabled the radar to fly twice more, each mission more capable than the last, culminating in the shuttle radar topography mission (SRTM) in 2000. SRTM created a near-global high-resolution digital terrain map of Earth's land masses, a product still being used by our military forces and in civil aviation cockpits.

The list of high-value science and security payloads carried by the shuttle is a long one, including Spacelab for long-duration science investigations in LEO; planetary probes such as Magellan, Galileo and Ulysses; the unmatched Hubble Space Telescope; and military payloads such as the Defense Support Program satellites. (In addition, 11 classified shuttle missions launched a variety of defense or intelligence collection craft.)

The astronauts accompanying these cargoes were also capable of dealing with balky payload systems that might have threatened loss of mission. The crew on STS-37, for example, freed the Compton Gamma Ray Observatory's stuck high-gain antenna, and the STS-51I astronauts brought the circuitry of the comatose Leasat-3 satellite back to life after the four months it spent adrift in LEO. On-orbit repair capabilities culminated in complex "catch and release" operations such as the 1992 Intelsat VI rescue and the stunning recovery of Hubble's optical performance. STS-61 in 1993 restored the telescope's flawed optics, while four subsequent visits replaced its failing systems and upgraded its scientific capabilities to a level never imagined by its designers.



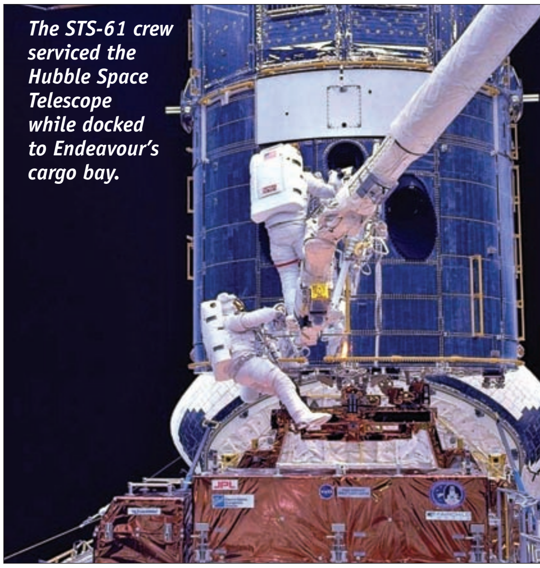
The Space Radar Laboratory-2 in Endeavour's cargo bay is backdropped against the blackness of space.

Not your father's space shuttle

Seventeen years of robotic, EVA and rendezvous experience positioned NASA to begin space station construction in December 1998, when Endeavour joined America's Unity docking node to the Russian-built Zarya module. Building an orbiting station was one of the earliest tasks envisioned for the shuttle, but not until nearly two decades after its first flight did ISS construction actually begin. During those decades when the nation's future in space was not at all clear (a situation in which we find ourselves again today), the shuttle nurtured larger ambitions while providing a stream of research results and invaluable operations experience.

From its inception in 1984, the ISS project depended on the versatile skill set of the shuttle fleet. The orbiters delivered, using all their unique capabilities—large upmass, precise proximity operations and complex robotics and EVA functions—to tackle this ultimate mission.

With construction now more than 90% complete, the station incorporates three active research laboratories and a six-person crew. Shuttles delivered the bulk of the structure, most of its supplies (including tons of fuel-cell-derived water), all manner of experiments and outfitting hardware, and a steady stream of multinational astronaut crews. The end product is an outpost that now tops 800,000 lb in mass, spans 356 ft, and encloses 12,000 ft³ of pressurized volume, equivalent to a five-bedroom house.


The STS-61 crew serviced the Hubble Space Telescope while docked to Endeavour's cargo bay.

Astronaut Nicholas Patrick participates in the mission's third and final spacewalk as construction and maintenance continue on the international space station. During the spacewalk, Patrick and astronaut Robert Behnken completed all of their planned tasks, removing insulation blankets and launch restraint bolts from each of the Cupola's seven windows.

There are many ways to build a space station, but without the shuttle, the one circling 200 mi. above Earth for the past 11 years would never have materialized. As the ISS approaches 10 years of continuous occupancy, the shuttle is arguably the one tool whose existence was essential to the permanent habitation of humans off the planet.

Brilliant but flawed

In 30 years, no nation has matched the space shuttle's capabilities, adaptability and flexibility. But after two horrifying accidents that claimed the lives of 14 crewmembers, shuttle astronauts take an "eyes-open" approach to the vehicle's shortcomings. The design compromises of the 1970s gave the shuttle large delta wings (protected by thousands of brittle heat shield tiles) and stacked the orbiter next to millions of pounds of explosive liquid and solid propellants. The crew escape system, a minimal bailout capability added after the 1986 Challenger accident, ties the crew's fate to that of the orbiter itself.

In 1986, and again in 2003 after Columbia's loss, NASA examined proposals for an escape "pod" that could rocket the crew clear of a crippled orbiter. But the cost of such a major modification was deemed prohibitive. Post-Columbia, the shuttle would fly for at most five more years, NASA thought, so forgoing an upgraded escape capability seemed an acceptable risk. Ill-informed congressional talk of adding shuttle missions to close the LEO access gap consistently skirts this life-and-death issue. The U.S. owes its astronauts a better chance at survival than the current orbiter can offer.

The shuttle has other shortcomings as well. The external tank thermal insulation and orbiter tiles are vulnerable to severe weather damage on the launch pad, and to debris impacts during ascent and orbit. The orbiter's inability to withstand the impact of raindrops in flight (without suffering severe tile damage) has caused months of cumulative launch delays. Although NASA has been recertifying critical orbiter systems over the past few years, the aging of the fleet means thorny problems are sure to keep turning up, from corrosion and damaged wiring to balky valves and propellant system leaks. The shuttle's Achilles heel has always been the intensive (and expensive) maintenance required for turnaround; that factor is bound to worsen if extension becomes reality.

Each time I flew in space, I believed—I think correctly—that I was strapping into the best maintained, most thoroughly vetted vehicle that human beings could ready for launch. In 2010, I believe the machine is in even better shape, with respect to the operations team's corporate knowledge and the skill of its maintainers. But shuttle managers are aware that the storied spacecraft is always just one serious in-flight anomaly away from being grounded in its tracks.

Learning from the shuttle

Even if it stopped flying tomorrow, the shuttle has written volumes full of hard-won lessons advancing the science of human spaceflight. Some of the "Do" lessons: Do design for crew safety and robust escape capability. Split cargo and crew when feasible, to enhance crew survival. Design for minimum life-cycle costs, anticipating a service life measured in decades. Do enable your human crew with provision for robotics and EVA. Design for ease of future upgrades to computers, communications and human interfaces.

The "Don't" lessons are even more valuable: Don't expect multiple users to guarantee cost savings or streamlined operations. Don't assume reusability is a cost saver—it can limit upgrades and raise turnaround costs. Don't carry landing gear and wings to orbit and back unless a runway landing is truly a mission requirement. Don't keep your vehicle sitting exposed on the launch pad for weeks. Don't retire your sole downmass capability until you have a replacement payload return system ready.

Spacecraft designers will use the shuttle as a case study for decades to come.

Into the orbital sunset

Today, the space shuttle approaches its final missions at the top of its game. For

STS-59, the author's first shuttle ride, began on April 9, 1994.

30 years, albeit at great human and economic cost, it has provided unmatched capability for U.S. ambitions in space. On the day it retires, the nation will lose a significant portion of its preeminence in space. When we will see its equal in orbit again is impossible to predict.

Of greater importance than the loss of specific capabilities will be the question of whether we can retain the talent pool and collective experience that built and maintained the orbiter fleet. The near-term answer from the administration seems to be no.

Whatever direction the nation adopts for human spaceflight, we should not assume the capabilities lost at shuttle retirement will be easy or cheap to resurrect. NASA will not have the budget to build a beyond-LEO transportation system *and* replace the shuttle's many capabilities. Instead, the commercial sector should be asked to provide some mix of the shuttle's attributes, as part of a broad LEO services contract.

This new orbiter would take on EVA and robotic operations that cannot be performed at ISS. Ideally, the successor would reside on-orbit, robotically serviced and refurbished. Its crews would visit only temporarily (bringing their reentry vehicle along) to carry out high-value repair, rescue or assembly tasks. This orbital work platform could be reconfigured for various tasks, then upgraded and expanded as new technology makes economic and operational sense.

The first time I felt the three main engines roar to life under me, the first time I felt twin solid rocket boosters jolt and rattle my body to the bone, I was in awe of the space shuttle. Indeed, I felt somehow indebted to this machine—and the people who designed, built and operated it—for enabling ambitious tasks to be tackled in space, and for bringing me home at mission's end. Perhaps I overlooked its shortcomings too easily. But when Americans see these magnificent vehicles up close at Udvar-Hazy and other museums across the country, we should swell with justifiable pride.

The shuttle gave us incredible competence and sophistication in space operations. It seasoned us with the maturity needed to take on the space challenges of a new century. The shuttle's matchless legacy should inspire us to craft machines even more versatile, able to carry explorers far beyond the orbiters' lofty reach. Their lasting record of accomplishment, and that of the team that made it possible, deserves nothing less. The final call of "*Houston, wheels stop*" should be only the beginning of an exciting new story in space.

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