The Historical Legacy

Major Milestones

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Astronauts John Young and Robert Crippen woke early on the morning of April 12, 1981, for the second attempted launch of the Space Shuttle Columbia—the first mission of the Space Shuttle Program. Two days earlier, the launch had been scrubbed due to a computer software error. Those working in the Shuttle Avionics Integration Laboratory at Johnson Space Center (JSC) in Houston, Texas, quickly resolved the issue and, with the problem fixed, the agency scheduled a second try soon after. Neither crew member expected to launch, however, because so much had to come together for liftoff to occur.

That morning, they did encounter a serious problem. With fewer than 2 hours until launch, the crew of Space Transportation System (STS)-1 locked the faceplates onto their helmets, only to find that they could not breathe. To avoid scrubbing the mission, the crew members looked at the issue and asked Loren Shriver, the astronaut support pilot, to help them. Finding a problem with the oxygen hose quick disconnect, Shriver tightened the line with a pair of pliers, and the countdown continued.

At 27 seconds before launch, Crippen realized that this time they were actually going to fly. His heart raced to 130 beats per minute while Young's heart, that of a veteran commander, stayed at a calm 85 beats. Young later joked, "I was excited too. I just couldn't get my heart to beat any faster." At 7:00 a.m., Columbia launched, making its maiden voyage into Earth orbit on the 20th anniversary of Yuri Gagarin's historic first human flight into space (1961).

The thousands who had traveled to the beaches of Florida's coastline to watch the launch were excited to see the United States return to flying in space. The last American flight was the Apollo-Soyuz Test Project, which flew in July 1975 and featured three American astronauts and two cosmonauts who rendezvoused and docked their spacecraft in orbit. Millions of others who watched the launch of STS-1 from their television sets were just as elated. America was back in space.

Like their predecessors, Young and Crippen became heroes for flying this mission—the boldest test flight in history. The shuttle was like no other vehicle that had flown; it was reusable. Unlike the space capsules of the previous generation, the shuttle had not been tested in space. This was the first test flight of the Columbia and the only time astronauts had actually flown a spacecraft on its first flight. The primary objective was to prove that the shuttle could safely launch a crew and then return safely to Earth. Two days later, the mission ended and the goal was accomplished when Young landed the shuttle at Dryden Flight Research Center on the Edwards Air Force Base runway in California. The spacecraft had worked like a "champ" in orbit—even with the loss of several tiles during launch. After landing, Christopher Kraft, director of JSC, said, "We just became infinitely smarter."

Design and Development

It would be a mistake to say that the first flight of Columbia was the start of the Space Shuttle Program. The idea of launching a reusable winged vehicle was not a new concept. Throughout the 1960s, NASA and the Department of Defense (DoD) studied such concepts. Advanced Space Shuttle studies began in 1968 when the Manned Spacecraft Center—which later became JSC—and Marshall Space Flight Center in Huntsville, Alabama, issued a joint request for proposal for an integral launch and re-entry vehicle to study different configurations for a round-trip vehicle that could reduce costs, increase safety, and carry payloads of up to 22,680 kg (50,000 pounds). This marked the beginning of the design and development of the shuttle.

Maxime Faget, director of engineering and development at the Manned Spacecraft Center in 1969, holding a balsa wood model of his concept of the spaceship that would launch on a rocket and land on a runway.

Four contractors—General Dynamics/Convair, Lockheed, McDonnell Douglas, and North American Rockwell—received 10-month contracts to study different approaches for the integral launch and re-entry vehicle. Experts examined a number of designs, from fully reusable vehicles to the use of expendable rockets. On completion of these studies, NASA determined that a two-stage, fully reusable vehicle met its needs and would pay off in terms of cost savings.

On April 1, 1969, Maxime Faget, director of engineering and development at the Manned Spacecraft Center, asked 20 people to report to the third floor of a building that most thought did not have a third floor. Because of that, many believed it was an April Fool's prank but went anyway. Once there, they spotted a test bay, which had three floors, and that was where they met. Faget then walked through the door with a balsa wood model of a plane, which he glided toward the engineers. "We're going to build America's next spacecraft. And it's going to launch like a spacecraft, it's going to land like a plane," he told the team. America had not yet landed on the moon, but NASA's engineers moved ahead with plans to create a new space vehicle.

As the contractors and civil servants explored various configurations for the next generation of spacecraft, the Space Task Group, appointed by President Richard Nixon, issued its report for future space programs. The committee submitted three options: the first and most ambitious featured a manned Mars landing as early as 1983, a lunar and Earth-orbiting station, and a lunar surface base; the second supported a mission to Mars in 1986; and the third deferred the Mars landing, providing no scheduled date for its completion. Included in the committee's post-Apollo plans were a Space Shuttle, referred to as the Space Transportation System, and a space station, to be developed simultaneously. Envisioned as less costly than the Saturn rocket and Apollo capsules, which were expended after only one use, the shuttle would be reusable and, as a result, make space travel more routine and less costly. The shuttle would be capable of carrying passengers, supplies, satellites, and other equipment—much as an airplane ferries people and their luggage—to and from orbit at least 100 times before being retired. The system would support both the civil and military space programs and be a cheaper way to launch satellites. Nixon, the Space Task Group proposals, and NASA cut the moon and Mars from their plans. This left only the shuttle and station for development, which the agency hoped to develop in parallel.

The decision to build a shuttle was extremely controversial, even though NASA presented the vehicle as economical—a cost-saver for taxpayers—when compared with the large outlays for the Apollo Program. In fact, in 1970 the shuttle was nearly defeated by Congress, which was dealing with high inflation, conflict in Vietnam, spiraling deficits, and an economic recession. In April 1970, representatives in the House narrowly defeated an amendment to eliminate all funding for the shuttle. A similar amendment offered in the Senate was also narrowly defeated. Minnesota Senator Walter Mondale explained that the money NASA requested was simply the "tip of the iceberg." He argued that the $110 million requested for development that year might be better spent on urban renewal projects, veterans' care, or improving the environment. Political support for the program was very tenuous, including poor support from some scientific and aerospace leaders.

To garner support for the shuttle and eliminate the possibility of losing the program, NASA formed a coalition with the US Air Force and established a joint space transportation committee to meet the needs of the two agencies. As an Air Force spokesman explained, given the political and economic realities of the time, "Quite possibly neither NASA nor the DoD could justify the shuttle system alone. But together we can make a strong case."

The Space Shuttle design that NASA proposed did not initially meet the military's requirements. The military needed the ability to conduct a polar orbit with quick return to a military airfield. This ability demanded the now-famous delta wings as opposed to the originally proposed airplane-like straight wings. The Air Force also insisted that it needed a larger payload bay and heavier lift capabilities to carry and launch reconnaissance satellites. A smaller payload bay would require the Air Force to retain their expendable launch vehicles and chip away at the argument forwarded by NASA about the shuttle's economy and utilitarian purpose. The result was a larger vehicle with more cross-range landing capability.

Though the president and Congress had not yet approved the shuttle in 1970, NASA awarded preliminary design contracts to McDonnell Douglas and North American Rockwell, thus beginning the second phase of development. By awarding two contracts for the country's next-generation spacecraft, NASA signaled its decision to focus on securing support for the two-stage reusable space plane over the station, which received little funding and was essentially shelved until 1984 when President Ronald Reagan directed the agency to build a space station within a decade. In fact, when James Fletcher became NASA's administrator in April 1971, he wholeheartedly supported the shuttle and proclaimed, "I don't want to hear any more about a space station, not while I am here."

Fletcher was doggedly determined to see that the federal government funded the shuttle, so he worked closely with the Nixon administration to assure the program received approval. Realizing that the $10.5 billion price tag for the development of the fully reusable, two-stage vehicle was too high, and facing massive budget cuts from the Office of Management and Budget, the administrator had the agency study the use of expendable rockets to cut the high cost and determine the significant cost savings with a partially reusable spacecraft as opposed to the proposed totally reusable one. On learning that use of an expendable External Tank, which would provide liquid oxygen and hydrogen fuel for Orbiter engines, would decrease costs by nearly half, NASA chose that technology—thereby making the program more marketable to Congress and the administration.

Robert Thompson, former Space Shuttle Program manager, believed that the decision to use an expendable External Tank for the Space Shuttle Main Engines was "perhaps the single most important configuration decision made in the Space Shuttle Program," resulting in a smaller, lighter shuttle. "In retrospect," Thompson explained, "the basic decision to follow a less complicated development path at the future risk of possible higher operating costs was, in my judgment, a very wise choice." This decision was one of the program's major milestones, and the decreased costs for development had the desired effect.

Presidential Approval

Nixon made the announcement in support of the Space Shuttle Program at his Western White House in San Clemente, California, on January 5, 1972. Believing that the shuttle was a good investment, he asked the space agency to stress that the shuttle was not an expensive toy. The president highlighted the benefits of the civilian and military applications and emphasized the importance of international cooperation, which would be ushered in with the program. Ordinary people from across the globe, not just American test pilots, could fly on board the shuttle.

From the start, Nixon envisioned the shuttle as a truly international program. Even before the president approved the program, NASA Administrator Thomas Paine, at Nixon's urging, approached other nations about participating. As NASA's budget worsened, partnering with other nations became more appealing to the space agency. In 1973, Europe agreed to develop and build the Spacelab, which

Rollout tests of the Solid Rocket Boosters. Mobile Launcher Platform number 3, with twin Solid Rocket Boosters bolted to it, inches along the crawlerway at various speeds up to 1.6 km (1 mile) per hour in an effort to gather vibration data. The boosters are braced at the top for stability. Data from these tests, completed September 2004, helped develop maintenance requirements on the transport equipment and the flight hardware.

would be housed in the payload bay of the Orbiter and serve as an in-flight space research facility. The Canadians agreed to build the Shuttle Robotic Arm in 1975, making the Space Shuttle Program international in scope.

Having the Nixon administration support the shuttle was a major hurdle, but NASA still had to contend with several members of Congress who disagreed with the administration's decision. In spite of highly vocal critics, both the House and Senate voted in favor of NASA's authorization bill, committing the United States to developing the Space Shuttle and, thereby, marking another milestone for the program.

To further reduce costs, NASA decided to use Solid Rocket Boosters, which were less expensive to build because they were a proven technology used by the Air Force in the Minuteman intercontinental ballistic missile program. As NASA Administrator Fletcher explained, "I think we have made the right decision at the right time. And I think it is the right price." Solids were less expensive to develop and cost less than liquid boosters. To save additional funds, NASA planned to recover the Solid Rocket Boosters and refurbish them for future flights.

Contracting out the Work

Two days after NASA selected the parallel burn Solid Rocket Motor propellant configuration, the agency put out a request for proposal for the development of the Orbiter. Four companies responded. NASA selected North American Rockwell, awarding the company a $2.6 billion contract. The Orbiter that Rockwell agreed to build illustrated the impact the Air Force had on the design. The payload bay measured 18.3 by 4.6 m (60 by 15 ft), to house the military's satellites. The Orbiter also had delta wings and the ability to deploy a 29,483-kg (65,000-pound) payload from a due-east orbit.

As NASA studied alternative concepts for the program, the agency issued a request for proposal for the Space Shuttle Main Engines. In the summer of 1971, NASA selected the Rocketdyne Division of Rockwell. Rocketdyne built the large, liquid fuel rocket engines used on the NASA Saturn V (moon rocket). However, the shuttle engines differed dramatically from their predecessors. As James Kingsbury, the director of Science and Engineering at the Marshall Space Flight Center, explained, "It was an unproven technology. Nobody had ever had a rocket engine that operated at the pressures and temperatures of that engine." Because of the necessary lead time needed to develop the world's first reusable rocket engine, the selection of the Space Shuttle Main Engines contractor preceded other Orbiter decisions, but a contract protest delayed development by 10 months. Work on the engines officially began in April 1972.

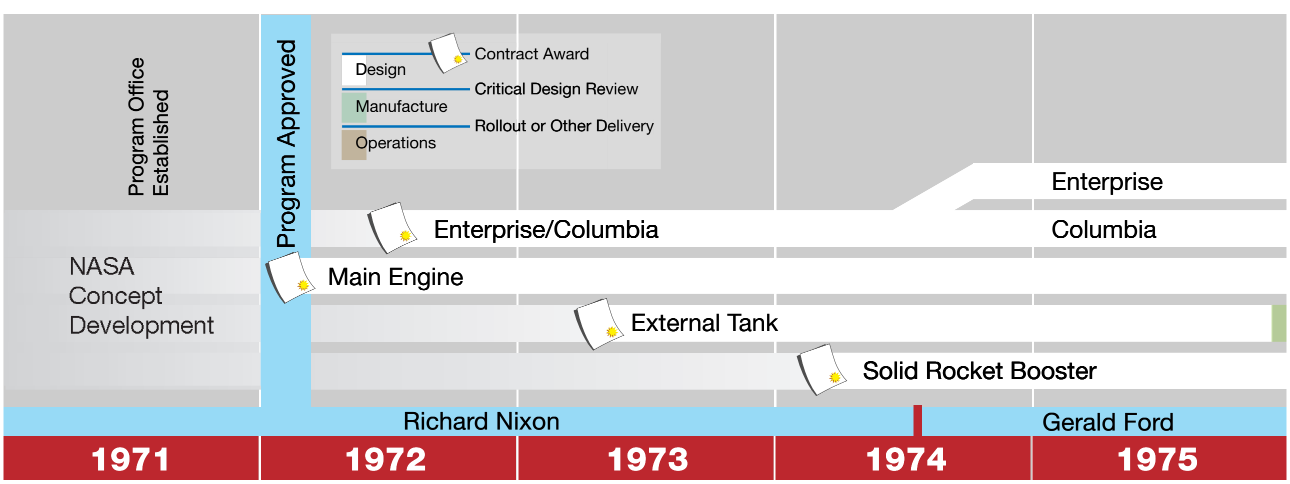
Other large companies benefiting from congressional approval of the Space Shuttle Program included International Business Machines, Martin Marietta, and Thiokol. The computer giant International Business Machines would provide five on-board computers, design and maintain their software, and support testing in all ground facilities that used the flight software and general purpose computers, including the Shuttle Avionics Integration Laboratory, the Shuttle Mission Simulator, and other facilities. Thiokol received the contract for the solid rockets, and NASA selected Martin Marietta to build the External Tank. Although Rockwell received the contract for the Orbiter, the corporation parceled out work to other rival aerospace companies: Grumman built the wings; Convair Aerospace agreed to build the mid-fuselage; and McDonnell Douglas managed the Orbiter rocket engines, which maneuvered the vehicle in space.

Delays and Budget Challenges

Although NASA received approval for the program in 1972, inflation and budget cuts continually ate away at funding throughout the rest of the decade. Over time, this resulted in slips in the schedule as the agency had to make do with effectively fewer dollars each year and eventually cut or decrease spending for less-prominent projects, or postpone them. This also led to higher total development costs. Technical problems with the tiles, Orbiter heat shield, and main engines also resulted in delays, which caused development costs to increase. As a result, NASA kept extending the first launch date.

The shuttle continued to evolve as engineers worked to shave weight from the vehicle to save costs. In 1974, engineers decided to remove the shuttle's air-breathing engines, which would have allowed a powered landing of the vehicle. The engines were to be housed in the payload bay and would have cost more than $300 million to design and build, but

The Space Shuttle Main Engines were the first rocket engines to be reused from one mission to the next. This picture is of Engine 0526, tested on July 7, 2003. A remote camera captures a close-up view of a Space Shuttle Main Engine during a test firing at the John C. Stennis Space Center in Hancock County, Mississippi.



they took up too much space in the bay and added substantial complexity to the design. Thus, the agency decided to go forward with the idea of an unpowered landing to glide the Orbiter and crew safely to a runway.

This decision posed an important question for engineers: how to bring the Orbiter from California, where Rockwell was building it, to the launch sites in Florida, Vandenberg Air Force Base, or test sites in Alabama. NASA considered several options: hanging the Orbiter from a dirigible; carrying the vehicle on a ship; or modifying a Lockheed C-5A or a Boeing 747 to ferry the Orbiter in a piggyback configuration on the back of the plane. Eventually, NASA selected the 747 and purchased a used plane from American Airlines in 1974 to conduct a series of tests before transforming the plane into the Shuttle Carrier Aircraft. Modifications of the 747 began in 1976.

Final Testing

Rollout

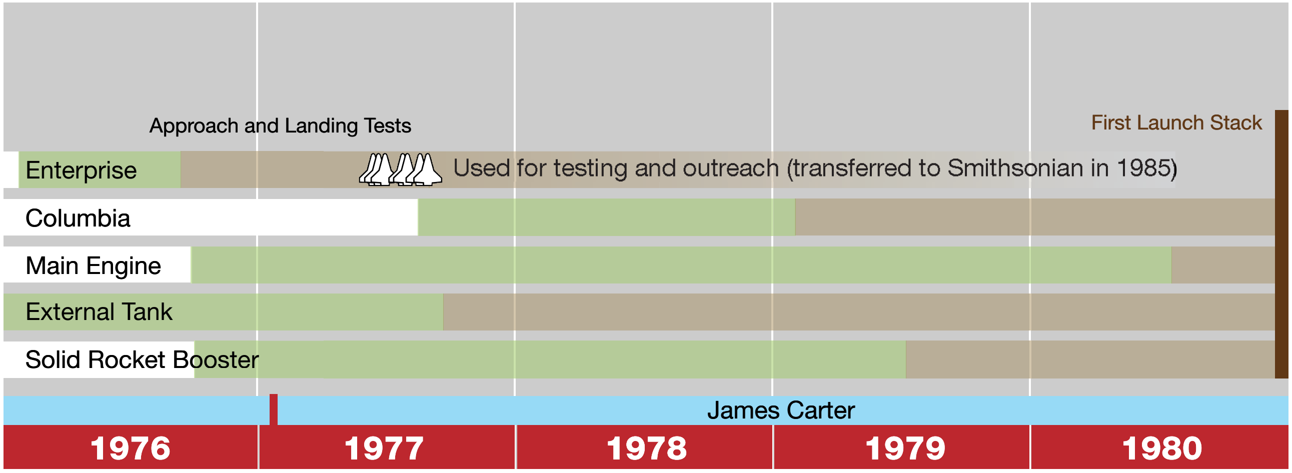
On September 17, 1976, Americans got an initial glimpse of NASA's first shuttle, the Enterprise, when a red, white, and blue tractor pulled the glider out of the hangar at the Air Force Plant in Palmdale, California. Enterprise was not a complete shuttle: it had no propellant lines and the propulsion systems (the main engines and orbital maneuvering pods) were mock-ups. Originally, NASA intended to name the vehicle Constitution in honor of the bicentennial of the United States, but fans of the television show *Star Trek* appealed to NASA and President Gerald Ford, who eventually relented and decided to name the shuttle after Captain Kirk's spaceship. Speaking at the unveiling, Fletcher proclaimed that the debut was "a very proud moment" for NASA. He emphasized the dramatic changes brought about by the program: "Americans and the people of the world have made the evolution to man in space—not just astronauts." The rollout of Enterprise marked the beginning of a new era in spaceflight, one in which all could participate.

In fact, earlier that summer, the agency had issued a call for a new class of astronauts, the first to be selected since the late 1960s when nearly all astronauts were test pilots. A few held advanced degrees in science and medicine, but none were women or minorities. Consequently, NASA emphasized its determination to select people from these groups and encouraged women and minorities to apply.

Approach and Landing Tests

In 1977, Enterprise flew the Approach and Landing Tests at Dryden Flight Research Center using Edwards Air Force Base runways in California. The program was a series of ground and flight tests designed to learn more about the landing characteristics of the Orbiter and how the mated shuttle and its carrier operated together. First, crewless high-speed taxi tests proved that the Shuttle Carrier Aircraft, when mated to the Enterprise, could steer and brake with the Orbiter perched on top of the airframe. The pair, then ready for flight, flew five captive inert flights without astronauts in February and March, which qualified the 747 for ferry operations. Captive-active flights followed in June and July and featured two-man crews.

The final phase was a series of free flights (when Enterprise separated from the Shuttle Carrier Aircraft and landed at the hands of the two-man crews) that flew in 1977, from August to October, and proved the flightworthiness of the shuttle and the techniques of unpowered landings. Most important, the Approach and Landing Tests Program pointed out sections of the Orbiter that needed to be strengthened or made of different materials to save weight.



Enterprise atop the Shuttle Carrier Aircraft in a flight above the Mojave Desert, California (1977).

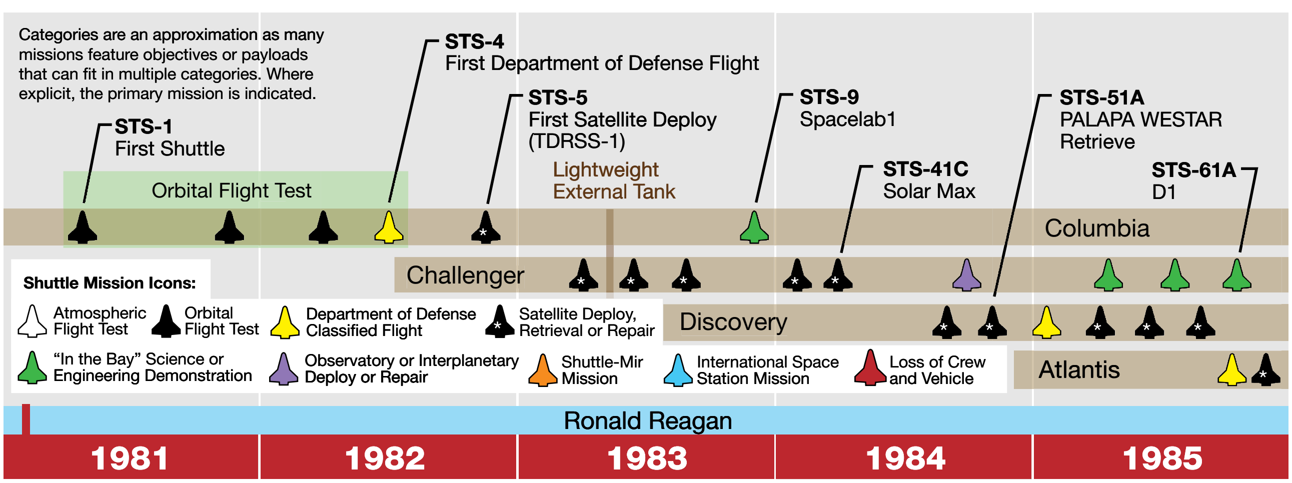
NASA had planned to retrofit Enterprise as a flight vehicle, but that would have taken time and been costly. Instead, the agency selected the other alternative, which was to have the structural test article rebuilt for flight. Eventually called Challenger, this vehicle would become the second Orbiter to fly in space after Columbia. Though Enterprise was no longer slated for flight, NASA continued to use it for a number of tests as the program matured.

Getting Ready to Fly

Concurrent with the Approach and Landing Tests Program, the astronaut selection board in Houston held interviews with 208 applicants selected from more than 8,000 hopefuls. In 1978, the agency announced the first class of Space Shuttle astronauts. This announcement was a historic one. Six women who held PhDs or medical degrees accepted positions along with three African American men and a Japanese American flight test engineer. After completing 1 year of training, the group began following the progress of the shuttle's subsystems, several of which had caused the program's first launch to slip.

The Space Shuttle Main Engines were behind schedule and threatened to delay the first orbital flight, which was tentatively scheduled for March 1979. Problems plagued the engines from the beginning. As early as 1974, the engines ran into trouble as cost overruns threatened the program and delays dogged the modification of facilities in California and the development of key engine components. Test failures occurred at Rocketdyne's California facility and the National Space Technology Laboratory in Mississippi, further delaying development and testing.

Another pacing item for the program was the shuttle's tiles. As Columbia underwent final assembly in California, Rockwell employees began applying the tiles, with the work to be completed in January 1979. Their application was much more time consuming than had been anticipated, and NASA transferred the ship to Kennedy Space Center (KSC) in March, where the task would be completed in the Orbiter Processing Facility and later in the Vehicle Assembly Building. Once in Florida, mating of the tiles to the shuttle ramped up. Unfortunately, engineers found that many of the tiles had to be strengthened. This resulted in many of the 30,000 tiles being removed, tested, and replaced at least once. The bonding process was so time consuming that technicians worked



around the clock, 7 days a week at KSC to meet the launch deadline.

Aaron Cohen, former manager for the Space Shuttle Orbiter Project and JSC director, remembered the stress and pressure caused by the delays in schedule. “I really didn’t know how we were going to solve the tile problem,” he recalled. As the challenges mounted, Cohen, who was under tremendous pressure from NASA, began going gray, a fact that his wife attributed to “every tile it took to put on the vehicle.” Eventually, engineers came up with a solution—a process known as densification, which strengthened the tiles and, according to Cohen, “bailed us out of a major, significant problem” and remained the process throughout the program.

After more than 10 years of design and development, the shuttle appeared ready to fly. In 1979 and 1980, the Space Shuttle Main Engines proved their flightworthiness by completing a series of engine acceptance tests. The tile installation finally ended, and the STS-1 crew members, who had been named in 1978, joked that they were “130% trained and ready to go” because of all the time they spent in the shuttle simulators. Young and Crippen’s mission marked the beginning of the shuttle flight test program.

Spaceflight Operations

Columbia’s First Missions

Columbia flew three additional test flights between 1981 and 1982. These test flights were designed to verify the shuttle in space, the testing and processing facilities, the vehicle’s equipment, and crew procedures. Ground testing demonstrated the capability of the Orbiter, as well as of its components and systems. Without flight time, information about these systems was incomplete. The four tests were necessary to help NASA understand heating, loads, acoustics, and other concepts that could not be studied on the ground.

This test program ended on July 4, 1982, when commander Thomas Mattingly landed the shuttle at Dryden Flight Research Center (DFRC) on the 15,000-ft runway at Edwards Air Force Base in California. Waiting at the foot of the steps, President Reagan and First Lady Nancy Reagan congratulated the STS-4 crew on a job well done. Speaking to a crowd of more than 45,000 people at DFRC, the president said that the completion of this task was “the historical equivalent to the driving of the golden spike which completed the first transcontinental railroad. It marks our entrance into a new era.”

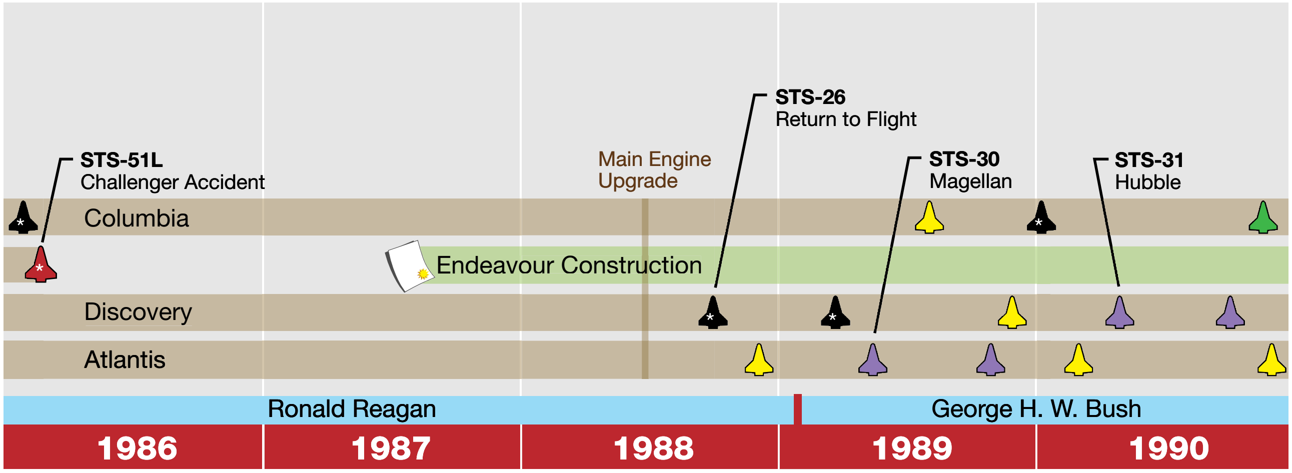
The operational flights, which followed the flight test program, fell into several categories: DoD missions; commercial satellite deployments; space science flights; notable spacewalks (also called extravehicular activities); or satellite repair and retrieval.

To improve costs, beginning in 1983 all launches and landings at KSC were managed by one contractor, Lockheed Space Operations Company, Titusville, Florida. This consolidated many functions for the entire shuttle processing.

Department of Defense Flights

STS-4 (1982) featured the first classified payload, which marked a fundamental shift in NASA’s traditionally open environment. Concerned with national security, the DoD instructed NASA Astronauts Mattingly and Henry Hartsfield to not transmit images of the cargo bay during the flight, lest pictures of the secret payload might inadvertently be revealed. STS-4 did differ somewhat from the other future DoD-dedicated flights: there was no secure communication line, so the crew worked out a system of communicating with the ground.

“We had the checklist divided up in sections that we just had letter names like Bravo Charlie, Tab Charlie, Tab



Bravo that they could call out. When we talked to Sunnyvale [California] to Blue Cube out there, military control, they said, 'Do Tab Charlie,' or something. That way it was just unclassified," Hartsfield recalled. Completely classified flights began in 1985.

Even though Vandenberg Air Force Base had been selected as one of the program launch sites in 1972, the California shuttle facilities were not complete when classified flights began. Anticipating slips, the DoD and NASA decided to implement a controlled mode at JSC and KSC that would give the space agency the capability to control classified flights out of the Texas and Florida facilities. Flight controllers at KSC and JSC used secured launch and flight control rooms separate from the rooms used for non-DoD flights. Modifications were also made to the flight simulation facility, and a room was added in the astronaut office, where flight crew members could store classified documents inside a safe and talk on a secure line.

Although the facilities at Vandenberg Air Force Base were nearly complete in 1984, NASA continued to launch and control DoD flights. Two DoD missions flew in 1985: STS-51C and STS-51J. Each flight included a payload specialist from the Air Force. That year, the department also announced the names of the crew of the first Vandenberg flight, STS-62A, which would have been commanded by veteran Astronaut Robert Crippen, but was cancelled in the wake of the Challenger accident (1986).

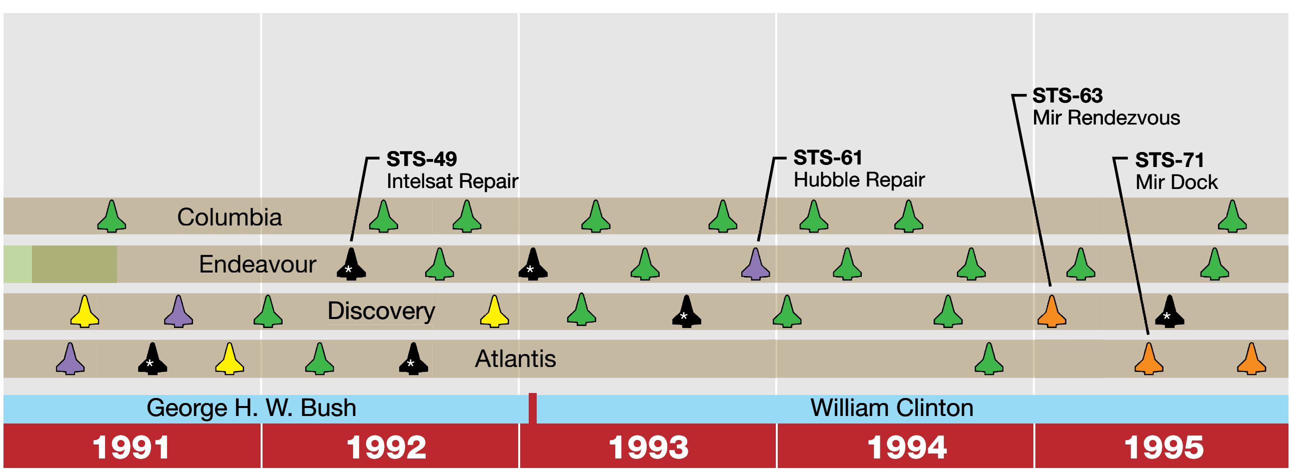
Flying classified flights complicated the business of spaceflight. For national security reasons, the Mission Operations Control Room at JSC was closed to visitors during simulations and these flights. Launch time was not shared with the press and, for the first time in NASA's history, no astronaut interviews were granted about the flight, no press kits were distributed, and the media were prohibited from listening to the air-to-ground communications.

Shuttle Operations, 1982-1986

STS-5 (1982) marked both the beginning of shuttle operations and another turning point in the history of the Space Shuttle Program. As Astronaut Joseph Allen explained, spaceflight changed "from testing the means of getting into space to using the resources found there." Or, put another way, this four-member crew (the largest space crew up to that point; the flight tests never carried more than two men at a time) was the first to launch two commercial satellites. This "initiated a new era in which the business of spaceflight became business itself." Dubbed the "Ace Moving Company," the crew jokingly promised "fast and courteous service" for its future launch services.

Many of the early shuttle flights were, in fact, assigned numerous commercial satellites, which they launched from the Orbiter's cargo bay. With NASA given a monopoly in the domestic launch market, many flight crews released at least one satellite on each flight, with several unloading as many as three communication satellites for a number of nations and companies. Foreign clients, particularly attracted to NASA's bargain rates, booked launches early in the program.

Another visible change that occurred on this, the fifth flight of Columbia was the addition of mission specialists—scientists and engineers—whose job it was to deploy satellites, conduct spacewalks, repair and retrieve malfunctioning satellites, and work as scientific researchers in space. The first two mission specialists—Joseph Allen, a physicist, and William Lenoir, an electrical engineer—held PhDs in their respective fields and had been selected as astronauts in 1967. Those who followed in their footsteps had similar qualifications, often holding advanced degrees in their fields of study.



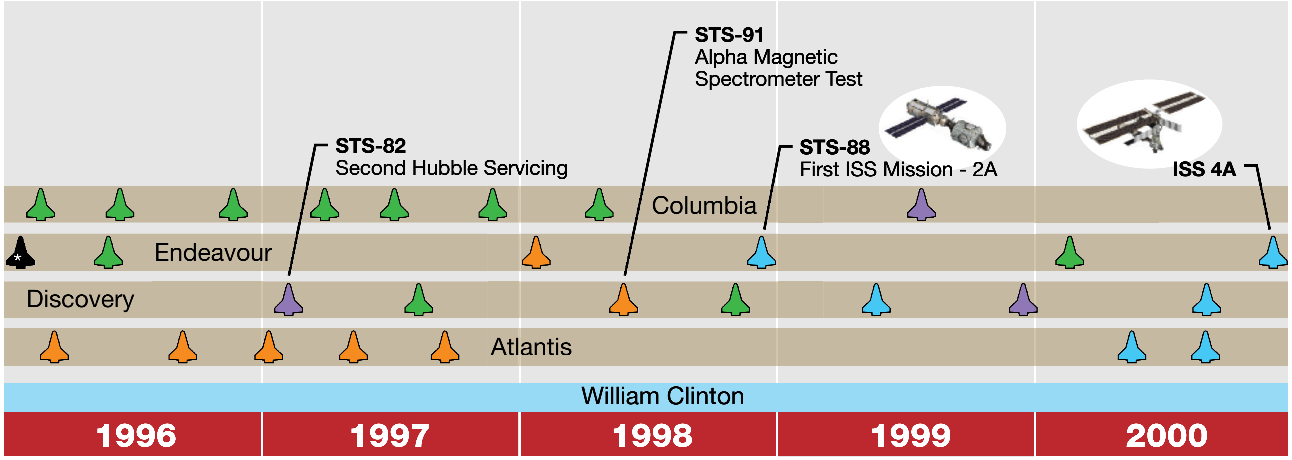
Christopher Kraft
Director of Johnson Space Center during shuttle development and early launches (1972-1982).
Played an instrumental role in the development and establishment of mission control.

"We went through a lot to prove that we should launch STS-1 manned instead of unmanned; it was the first time we ever tried to do anything like that. We convinced ourselves that the reliability was higher and the risk lower, even though we were risking the lives of two men. We convinced ourselves that that was a better way to do it, because we didn't know what else to do. We had done everything we could think of."

With the addition of mission specialists and the beginning of operations, space science became a major priority for the shuttle, and crews turned their attention to research. A variety of experiments made their way on board the shuttle in Get Away Specials, the Shuttle Student Involvement Project, the middeck (crew quarters), pallets (unpressurized platforms designed to support instruments that require direct exposure to space), and Spacelabs. Medical doctors within NASA's own Astronaut Corps studied space sickness on STS-7 (1983) and STS-8 (1983), subjecting their fellow crew members to a variety of tests in the middeck to determine the triggers for a problem that plagues some space travelers. Aside from medical experiments, many of the early missions included a variety of Earth observation instruments. The crews spent time looking out the window, identifying and photographing weather patterns, among other phenomena. A number of flights featured material science research, including STS-61C (1986), which included Marshall Space Flight Center's Material Science Laboratory.

As space research expanded, so did the number of users, and the aerospace industry was not excluded from this list. They were particularly active in capitalizing on the potential benefits offered by the shuttle and its platform as a research facility. Having signed a Joint Endeavor Agreement (a quid pro quo arrangement, where no money exchanged hands) with NASA in 1980, McDonnell Douglas Astronautics flew its Continuous Flow Electrophoresis System on board the shuttle numerous times to explore the capabilities of materials processing in space. The system investigated the ability to purify erythropoietin (a hormone) in orbit and to learn whether the company could mass produce the purified pharmaceutical in orbit. The company even sent one of its employees—who, coincidentally, was the first industrial payload specialist—into space to monitor the experiment on board three flights, including the maiden flight of Discovery. Other companies, like Fairchild Industries and 3M, also signed Joint Endeavor Agreements with NASA.

When the ninth shuttle flight lifted off the pad in November 1983, Columbia had six passengers and a Spacelab in its payload bay. This mission, the first flight of European lab, operated 24 hours a day, featured more than 70 experiments,



William Lucas, PhD
Former director of Marshall Space Flight Center during shuttle operations until Challenger accident (1974-1986).
Played an instrumental role in Space Shuttle Main Engine, External Tank, and Solid Rocket Booster design, development, and operations.

On October 11, 1974, newly appointed Marshall Space Flight Center (MSFC) Director Dr. William Lucas (right) and a former MSFC Director Dr. Wernher von Braun view a model.

"The shuttle was an important part of the total space program and it accomplished, in a remarkable way, the unique missions for which it was designed. In addition, as an element of the continuum from the first ballistic missile to the present, it has been a significant driver of technology for the benefit of all mankind."

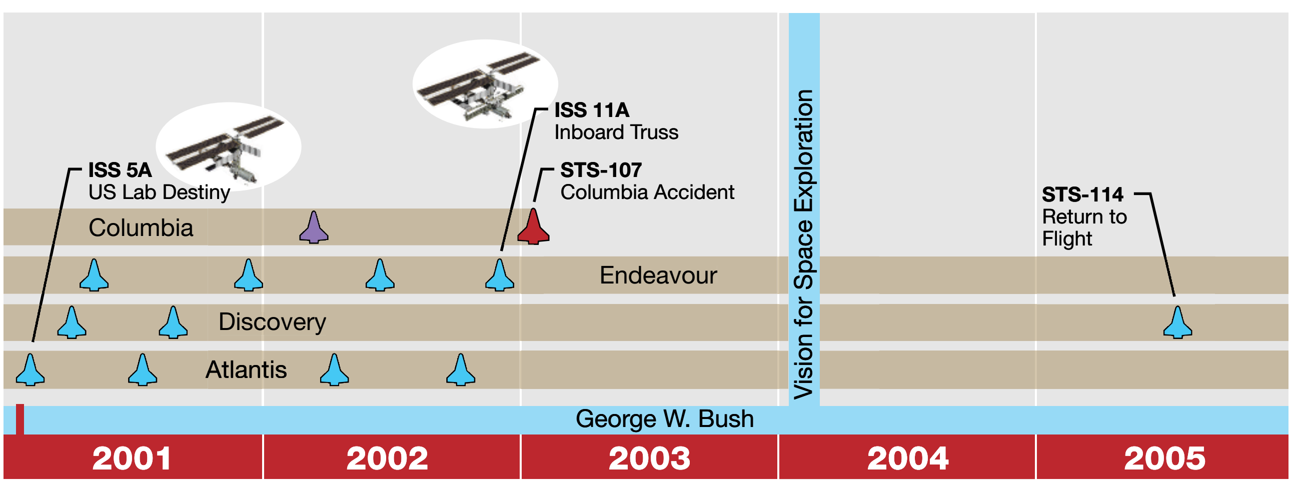
and carried the first noncommercial payload specialists to fly in space.

Three additional missions flew Spacelabs in 1985, with West Germany sponsoring the flight of STS-61A, the first mission financed and operated by another nation. One of the unique features of this flight was how control was split between centers. JSC's Mission Control managed the shuttle's systems and worked closely with the commander and pilot while the German Space Operations Center in Oberpfaffenhofen oversaw the experiments and scientists working in the lab.

By 1984, the shuttle's capabilities expanded dramatically when Astronauts Bruce McCandless and Bob Stewart tested the manned maneuvering units that permitted flight crews to conduct untethered spacewalks. At this point in the program, this was by far the most demanding spacewalk conducted by astronauts. The first spacewalk, conducted just months before the flight of STS-41B, tested the suits and the capability of astronauts to work in the payload bay. As McCandless flew the unit out of the cargo bay for the first time, he said, "It may have been one small step for Neil, but it's a heck of a big leap for me." Set against the darkness of space, McCandless became the first human satellite in space. Having proved the capabilities of the manned maneuvering unit, NASA exploited its capabilities and used the device to make satellite retrieval and repair possible without the use of the Shuttle Robotic Arm.

Early Satellite Repair and Retrievals

Between 1984 and 1985, the shuttle flew three complicated satellite retrieval or repair missions. On NASA's 11th shuttle mission, STS-41C, the crew was to capture and repair the Solar Maximum Satellite (SolarMax), the first one built to be serviced and repaired by shuttle astronauts. Riding the manned maneuvering unit, spacewalker George Nelson tried to capture the SolarMax, but neither he nor the Robotic Arm operator Terry Hart was able to do so. Running low on fuel, the crew backed away from the satellite while folks at the Goddard Space Flight Center in



Maryland stabilized the SolarMax. The shuttle had just enough fuel for one more rendezvous with the satellite. Fortunately, Hart was able to grapple the satellite, allowing Nelson and James van Hoften to fix the unit, which was then rereleased into orbit.

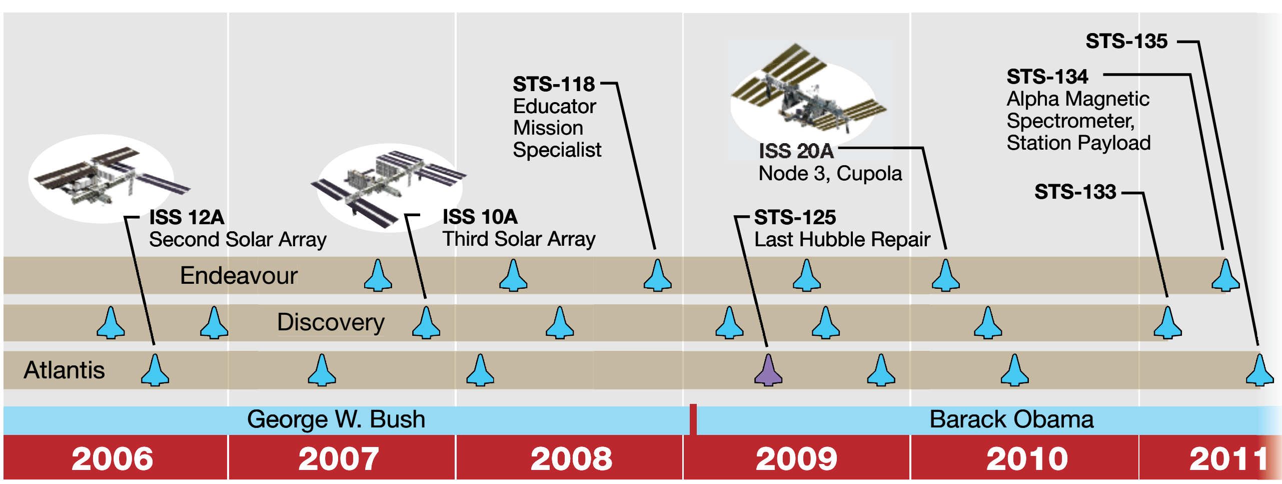
The following retrieval mission was even more complex. STS-51A was the first mission to deploy two satellites and then retrieve two others that failed to achieve their desired orbits. Astronauts Joseph Allen and Dale Gardner used the manned maneuvering unit to capture Palapa and Westar, originally deployed on STS-41B 9 months earlier. They encountered problems, however, when stowing the first recovered satellite, forcing Allen to hold the 907-kg (2,000-pound) satellite over his head for an entire rotation of the Earth—90 minutes. When the crew members reported that they had captured and secured both satellites in Discovery's payload bay, Lloyd's of London—one of the underwriters for the satellites—rang the Lutine bell, as they had done since the 1800s, to announce events of importance. As Cohen, former director of JSC, explained, "Historically Lloyd's of London, who would insure high risk adventures, rang a bell whenever ships returned to port with recovered treasure from the sea." He added that the salvage of these satellites in 1984 "was at that time the largest monetary treasure recovered in history."

The program developed a plan for the crew of STS-51I (1985) to retrieve and repair a malfunctioning Hughes satellite that had failed to power up just months before the flight. With only 4 months to prepare, NASA built a number of tools that had not been tested in space to accomplish the crew's goal. In many ways, the crew's flight was a first. Van Hoften, one of the walkers on STS-41C, recalled the difference between his first and second spacewalk: "It wasn't anything like the first one. The first one was so planned out and choreographed. This one, we were winging it, really." Instead of planning their exact moves, crew members focused instead on skills and tasks. Their efforts paid off when the ground activated the satellite.

Space Station Reemerges

As the Space Shuttle Program matured, NASA began working on the Space Station Program, having been directed to do so by President Reagan in his 1984 State of the Union address. The shuttle would play an important role in building the orbiting facility. In the winter of 1985, STS-61B tested structures and assembly methods for the proposed long-duration workshop. Spacewalkers built a 13.8-m (45-ft) tower and a 3.7-m (12-ft) structure, proving that crews could feasibly assemble structures using parts carried into space by the Orbiter. NASA proceeded with plans to build Space Station Freedom, which in the 1990s was transformed to the International Space Station (ISS).

To fund the space station, NASA needed to cut costs for shuttles by releasing requests for proposals for three new contracts. In 1983, the Shuttle Processing Contract integrated all processing at KSC. Lockheed Space Operations Company received this contract. In 1985, the Space Transportation Systems Operations Contract and the Flight Equipment Contract were solicited. The former contract consolidated 22 shuttle operations contracts, while the latter combined 15 agreements involving spaceflight equipment (e.g., food, clothes, and cameras). NASA Administrator James Beggs hoped that by awarding such contracts, he could reduce shuttle costs by as much as a quarter by putting cost incentives into the contracts. Rockwell International won the Space Transportation Systems Operations Contract, and NASA chose Boeing Aerospace Operations to manage the Flight Equipment Processing Contract.



Challenger Accident

In January 1986, NASA suspended all shuttle flights after the Challenger accident in which seven crew members perished. A failure in the Solid Rocket Booster motor joint caused the vehicle to break up. The investigation board was very critical of NASA management, especially about the decision to launch. For nearly 3 years, NASA flew no shuttle flights. Instead, the agency made changes to the shuttle. It added a crew escape system and new brakes, improved the main engines, and redesigned the Solid Rocket Boosters, among other things.

In the aftermath of the accident, the agency made several key decisions, which were major turning points. The shuttle would no longer deliver commercial satellites into Earth orbit unless "compelling circumstances" existed or the deployment required the unique capabilities of the space truck. This decision forced industry and foreign governments who hoped to deploy satellites from the shuttle to turn to expendable launch vehicles. Fletcher, who had returned for a second term as NASA administrator, cancelled the Shuttle/Centaur Program because it was too risky to launch the shuttle carrying a rocket with highly combustible liquid fuel. Plans to finally activate and use the Vandenberg Air Force Base launch site were abandoned, and the shuttle launch site was eventually mothballed. The Air Force decided to launch future payloads on Titan rockets and ordered additional expendable launch vehicles. A few DoD-dedicated missions would, however, fly after the accident. Finally, in 1987, Congress authorized the building of Endeavour as a replacement for the lost Challenger. Endeavour was delivered to KSC in the spring of 1991.

Post-Challenger Accident Return to Flight

STS-26 was the Space Shuttle's Return to Flight. Thirty-two months after the Challenger accident, Discovery roared to life on September 29, 1988, taking its all-veteran crew into space where they deployed the second Tracking and Data Relay Satellite. The crew safely returned home to DFRC 4 days later, and Vice President George H.W. Bush and his wife Barbara Bush greeted the crew. That mission was a particularly significant accomplishment for NASA. STS-26 restored confidence in the agency and marked a new beginning for NASA's human spaceflight program.

Building Momentum

Following the STS-26 flight, the shuttle's launch schedule climbed once again, with the space agency eventually using all three shuttles in the launch processing flow for upcoming missions. The first four flights after the accident alternated between Discovery and Atlantis, adding Columbia to the mix for STS-28 (1989). Even though the flight crews did not launch any commercial satellites from the payload bay, several deep space probes—the Magellan Venus Radar Mapper, Galileo, and Ulysses—required the shuttle's unique capabilities. STS-30 (1989) launched the mapper, which opened a new era of exploration for the agency. This was the first time a Space Shuttle crew deployed an interplanetary probe, thereby interlocking both the manned and unmanned spaceflight programs. In addition, this flight was NASA's first planetary mission of any kind since 1977, when it launched the Voyager spacecraft. STS-34 (1989) deployed the Galileo spacecraft toward Jupiter. Finally, STS-41 (1990) delivered the European Space Agency's Ulysses spacecraft, which would study the polar regions of the sun.

Astronaut James Voss is pictured during an STS-69 (1995) extravehicular activity that was conducted in and around Endeavour's cargo bay. Voss and Astronaut Michael Gernhardt performed evaluations for space station-era tools and various elements of the spacesuits.

Extended Duration Orbiter Program

Before 1988, shuttle flights were short, with limited life science research. NASA thought that if the shuttle could be modified, it could function as a microgravity laboratory for weeks at a time. The first stage was to make modifications to the life support, air, water, and waste management systems for up to a 16-day stay. There were potential drawbacks to extended stays in microgravity. Astronauts were concerned about the preservation of their capability for unaided egress from the shuttle, including the capability for bailout. Another concern was degradation of landing proficiency after such a long stay, as this had never been done before.

Between 1992 (STS-50) and 1995, this program successfully demonstrated that astronauts could land and egress after such long stays, but that significant muscle degradation occurred. The addition of a new pressurized g-suit provided relief to the light-headedness (feeling like fainting) experienced when returning to Earth. Improvements included the addition of a crew transport vehicle that astronauts entered directly from the landed shuttle in which they reclined during medical examination until they were ready to walk. On-orbit exercise was tested to improve their physical capabilities for emergency egress and landing. The research showed that with more than 2 weeks of microgravity, astronauts probably should not land the shuttle as it was too complicated and risky. In the future, shuttle landing would only be performed by a short-duration astronaut.

The Great Observatories

Months before the Ulysses deployment, the crew of STS-31 (1990) deployed the Hubble Space Telescope, which had been slated for launch in August 1986 but slipped to 1990 after the Challenger accident. Weeks before the launch, astronauts and NASA administrators laid out the importance of the flight. Lennard Fisk, NASA's associate administrator for Space Science and Applications, explained, "This is a mission from which (people) can expect very fundamental discoveries. They could begin to understand creation. Hubble could be a turning point in humankind's perception of itself and its place in the universe."

Unfortunately, within just a few short months NASA discovered problems with the telescope's mirror—problems that generated a great deal of controversy. Several in Congress believed that the telescope was a colossal waste of money. Only 4 years after the accident, NASA's morale plunged again. Fortunately, the flight and ground crews, along with employees at Lockheed Martin, took the time to work out procedures to service the telescope in orbit during the flight hiatus. In 1992, NASA named the crew that would take on this challenge. The astronauts assigned to repair the telescope felt pressure to succeed. "Everybody was looking at the servicing and repair of the Hubble Space Telescope as the mission that could prove NASA's worth," Commander Dick Covey recalled. The mission was one of the most sophisticated ever planned at NASA. The spacewalkers rendezvoused for the first time with the telescope, one of the largest objects the shuttle had rendezvoused with at that point, and conducted a record-breaking five spacewalks. The repairs were successful, and the public faith rebounded. Four additional missions serviced the Hubble, with the final launching in 2009.

Two other major scientific payloads, part of NASA's Great Observatories including the Compton Gamma Ray Observatory and the Chandra X-ray Observatory, launched from the Orbiter's cargo bay. When the Compton Gamma Ray Observatory's high-gain antenna failed to deploy, Astronauts Jerry Ross and Jay Apt took the first spacewalk in 6 years (the last walk occurred in 1985) and freed the antenna. The crew of STS-93, which featured NASA's first female mission commander, Eileen Collins, delivered the Chandra X-ray Observatory to Earth orbit in 1999.

Satellite Retrieval and Repair

Satellite retrieval and repair missions all but disappeared from the shuttle manifest after the Challenger accident. STS-49 (1992) was the one exception. An Intelsat was stranded in an improper orbit for several years, and spacewalkers from STS-49 were to attach a new kick-start motor to it. The plan seemed simple enough. After all, NASA had plenty of practice capturing ailing satellites. After two unsuccessful attempts, flight controllers developed a plan that required a three-person spacewalk, a first in the history of NASA's space operations. This finally allowed the crew to repair and redeploy the satellite, which occurred—coincidentally—during Endeavour's first flight.

New Main Engine

STS-70 flew in the summer of 1995 and launched a Tracking and Data Relay Satellite. The shuttle flew the new main engine, which contained an improved high-pressure liquid oxygen turbopump, a two-duct powerhead, and a single-coil heat exchanger. The new pumps were a breakthrough in shuttle reliability and quality, for they were much safer than those previously used on the Orbiter. The turbopumps required less maintenance than those used prior to 1995. Rather than removing each pump after every flight, engineers would only have to conduct detailed inspections of the pumps after six missions. A single-coil heat exchanger eliminated many of the welds that existed in the previous pump, thereby increasing engine reliability, while the powerhead enhanced the flow of fuel in the engine.

Space Laboratories

NASA continued to fly space laboratory missions until 1998, when Columbia launched the final laboratory and crew into orbit for the STS-90 mission. The shuttle had two versions of the payload bay laboratory: European Spacelab and US company Spacehab, Inc. Fifteen years had passed since the flight of STS-9—the first mission—and the project ended with the launch of Neurolab, which measured the impact of microgravity on the nervous system: blood pressure; eye-hand coordination; motor coordination; sleep patterns; and the inner ear. Scientists learned a great deal from Spacelab Life Sciences-1 and -2 missions, which flew in the summer of 1991 and 1993, respectively, and represented a turning point in spaceflight human physiology research. Previous understandings of how the human body worked in space were either incomplete or incorrect. The program scientist for the flight explained that the crew obtained "a significant number of surprising results" from the flight.

Other notable flights included the ASTRO-1 payload, which featured four telescopes designed to measure ultraviolet light from astronomical objects, life sciences missions, the US Microgravity Labs, and even a second German flight called D-2. The day before the crew of D-2 touched down at DFRC on an Edwards Air Force Base runway, the Space Shuttle Program reached a major milestone, having accrued a full year of flight time by May 5, 1993.

Spacehab, a commercially provided series of modules similar to Spacelab and used for science and logistics, was a significant part of the shuttle manifest in the 1990s. One of those Spacehab flights featured the return of Mercury 7 Astronaut and US Senator John Glenn, Jr. Thirty-six years had passed since he had flown in space and had become the first American to fly in Earth orbit. He broke records again in 1998 when he became the oldest person to fly in space. Given his age, researchers hoped to compare the similarities between aging on Earth with the effects of microgravity on the human body. Interest in this historic flight, which also fell on NASA's 40th anniversary, was immense. Not only was Glenn returning to orbit, but Pedro Duque—a European Space Agency astronaut—became the first Spanish astronaut, following in the footsteps of Spanish explorers Hernán Cortés and Francisco Pizarro.

US Senator John Glenn, Jr., payload specialist, keeps up his busy test agenda during Flight Day 7 on board Discovery STS-95 in 1998. This was a Spacehab flight that studied the effect of microgravity on human physiology. He is preparing his food, and on the side is the bar code reader used to record all food, fluids, and drug intakes.

Consolidating Contracts

The Space Shuttle Program seemed to hit its stride in the 1990s. In 1995, NASA decided to consolidate 12 individual contracts under a single prime contractor. United Space Alliance (USA), a hybrid venture between Rockwell International and Lockheed Martin, became NASA's selection to manage the space agency's Space Flight Operations Contract. USA was the obvious choice because those two companies combined held nearly 70% of the dollar value of prime shuttle contracts. Although the idea of handing over all processing and launch operations to a contractor was controversial, NASA Administrator Daniel Goldin, known for his "faster, better, cheaper" mantra, enthusiastically supported the sole source contract as part of President William Clinton's effort to trim the federal budget and increase efficiency within government. NASA awarded USA a $7 billion contract, which went into effect on October 1, 1996. Speaking at JSC about the agreement, Goldin proclaimed, "Today is the first day of a new space program in America. We are opening up the space program to commercial space involving humans. May it survive and get stronger."

STS-80, the first mission controlled by USA, launched in November 1996. The all-veteran crew, on the final flight of the year and the 80th of the program, stayed in space for a record-breaking 17 days. A failure with the hatch prohibited crew members from conducting two scheduled spacewalks, but NASA considered the mission a success because the crew brought home more scientific data than they had expected to gather with the Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite-II.

The Shuttle-Mir Program

As the Cold War (the Soviet-US conflict between the mid 1940s and early 1990s) ended, the George H.W. Bush administration began laying the groundwork for a partnership in space between the United States and the Soviet Union. Following the collapse of the Soviet Union in 1991, President Bush and Russian President Boris Yeltsin signed a space agreement, in June 1992, calling for collaboration between the two countries in space. They planned to place American astronauts on board the Russian space station Mir and to take Russian cosmonauts on board shuttle flights. Noting the historic nature of the agreement, Goldin said, "Our children and their children will look upon yesterday and today as momentous events that brought our peoples together." This agreement brokered a new partnership between the world's spacefaring nations, once adversaries.

Known as the Shuttle-Mir Program, these international flights were the first phase of the ISS Program and marked a turning point in history. The Shuttle-Mir Program—led from JSC, with its director George Abbey—was a watershed and a symbol of the thawing of relations between the United States and Russia.

For more than 4 years, from the winter of 1994 to the summer of 1998, nine shuttle flights flew to the Russian space station, with seven astronauts living on board the Mir for extended periods of time. The first phase began when Cosmonaut Sergei Krikalev flew on board STS-60 (1994).

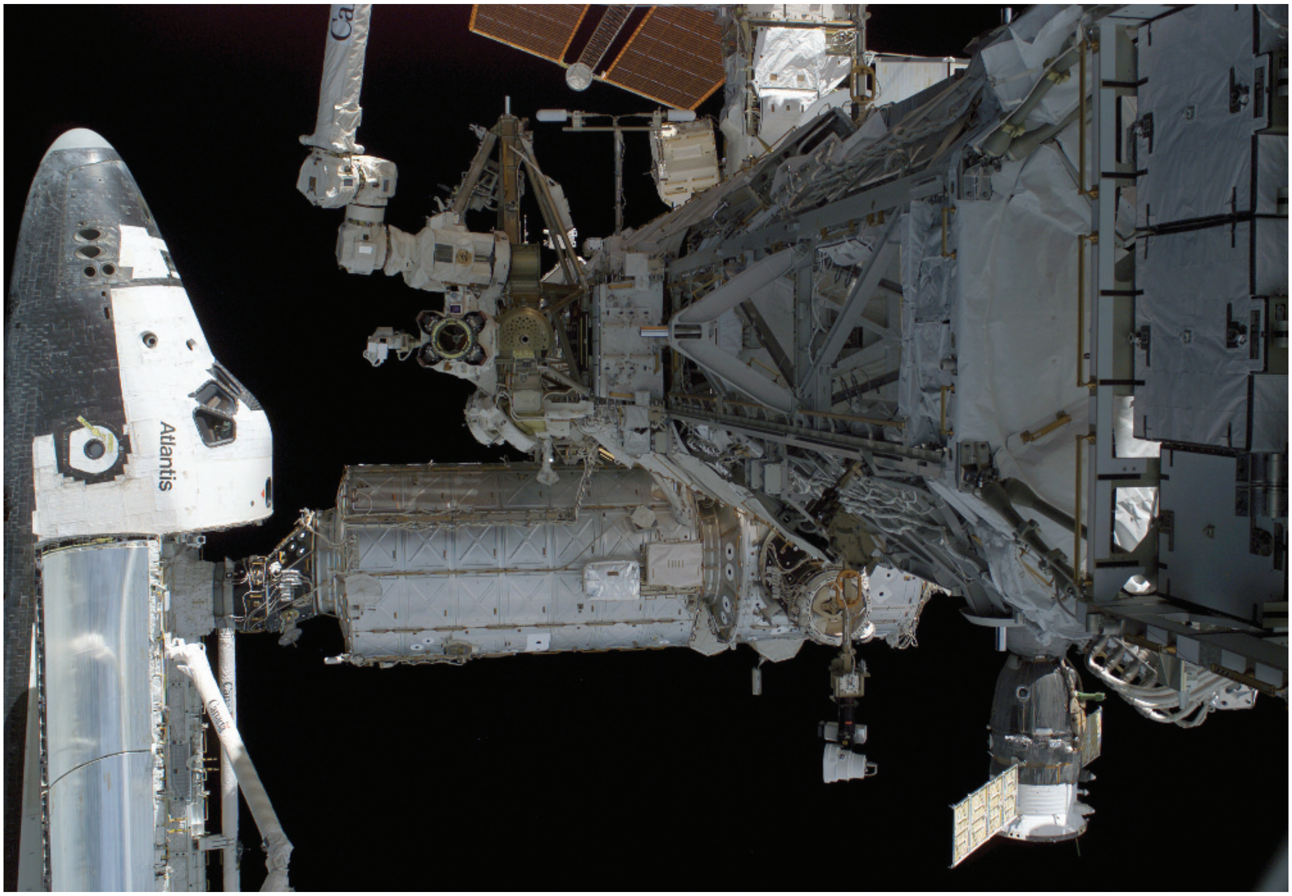
Twenty years had passed since the Apollo-Soyuz Test Project when, in the summer of 1995, Robert Gibson made history when he docked Atlantis to the much-larger Mir. The STS-71 crew members exchanged gifts and shook hands with the Mir commander in the docking tunnel that linked the shuttle and the Russian station. They dropped off the next Mir crew and picked up two cosmonauts and America's first resident of Mir, Astronaut Norman Thagard. Additional missions ferried crews and necessary supplies to Mir. One of the major milestones of the program was the STS-74 (1995) mission, which delivered and attached a permanent docking port to the Russian space station.

In 1996, Astronaut Shannon Lucid broke all American records for time in orbit and held the flight endurance record for all women, from any nation, when she stayed on board Mir for 188 days. Clinton presented Lucid with the Congressional Space Medal of Honor for her service, representing the first time a woman or scientist had received this accolade. Speaking about the importance of the Shuttle-Mir Program, the president said, "Her mission did much to cement the alliance in space we have formed with Russia. It demonstrated that, as we move into a truly global society, space exploration can serve to deepen our understanding, not only of our planet and our universe, but of those who share the Earth with us."

STS-91 (1998), which ended shuttle visits to Mir, featured the first flight of the super-lightweight External Tank. Made of aluminum lithium, the newly designed tank weighed 3,402 kg (7,500 pounds) less than the previous tank (the lightweight or second-generation tank) used on the previous flight, but its metal was stronger than that flown prior to the summer of 1998. By removing so much launch weight, engineers expanded the shuttle's ability to carry heavier payloads, like the space station modules, into Earth's orbit. Launching with less weight also enabled the crew to fly to a high inclination orbit of 51.6 degrees, where NASA and its partners would build the ISS. STS-91 also carried a prototype of the Alpha Magnetic Spectrometer into space. This instrument was designed to look for dark and missing matter in the universe. The preliminary test flight was in preparation for its launch to the ISS on STS-134. The Alpha Magnetic Spectrometer has a state-of-the-art particle physics detector, and includes the participation of 56 institutions and 16 countries led by Nobel Laureate Samuel Ting. By the end of the Shuttle-Mir Program, the number of US astronauts who visited the Russian space station exceeded the number of Russian cosmonauts who had worked aboard Mir.

The International Space Station

With the first phase completed, NASA began constructing the ISS with the assistance of shuttle crews, who played an integral role in building the outpost. In 1998, 13 years after spacewalker Jerry Ross demonstrated the feasibility of assembling structures in space (STS-61B [1985]), ISS construction began. During three spacewalks, Ross and James Newman connected electrical power and cables between the Russian Zarya module and America's Unity Module, also called Node 1. They installed additional hardware—handrails and antennas—on the station. NASA's dream of building a space station had finally come to fruition.



Although no astronauts are visible in this picture, action was brisk outside the Space Shuttle (STS-116)/space station tandem in 2006.

The shuttle's 100th mission (STS-92) launched from KSC in October 2000, marking a major milestone for the Space Shuttle and the International Space Station Programs. The construction crew delivered and installed the initial truss—the first permanent latticework structure—which set the stage for the future addition of trusses. The crew also delivered a docking port and other hardware to the station. Four spacewalkers spent more than 27 hours outside the shuttle as they reconfigured these new elements onto the station. The seven-member crew also prepared the station for the first resident astronauts, who docked with the station 14 days after the crew left the orbital workshop. Of the historic mission, Lead Flight Director Chuck Shaw said, "STS-92/ISS Mission 3A opens the next chapter in the construction of the International Space Station," when human beings from around the world would permanently occupy the space base.

Crews began living and working in the station in the fall of 2000, when the first resident crew (Expedition 1) of Sergei Krikalev, William Shepherd, and Yuri Gidzenko resided in the space station for 4 months. For the next 3 years, the shuttle and her crews were the station's workhorse. They transferred crews; delivered supplies; installed modules, trusses, the Space Station Robotic Arm, an airlock, and a mobile transporter, among other things. By the end of 2002, NASA had flown 16 assembly flights. Flying the shuttle seemed fairly routine until February 2003, when Columbia disintegrated over East Texas, resulting in the loss of the shuttle and her seven-member crew.

Columbia Accident

The cause of the Columbia accident was twofold. The physical cause resulted from the loss of insulating foam from the External Tank, which hit the Orbiter's left wing during launch and created a hole. When Columbia entered the Earth's atmosphere, the left wing leading edge thermal protection (reinforced carbon-carbon panels) was unable to prevent heating due to the breach. This led to the loss of control and disintegration of the shuttle, killing the crew. NASA's flawed culture of complacency also bore responsibility for the loss of the vehicle and its astronauts. All flights were put on hold for more than 2 years as NASA implemented numerous safety improvements, like redesigning the External Tank with an improved bipod fitting that minimized potential foam debris from the tank. Other improvements were the Solid Rocket Booster Bolt Catcher, impact sensors added to the wing's leading edge, and a boom for the shuttle's arm that allowed the crew to inspect the vehicle for any possible damage, among other things.

As NASA worked on these issues, President George W. Bush announced his new Vision for Space Exploration, which included the end of the Space Shuttle Program. As soon as possible, the shuttles would return to flight to complete the ISS by 2010 and then NASA would retire the fleet.

Post-Columbia Accident Return to Flight

In 2005, STS-114 returned NASA to flying in space. Astronaut Eileen Collins commanded the first of two Return to Flight missions, which were considered test flights. The first mission tested and evaluated new flight safety procedures as well as inspection and repair techniques for the vehicle. One of the changes was the addition of an approximately 15-m (50-ft) boom to the end of the robotic arm. This increased astronauts' capabilities to inspect the tile located

Leroy Chiao, PhD
Astronaut on STS-65 (1994), STS-72 (1996), and STS-92 (2000). Commander and science officer on ISS Expedition 10 (2004-2005).

"To me, the Space Shuttle is an amazing flying machine. It launches vertically as a rocket, turns into an extremely capable orbital platform for many purposes, and then becomes an airplane after re-entry into the atmosphere for landing on a conventional runway. Moreover, it is a reusable vehicle, which was a first in the US space program.

"The Space Shuttle Program presented me the opportunity to become a NASA astronaut and to fly in space. I never forgot my boyhood dream and years later applied after watching the first launch of Columbia. In addition to being a superb research and operations platform, the Space Shuttle also served as a bridge to other nations. Never before had foreign nationals flown aboard US spacecraft. On shuttle, the US had flown representatives from nations all around the world. Space is an ideal neutral ground for cooperation and the development of better understanding and relationships between nations.

"Without the Space Shuttle as an extravehicular activity test bed, we would not have been nearly as successful as we have been so far in assembling the ISS. The Space Shuttle again proved its flexibility and capability for ISS construction missions.

"Upon our landing (STS-92), I realized that my shuttle days were behind me. I was about to begin training for ISS. But on that afternoon, as we walked around and under Discovery, I savored the moment and felt a mixture of awe, satisfaction, and a little sadness. Shuttle, to me, represents a triumph and remains to this day a technological marvel. We learned so much from the program, not only in the advancement of science and international relations, but also from what works and what doesn't on a reusable vehicle. The lessons learned from shuttle will make future US spacecraft more reliable, safer, and cost effective.

"I love the Space Shuttle. I am proud and honored to be a part of its history and legacy."

on the underbelly of the shuttle. When NASA discovered two gap fillers sticking out of the tiles on the shuttle's belly on the first mission, flight controllers and the astronauts came up with a plan to remove the gap fillers—an unprecedented and unplanned spacewalk that they believed would decrease excessive temperatures on re-entry. The plan required Astronaut Stephen Robinson to ride the arm underneath the shuttle and pull out the fillers. In 24 years of shuttle operations, this had never been attempted, but the fillers were easily removed. STS-114 showed that improvements in the External Tank insulation foam were insufficient to prevent dangerous losses during ascent. Another year passed before STS-121 (2006), the second Return to Flight mission, flew after more improvements were made to the foam applications.

Final Flights

Educator Astronaut

Excitement began to build at NASA and across the nation as the date for Barbara Morgan's flight, STS-118 (2007), grew closer. Morgan had been selected as the backup for Christa McAuliffe, NASA's first Teacher in Space in 1985. After the Challenger accident, Morgan became the Teacher in Space Designee and returned to teaching in Idaho. She came back to Houston in 1998 when she was selected as an astronaut candidate. More than 20 years after being selected as the backup Teacher in Space, Morgan fulfilled that dream by serving as the first educator mission specialist. NASA Administrator Michael Griffin praised Morgan "for her interest, her toughness, her resiliency, her persistence in wanting to fly in space and eventually doing so." Adults recalled the Challenger accident and watched this flight with interest. STS-118 drew attention from students, from across America and around the globe, who were curious about the flight.

Return to Hubble

In May 2009, the crew of STS-125 made the final repairs and upgrades to the Hubble Space Telescope to ensure quality science for several more years. This flight was a long time coming due to the Columbia accident, after which NASA was unsure whether it could continue to fly to destinations with no safe haven such as the ISS.

With the ISS, if problems arose, especially with the thermal protection, the astronauts could stay in the space station until either another shuttle or the Russian Soyuz could bring them home. The Hubble orbited beyond the ability for the shuttle to get to the ISS if the shuttle was critically damaged. Thus, for several years, the agency had vetoed any possibility that NASA could return to the telescope.

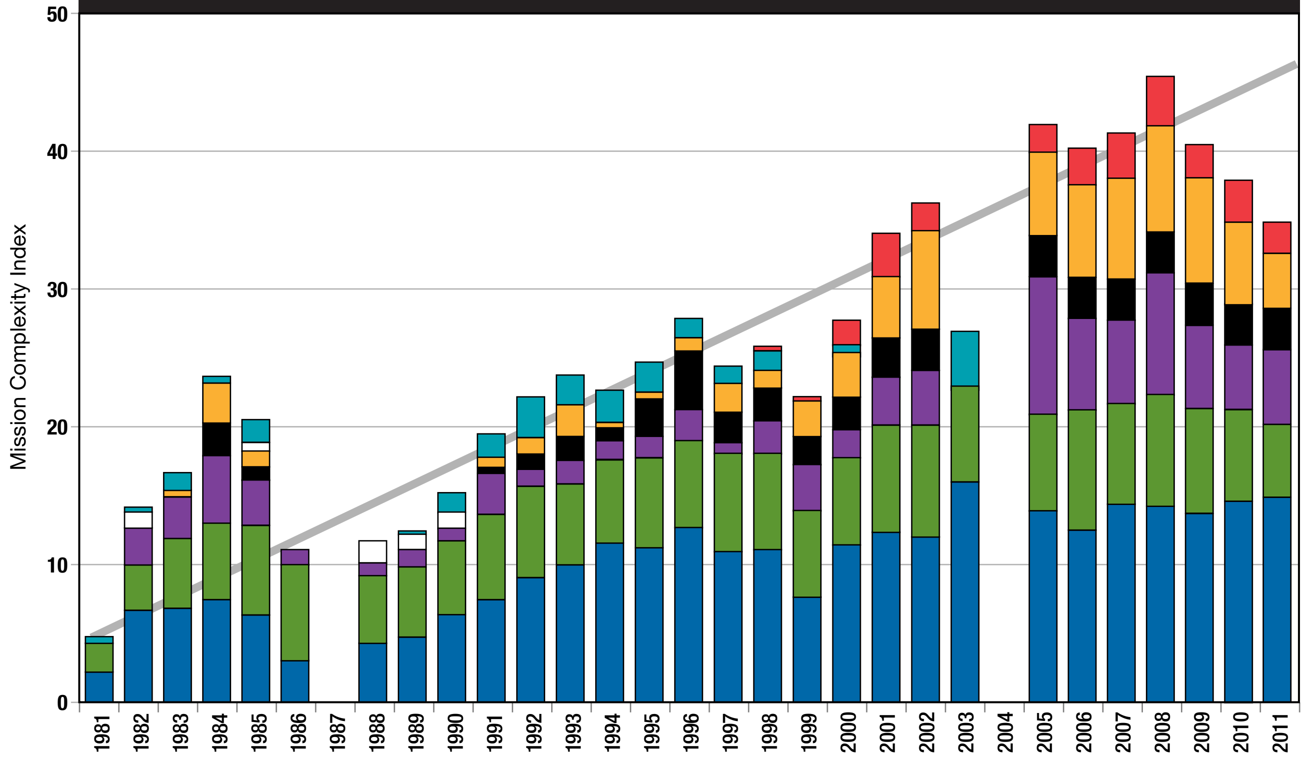
At that point, the Hubble had been functioning for 12 years in the very hostile environment of space. Not only did its instruments eventually wear out, but the telescope needed important upgrades to expand its capabilities. After the Return to Flight of STS-114 and STS-121, NASA reevaluated the ability to safety return astronauts after launch. The method to ensure safe return in the event of shuttle damage was to have a backup vehicle in place. So in 2009, Atlantis launched to repair the telescope, with Endeavour as the backup.

Improvements on the International Space Station Continued

Discovery flight STS-128, in 2009, provided capability for six crew members for ISS. This was a major milestone for ISS as the station had been operating with two to three crew members since its first occupation in 1999. The shuttle launched most of the ISS, including Canadian, European, and Japanese elements, to the orbiting laboratory. In 2010, Endeavour provided the final large components: European Space Agency Node 3 with additional hygiene compartment; and Cupola with a robotic work station to assist in assembly/maintenance of the ISS and a window for Earth observations.

This Commemorative Patch celebrates the 30-year life and work of the Space Shuttle Program. Selected from over 100 designs, this winning patch by Mr. Blake Dumesnil features the historic icon set within a jewel-shape frame. It celebrates the shuttle's exploration within low-Earth orbit, and our desire to explore beyond. Especially poignant are the seven stars on each side of the shuttle, representing the 14 lives lost—seven on Columbia, seven on Challenger—in pursuit of their dream, and this nation's dream of further exploration and discovery. The five larger stars represent the shuttles that made up the fleet—each shuttle a star in its own right.

Changes in Mission Complexity Over Nearly 3 Decades



Components of Mission Complexity

- *Length of flight as mission days. Early flights lasted less than 1 week, but, as confidence grew, some flights lasted 14 to 15 days.*
- *Crew size started at two—a commander and pilot—and grew to routine flights with six crew members. During the Shuttle-Mir and International Space Station (ISS) Programs, the shuttle took crew members to the station and returned crew members, for a total of seven crew members.*
- *Deploys occurred throughout the program. During the first 10 years, these were primarily satellites with sometimes more than one per flight. Some satellites, such as Hubble Space Telescope, were returned to the payload bay for repair. With construction of the ISS, several major elements were deployed.*
- *Rendezvous included every time the shuttle connected to an orbiting craft from satellites, to Hubble, Mir, and ISS. Some flights had several rendezvous.*
- *Extravehicular activity (EVA) is determined as EVA crew days. Many flights had no EVAs, while others had one every day with two crew members.*
- *Secret Department of Defense missions were very complex.*
- *Spacelabs were missions with a scientific lab in the payload bay. Besides the complexity of launch and landing, these flights included many scientific studies.*
- *Construction of the ISS by shuttle crew members.*

Over the 30 years of the Space Shuttle Program, missions became more complex with increased understanding of the use of this vehicle, thereby producing increased capabilities. This diagram illustrates the increasing complexity as well as the downtime between the major accidents—Challenger and Columbia.