



STS-135: The Final Mission

Dedicated to the courageous men and women who have devoted their lives to the Space Shuttle Program and the pursuit of space exploration



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2011

2009

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2001



STS-1: The First Mission





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SPACE SHUTTLE HISTORY

INTRODUCTION

Shuttle History: Knowledge, Capabilities, and Cooperation

For 30 years, the space shuttle has been the U.S. human access to space. It has capabilities no other spacecraft can claim. No other spacecraft is likely to match those capabilities in this generation.

It is the fastest winged vehicle ever to fly, with an orbital velocity of 17,500 mph, 10 times the speed of a high-powered rifle bullet. It is the only winged vehicle to reach orbit, and the only reusable space launch and landing vehicle.

The shuttle can carry cargos of substantial weight and dimensions. It has taken into space more than half the mass of all payloads launched by all nations since Sputnik in 1957 – 3,450,143 pounds (though STS-132) and counting as the final shuttle launch approaches.

More singular still is the shuttle's ability to return payloads from space. It has brought back from orbit more than 97 percent of all mass returned to Earth, a total of 225,574 pounds (though STS-132) before the upcoming final flight.

It has launched 802 crew members including those lost on Challenger and Columbia. Crew members returning on the shuttle numbered 789. Many crew members flew more than once. A total of 356 different individuals have flown aboard the shuttle (all through STS-132).

It leaves a significant legacy.

Engineering and technological advances were required in development of the shuttle. It was called the most complex machine ever built. Its main engines stretched design and metallurgical capabilities. Its thermal protection system, which shielded the orbiter from temperatures as high as 3,000 degrees Fahrenheit during re-entry, was a work in progress until shortly before the first shuttle launch. Engines and the thermal protection system were designed for repeated reuse.

Both have been continually improved during the life of the Space Shuttle Program. So has just about every other major shuttle system.

Science, in addition to the advances required for the spacecraft's development, has made huge strides with the help of the space shuttle. We have learned more about ourselves, about how our bodies and those of other organisms function, from the subcellular level on up. We have learned how we as individuals interact with one another under unusual and stressful circumstances – and how to work together.

We have learned about our planet, its land masses, its oceans, its atmosphere and its environment as a whole. With the help of the shuttle we have learned more about our moon, solar system, our galaxy and our universe.

The Hubble Space Telescope, for example, launched and repeatedly upgraded and repaired on shuttle missions, has given us unprecedented vision of distant stars, some with planets orbiting them. It has allowed us to look at objects so distant that viewing the light from them takes us back in time to nearer the beginning of the universe.



Scientific advances continue aboard the International Space Station. The shuttle has been instrumental in the station's construction and operation.

Perhaps as important as any element of the shuttle legacy is the development of international cooperation in space. Humans from many nations have begun to work together in space. Shuttle visits to the Russian space station Mir were a beginning that led to that new cooperation we see today aboard the International Space Station.

It has helped to develop respect and understanding for people and technological capabilities of many countries, including some former enemies. Such synergies could give humans as a whole greater potential for space exploration and development that any single nation could achieve alone. Such capabilities eventually could be critical in how well our species flourishes or, indeed, survives.

The shuttle has provided inspiration – for the young and the not so young.

It has encouraged uncounted youths to focus on science and technology. The idea of becoming an astronaut, as some certainly will, is a powerful motivation. So too is the prospect of using such an education to advance human knowledge and understanding in space.

People of all the nations contributing to the space shuttle's design and operation can take pride in its accomplishments.

SPACE SHUTTLE CONCEPT AND DEVELOPMENT

Like any project of its magnitude, the space shuttle was a series of compromises. They

ranged from political and funding concerns to competing design ideas and conflicting systems requirements – when one system changed others were impacted.

There were different requirements of users. Contractors and program managers worked out compromises of their own.

All in all, more than 50 different shuttle versions were developed during the design process. Eventually, they evolved into the space shuttle that has flown since Columbia's first launch in April 1981. It was the first of 135 launches, a string scheduled to end in July.

The prospect of reusable spacecraft capable of carrying large cargos and humans into space had been talked about for decades in science fiction and by scientists since shortly after World War II.

Indeed, a German design looked at a winged craft to be launched from a supersonic sled, rocket itself into suborbital space, skip along the upper atmosphere and bomb New York. After gliding to a landing and refueling, it would return home using the same technique.

Ideas for the next generation of U.S. human spacecraft had been discussed within NASA and the Department of Defense. In late 1958, NASA had established a working group based at Langley Research Center in Hampton, Va., to look at the nation's future human space program.

Among the group's 37 original engineers headed by Robert Gilruth were Maxime Faget, head of engineering; Chris Kraft of flight operations; and Glynn Lunney, who, at 21, was the youngest member of the team.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'NASA', 'STS-135', and 'ORION'. To the right of the logo, the text 'STS-135: The Final Mission' is written in a large, bold, white font. The background of the banner is a dark blue and black space scene with a bright yellow and orange glow on the right side, suggesting a sunset or sunrise over a horizon.

STS-135: The Final Mission

On April 1, 1969, Faget, director of engineering and development at the Manned Spacecraft Center (now Johnson Space Center (JSC), held a meeting with 20 colleagues at which he presented a balsa-framed, paper-skinned model. It was about 18 inches long, had straight, stubby wings and a shark-like nose.

Faget, who designed the Mercury spacecraft and contributed to U.S. spacecraft design through the space shuttle, told them, "We're going to build America's next spacecraft. It's going to launch like a spacecraft; it's going to land like a plane." The first humans landed on the moon the following July 20.

A request for proposals for "An Integral Launch and Reentry Vehicle" had been issued on Oct. 30, 1968, through the Manned Spacecraft Center in Houston and the Marshall Space Flight Center in Huntsville, Ala. It called for studies on configurations for launch and landing vehicles. Safety and economy were emphasized over the capability to carry heavy cargos.

Four companies got 10-month study contracts in February 1969. General Dynamics, Lockheed, McDonnell Douglas, and North American Rockwell came up with various concepts, some involving expendable and some reusable launchers. Engine contracts went to Pratt & Whitney and Rocketdyne. This was the beginning of Phase A of a four-step process culminating in production and operation of a national space shuttle.

NASA decided during Phase A that it wanted a two-stage craft, both stages reusable.

While those studies were going on, the Space Task Group, established by newly elected President Richard Nixon and chaired by Vice

President Spiro Agnew, was established that February. It issued a report called "The Post-Apollo Space Program: Directions for the Future" in September 1969.

The Space Task Group recommended, among other things, "low-cost, flexible, long-lived, highly reusable, operational space systems with a high degree of commonality and reusability." It suggested a system that could carry people, equipment, supplies and fuel to and from orbit routinely, as well as support a range of Department of Defense missions.

Phase B contracts for project definition went to two orbiter teams, one McDonnell Douglas and Martin Marietta, and the other North American Rockwell and General Dynamics. Both teams would look at competing NASA designs, the Maxime Faget design with limited cross-range and cargo capabilities but lower heating on re-entry and a high cross-range design with a delta wing, a larger cargo bay and cargo capability. Main engine contracts went to Pratt & Whitney, Rocketdyne and Aerojet.

Funding limitations caused Phase B to be amended, with the option of an expendable external tank. Eventually, that concept was adopted, and solid rocket boosters were attached to the tank. The Air Force insisted on the long cargo bay and heavy payload capability as well as a cross range of 1,265 miles to launch large satellites into polar orbit from Vandenberg Air Force Base in California and return there after a single orbit. Department of Defense political support was an important shuttle consideration.

Cargo bay dimensions were an example of the compromises at work. The length, which wound up being 60 feet, was the Air Force

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requirement, while NASA required the 15-foot width to accommodate space station modules.

The requirement for two fly-back stages was dropped as was, in early 1974, the idea to provide air-breathing engines for the orbiter approach and landing and ferry flights under its own power.

Phases C (design) and D (production and operation) were combined. President Nixon gave NASA the OK to go ahead with the larger payload bay on Jan. 3, 1972. North American Rockwell was named winner of the orbiter contract on July 26 of that year.

Rocketdyne, a division of North American Rockwell, had been named winner of the engine contract on July 13. NASA announced Thiokol as winner of the Solid Rocket Booster development contract on June 24, 1973, and less than a month later, Martin Marietta got the nod to design, develop and test the external tank.

The war in Southeast Asia, a recession and the fading of the excitement of the Apollo moon landings had made spaceflight funding tight. Shuttle development was to be stretched over a longer time and the space station, one justification for the shuttle's development, was put on hold. Appeals of some of the contract awards also caused delays.

Rockwell began building the first orbiter, Orbiter Vehicle 101, in Palmdale, Calif., on June 4, 1974. It was to have been named Constitution, but after 100,000 fans of the TV series "Star Trek" wrote in, the name was changed to Enterprise. It was rolled out on Sept. 17, 1976.

By then, it already had been subjected to a series of vibration tests. It had no main or

orbital maneuvering system engines. But Enterprise would provide additional valuable information on flight characteristics, atop a shuttle carrier aircraft and in free flight.

When the shuttle's air-breathing engines were dropped, it became apparent that NASA would have to find a way to transport the orbiter. Designing a specific-purpose aircraft and using the Air Force C5A were considered.

Eventually, NASA settled for a used 747-100 that had flown almost 9,000 hours for American Airlines, most on its New York-Los Angeles route. It bought the plane on July 18, 1974. (A second used 747 was acquired from Japan Air Lines for NASA by Boeing in April 1988 and delivered to the space agency in November 1990.)

Under a \$30 million contract with Boeing, the former American Airlines plane's structure was strengthened and instrumentation improved, orbiter mounting assembly fittings were installed and vertical endplates were added to its horizontal stabilizers. The modifications were completed by January 1977.

Approach and landing tests using Enterprise and the 747 (its American Airlines logo still faintly visible on each side) began the following month at Edwards Air Force Base in California. First came three taxi tests on Feb. 15, the third reaching a speed of 157 mph. Five "inactive" flight tests followed from Feb. 18 to March 2.

Two astronaut crews, the first Fred Haise and Charles "Gordon" Fullerton and the second Joe Engle and Richard Truly, alternated at Enterprise controls for three active test flights captive atop the 747 beginning Aug. 12 and five free flights involving Enterprise being released from the aircraft and landing at Edwards.

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The first four of the five, beginning Aug. 12, landed on Edwards' dry lakebed. The fifth, on Oct. 26, wound up the 1977 test series with an exciting Enterprise landing by Haise and Fullerton on Edwards' concrete runway. The fourth and fifth of those flights were flown without the tail cone, giving a more accurate picture of how an orbiter would glide to a landing after a spaceflight.

After some additional tests, Enterprise was to have been returned to Rockwell to be outfitted to fly in space, but it was not to be. NASA decided it would be quicker and cheaper to convert a structural test article, OV-99, into a flight orbiter. That orbiter was named Challenger.

Enterprise was subjected to additional tests, including some at Vandenberg, and was displayed at several locations, including the Paris Air Show in 1983 and the World's Fair in New Orleans in 1985. It was officially transferred to the Smithsonian Institution's National Air and Space Museum on Nov. 18, 1985, though NASA continued to borrow parts from it for testing in subsequent years.

Other preparations for shuttle flight continued:

NASA bought two Gulfstream II business jets and converted them into shuttle training aircraft. They realistically simulate the behavior of a returning orbiter between 35,000 feet and a point just above the runway – the height of the spacecraft's cockpit on landing.

The controls on the left side are much like those used by a space shuttle commander on landing, and the plane reacts to inputs like a descending orbiter. (Two additional

Gulfstreams were acquired in the 1980s and converted to shuttle trainers.)

New crew members would be needed. In January 1978 a new group of astronauts was selected. It was the first new astronaut class since the seven new astronauts had been selected in August 1969.

The group, the eighth beginning with the Mercury astronauts selected in 1957, was unlike any chosen before. Six of the 35 members were women; two of them were medical doctors and the others held Ph.D.s. Three were African American; two of them held Ph.D.s. One was an Asian American.

Many members of the new group would become the heart of the new category of astronauts, shuttle mission specialists. Their qualifications were varied from the mostly test pilots who made up earlier groups. Several of the new selectees were civilians, often with considerably different perspectives than their military predecessors.

Mission specialist physical qualifications were different, and still differ slightly, for pilots and mission specialists. Mercury astronauts could be no taller than 5 feet 11 inches – for groups of the Gemini and Apollo era, the maximum was 6 feet -- so they would fit into space capsules. Now astronauts well over six feet tall could fly in space.

Launch facilities and equipment were modified at Kennedy Space Center in Florida and a new launch site was being built at Vandenberg. Various contractor and NASA field center test facilities were established or modified.

As development continued, efforts were made to reduce spacecraft weight and improve

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performance. Qualification testing, aimed at showing various elements of the shuttle were ready to fly safely, was heating up.

By early 1980, formal qualification tests had been completed on the orbital maneuvering system engines and the reaction control system jets. Testing for qualification of the solid rocket boosters was completed about that time.

NASA had not used solid rockets in human spaceflight before. Each solid rocket booster has four motor segments. They are transported by rail from Thiokol's Utah facility and that mode of travel, with its curves and tunnels, necessitated their being built in segments and attached to one another once they reach Florida.

Marshall Space Flight Center did a series of tests on the external tank. A series of weight-saving measures, and additional tests, were introduced during early phases of tank construction and beyond. Later tanks were more than 10,000 pounds lighter than the early production models.

It became apparent that the greatest threat of delay was in development of the shuttle main engines and the thermal protection system.

The main engine was a challenge. Chamber pressures were higher than those of any previous liquid-fueled rocket engine. The design was for a reusable, two-stage engine that could be throttled. It required turbopumps that operated at higher speeds and higher pressures than any before.

Rocketdyne built an engine test bed at a NASA facility in Mississippi, at what is now Stennis Space Center, where it tested an engine larger and heavier than those built for flight, which were not yet available. It found and resolved a

number of problems. In April 1977, a test of two engines was dubbed successful, but turbopump problems continued.

Finally, by late 1980, the difficulties seemed to be largely resolved. A key test was completed on Jan. 17, 1981. Columbia's three main engines were successfully test fired at the launch pad for 20 seconds on Feb. 20, providing additional confidence for launch of STS-1 less than two months later, on April 12.

The thermal protection system, particularly the tiles, was a persistent problem. The ablative heat shields used from Mercury through Apollo were obviously not reusable. Reinforced carbon-carbon was used in areas subject to the greatest heating like the nose cone and wing leading edges.

After a lot of testing, a ceramic heat shield was chosen to protect much of the aluminum body of the orbiter. Shielding in these areas was made up of tiles.

Black tiles were used where heat did not exceed 2,300 degrees Fahrenheit (e.g., orbiter's bottom) and white tiles were used where temperatures did not get above 1,200 degrees. Thermal blankets were used in areas that stayed below 700 degrees.

Attaching the rigid tiles to the aluminum skin of the orbiter was a problem. An intervening felt pad was thought to be a solution. A stronger bond between the tile and the pad was found to be necessary, but when that was done, the combination of adhesive, felt, adhesive, tile resulted in a loss of about 50 percent of the strength of the four elements.

NASA decided to fill voids on the inward side of the tile, a "densification" process. Far



behind schedule because of the delays, NASA decided to fly Columbia from Palmdale to Kennedy in March 1979, with about 6,000 of the 30,000 tiles still not installed. A number of tiles that had been installed were lost during that flight.

Nondestructive tests were developed to check tiles' conditions, and gap fillers were installed to prevent tile rotation under shock-wave stress. Tile installation and testing went on around the clock six days a week for 20 months. Many newly installed tiles had to be removed after testing and reinstalled. By the end of November 1980, the number of tiles to be installed was below 1,000.

Finally, on Dec. 29, 1980, Columbia was rolled out on the newly modified mobile launch platform, from Kennedy's Vehicle Assembly Building to Pad 39A. Its gleaming white external tank seemed to harmonize with the white of the solid rocket boosters and the black-trimmed white of the orbiter.

THE SPACE SHUTTLE ERA BEGINS

On April 12, 1981, Commander John Young and Pilot Robert Crippen launched from Kennedy Space Center's Pad 39A aboard Columbia on STS-1.

The space shuttle era was under way.

STS-1 was the first of four test flights. Each carried a two-man crew. The commander and pilot had ejection seats.

The first flight lasted just over two days, six hours and 20 minutes. It orbited the Earth 36 times at an inclination of 40 degrees and an altitude of 166 statute miles and traveled 1,074,111 miles. After testing orbiter systems,

Young and Crippen landed Columbia on the dry lakebed at Edwards Air Force Base.

STS-2, commanded by Joe Engle and piloted by Richard Truly, launched Nov. 12 marking the first time a launch and entry spacecraft had been used. It was the first flight of the Canadian robotic arm, which was tested thoroughly during the mission.

The arm, just over 50 feet long, was an early international contribution to the shuttle program. Stowed on the left sill of the payload bay, it can deploy and retrieve payloads, move spacewalkers around and help inspect the orbiter.

Although the flight was shortened from five days to two days, six hours after one of three fuel cells failed, the two crew members completed most of their planned tasks. They also landed on Edwards' dry lake bed.

The third flight was different in a number of ways, beginning visually. The external tank, which had been painted white on the first two flights, was now the rust color that characterized it from then on. Engineers decided the white paint was not needed. That decision resulted in a weight savings of 595 pounds, almost all of it translating into increased cargo capacity.

Commander Jack Lousma and Pilot Gordon Fullerton launched STS-3 on March 22, 1982. They flew Columbia in various attitudes to check out thermal characteristics, conducted more tests of the robotic arm and did scientific experiments, some involving plants and insects.

Rain at Edwards caused the landing to be moved to the strip on the White Sands Missile

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Range, and a New Mexico dust storm delayed it for a day. Finally, on March 30, they landed after a flight of just over eight days.

The final test flight launched June 27, 1982, with Commander Ken Mattingly and Pilot Henry Hartsfield. They did extensive tests of Columbia systems and conducted several experiments.

Among the experiments was a classified one from the Department of Defense. It marked a new way of doing things for NASA. Previous public openness was partly muted. No camera views of the payload bay were transmitted to Earth and oral communications relating to the payload were conducted in a simple, but effective code.

After a flight of more than seven days and 3.3 million miles, STS-4 landed on Edwards' concrete runway, a first for an orbiter returning from space.

At Edwards, they got a July 4 welcome from President Ronald Reagan and his wife Nancy and a holiday crowd of thousands. At the ceremony, NASA Administrator James Beggs declared the space shuttle operational.

The president compared the completion of the test flight series to the driving of the gold spike marking completion of the transcontinental railroad. "It marks our entrance into a new era," he said.

Shortly after Columbia had landed, Challenger passed close by. Atop the shuttle carrier aircraft, it was departing on its first cross country flight, its delivery to Kennedy Space Center.

With the test phase finished, it was time to get down to business.

Privately owned communications satellites had become a growing field while the shuttle was being developed and more and more communications satellites would require launch and the shuttle seemed perfectly suited to provide it.

Legislation had given the space agency a monopoly on the domestic satellite launch market. NASA aggressively marketed that launch capability, both domestically and internationally. Estimates had foreseen between 30 and 60 shuttle flights.

Bargain prices were offered for multiple launches over the first five years of the program, with the idea of building repeat business.

Columbia launched on the first operational flight on Nov. 11, 1982. In the crew compartment, in addition to Commander Vance Brand and Pilot Robert Overmyer, were the first mission specialists, Joseph P. Allen and William Lenore. Both had been among the Group 6 science astronauts selected in August 1967.

Two commercial satellites were in the payload bay. The first to be launched from a shuttle, SBS-C, left the payload bay about eight hours into the flight. The Canadian Telesat-E followed. Both were successfully boosted into geostationary orbits, 22,300 feet above the Earth, by Payload Assist Modules.

By mid-January 1986, a total of 24 commercial satellites had been deployed from the shuttle. Of those, the Payload Assist Module boosters of two, the Indonesian Palapa B2 and the Westar-VI, had failed to fire, leaving the satellites useless in a low orbit.

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The astronauts aboard Challenger on that 10th shuttle flight, STS-41-B, in February 1984 had performed flawlessly. But the failure of the boosters gave the shuttle a chance to demonstrate another capability.

Both those satellites were later retrieved and returned to Earth by Discovery astronauts on the 14th shuttle mission, STS-51-A. They worked under contract with the insurance companies, which already had paid the owners for their loss.

Lloyds of London was delighted with the recovery, and rang its Lutine bell to mark the importance of the event. It gave the insurance companies partial reimbursement. It was then called monetarily the largest salvage recovery. The satellites were refurbished and sold to new owners to be launched again.

The new numbering system for shuttle flights was introduced after STS-9. The following flight became STS-41-B. The first number designated the fiscal year and the second number was the launch site – 1 for Kennedy and 2 for Vandenberg Air Force Base. The letter was the order of launch assignment, so B was the second scheduled for that fiscal year.

The old numbering system was revived for STS-26, the return-to-flight mission after the Challenger accident.

The STS-6 mission, Challenger's first flight, launched April 4, 1983, and began a series of other firsts. The flight carried the first Tracking and Data Relay Satellite (TDRS). The TDRS system replaced the ground, a NASA communications satellite which began the replacement of the ground stations on which the space agency had relied through the end of the Apollo era.

The TDRS booster sustained failure, leaving the spacecraft well below geosynchronous altitude but far too high for the shuttle to reach. NASA and TDRS builder, TRW, came up with a method to use its thrusters to gradually lift it to the proper orbit, a process that took several weeks.

Challenger's STS-7 mission launched June 18 to deploy two commercial satellites. It carried various experiments, including those on the German Shuttle Pallet Satellite which was deployed from the cargo bay by the robotic arm. After a time as a free flyer in its own orbit, Challenger rendezvoused with it, grappled it with the arm and secured it in the cargo bay for return home.

Commander Crippen's four crew members were from the shuttle-focused astronaut Group 8. It included Sally Ride, the first U.S. woman in space.

The next Challenger mission, STS-8, had three more Group 8 alumnae, including Guyon Bluford, the first U.S. black in space. Commanded by Truly, it was the first to launch at night, on Aug. 30, 1983. It deployed a satellite from India. Its landing also was at night.

Columbia was back for STS-9, launched Nov. 28 as the final flight of 1983. It was the first Spacelab flight. Commanded by Young (making the last of his six spaceflights, which included two missions to the moon) with Brewster Shaw as pilot, its six-man crew included the first payload specialists, Byron Lichtenberg of Massachusetts Institute of Technology and Ulf Merbold, a German physicist.

The European Space Agency built the \$1-billion, 23-foot laboratory flown in



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Columbia's cargo bay. The crew, including Mission Specialists Robert Parker and Owen Garriott, worked around the clock in two shifts, conducting more than 70 experiments.

The 10th shuttle flight, STS-41-B, saw the program's first spacewalks, and with them, demonstration of a jet backpack that took Mission Specialists Bruce McCandless and Robert Stewart untethered out of the cargo bay.

The mission, launched Feb. 3, 1984, with Commander Vance Brad, Pilot Robert Gibson and Mission Specialist Ronald McNair, was demonstrating the use of the Manned Maneuvering Unit's potential in the capture and repair of the Solar Maximum Satellite, scheduled for the next flight. They could not guess how important the jet backpack would be to the future of the two satellites deployed from their cargo bay, the Indonesian Palapa B2 and the Westar-VI.

It was the first mission to land at Kennedy Space Center.

Crippen commanded the STS-41-C flight, the program's 11th, with Pilot Francis "Dick" Scobee and Mission Specialist van Hoften. It launched April 6 with a 30-foot, 22,000-pound Long Duration Exposure Facility and its 57 experiments in the cargo bay. On the way to the ailing satellite, Mission Specialist Terry Hart used the robotic arm to deploy the container, scheduled to stay in orbit for a year.

After rendezvous with the satellite, Mission Specialist George Nelson flew to it with the jet backpack. Initial efforts to attach a docking device failed, but succeeded the next day after some help from Goddard Space Flight Center. In the cargo bay Nelson and van Hoften

replaced failed components. Hart put it back into its own orbit with the arm.

After an attention-getting June 26 abort seconds before scheduled liftoff, Discovery launched on its first flight, STS-41-D, flight 12, on Aug. 30 with Commander Hartsfield and Pilot Michael Coats. With Mission Specialists Richard Mullane, Steve Hawley, Judith Resnik and Charles Walker, they launched two communications satellites and deployed, tested and restowed a large solar array.

Crippen commanded STS-41-G. The 13th flight launched with Pilot Jon McBride on Oct. 5 on board Challenger. It was the first to have two women mission specialists, Ride and Kathryn Sullivan. Sullivan became the first female spacewalker on a 3.5-hour outing with Mission Specialist Dave Leestma to test a satellite refueling system.

Two mission specialists, Paul Scully-Power, an Australian oceanographer, and Canadian Marc Garneau made this seven-member crew the largest yet. The largely scientific flight focusing on Earth included release of a satellite to measure solar radiation reaching Earth.

The two-satellite retrieval mission, STS-51-A, was commanded by Frederick Hauck. Crew members were Pilot Dave Walker and Mission Specialists Joseph Allen, Anna Fisher and Dale Gardner. Discovery launched Nov. 8 on the year's final flight.

An early task was to launch two communications satellites it had brought into orbit. Then, after rendezvous with Palapa B-2, Allen jettied to the satellite with the backpack and attached a capture device. Fisher used the arm to bring it back to Discovery, but a problem prevented its docking in the cargo bay.



STS-135: The Final Mission

Using a backup plan, Allen got into foot restraints, removed the satellite from the arm and held it over his head for about 90 minutes, one orbit of the Earth. The satellite's weight on Earth was about 1,600 pounds, about nine times that of Allen. Gardner attached an adapter and secured the satellite for the trip home.

The Westar VI was less of a problem. Using their experience two days before, Gardner jettied to the satellite and together they secured it in the cargo bay.

Discovery's flight STS-51-C, the 15th flight was a Department of Defense mission, launched Jan. 24, 1985. Commanded by Mattingly, it lasted just over three days and had an all-military-astronaut crew.

The launch had been delayed one day because of freezing weather.

U.S. Senator Jake Garn of Utah, a former Navy pilot, was aboard Discovery for the 16th shuttle flight, STS-51-D. Launched on April 12 and commanded by Karol Bobko, the flight included Pilot Donald Williams, Mission Specialists Jeffrey Hoffman, David Griggs and Rhea Seddon and Payload Specialist Charles Walker.

The flight launched two communications satellites, but the booster of one did not activate. Crew members spent an extra two days in orbit, using the robotic arm with a flyswatter-like device at its end, trying without success to activate a switch satellite thought to be in the wrong position on the Leasat 3. The satellite was repaired on flight STS-51-I that October.

Garn, who chaired the Senate committee with NASA budget oversight, volunteered for space sickness studies. He said later he had indeed suffered from that malady.

Challenger's STS-51-B flight, the 17th of the program, launched April 29 and was the second Spacelab mission. Crew members were Commander Overmyer, Pilot Frederick Gregory, Mission Specialists Don Leslie Lind, Norman Thagard and William Thornton, and Payload Specialists Taylor E. Wang (a Jet Propulsion Laboratory physicist) and Lodewijk van der Berg, an EG & G scientist.

Again, the crew worked around the clock, in two shifts. The wide-ranging experiments involved disciplines, ranging from astronomy to materials processing. In the lab were two squirrel monkeys and 24 rats flown to test cages, which proved inadequate.

When the cages were opened to feed the occupants, food debris and feces were released to float throughout the lab and even into the crew compartment. The problem was solved by putting plastic bags over food trays when crew members, in surgical masks, removed them, and using a vacuum cleaner.

Daniel Brandenstein commanded the 18th shuttle flight, STS-51-G, in Discovery, with Pilot John Creighton, Mission Specialists John Fabian, Steve Nagel and Shannon Lucid, and Payload Specialists Patrick Baudry (a French astronomer) and Saudi Arabian Prince Sultan Salman Abdul Azziz Al Sa'ud.

The flight, launched June 17, deployed three communications satellites, one for Mexico, one for Saudi Arabia and one U.S. A satellite called Spartan, an astronomy experiment, was

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION 135' and 'FINAL MISSION'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white and yellow font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

deployed with the robotic arm and, subsequently, after a separation of more than 100 miles, was recaptured and returned to Earth. A number of other experiments were aboard including several from France.

Challenger's flight STS-51-F, the program's 19th, started badly. Five minutes and 45 seconds after the July 29 launch the No. 1 engine shut down prematurely (the cause turned out to be a faulty sensor reading) and an abort to orbit was declared.

After running the remaining two main engines for almost a minute and a half longer than planned, Challenger wound up in a lower than normal orbit, 164 by 124 statute miles. The orbital maneuvering system engines were used to raise the orbit enough to continue to the flight's planned conclusion.

This was another Spacelab mission, though the module was not aboard. Many experiments were on a pallet in the cargo bay. The crew, Commander Fullerton, Pilot Roy Bridges, Mission Specialists Story Musgrave, Anthony England and Karl Heinz, and Payload Specialists Loren Acton (a Lockheed solar physicist) and John-David Bartoe from the Naval Research Laboratory, worked around the clock in 12-hour shifts.

The 20th shuttle flight, STS-51-I, launched Aug. 27 on Discovery, to deploy three communications satellites, then capture, repair and release another – the Leasat-3. It had been the object of the unsuccessful flyswatter efforts by STS-51-D astronauts when it failed to activate after its deployment the previous April.

The crew, Commander Engle, Pilot Richard Covey and Mission Specialists van Hoften, William Fisher and John Lounge,

successfully deployed the new satellites (one Australian and two U.S., including Leasat-4), then successfully rendezvoused with and captured the Leasat-3. Van Hoften and Fisher, a surgeon, repaired it during two spacewalks and it was redeployed.

Atlantis made its first flight on STS-51-J, the 21st flight of the shuttle program. The Department of Defense mission, commanded by Bobko with Pilot Ronald J. Grabe, Mission Specialists David C. Hilmers and Stewart and Payload Specialist William A. Pailles, lasted just over four days and reached a then-record altitude of 319 statute miles.

Challenger flew the Spacelab module with its 76 experiments on 61-A, Mission No. 22. A record eight crew members were aboard, Commander Hartsfield, Pilot Nagel, Mission Specialists James. F. Buchli, Bluford and Bonnie J. Dunbar and Payload Specialists Reinhard Furrer of Germany, Wubbo Ockels of the Netherlands and Ernst Messerschmid, also of Germany.

The mission was largely financed by West Germany. The mostly material processing experiments were operated by two shifts of three crew members with the other two working as needed.

The last mission of 1985, the 23rd for a shuttle, 61-B by Atlantis, launched the night of Nov. 26 on a flight that put the space station on the spaceflight stage. President Reagan had told NASA to start work on a space station during his State of the Union message in 1984.

Two spacewalks, both by Mission Specialists Sherwood Spring and Jerry Ross, saw repeated assembly and disassembly of a framework beam using almost 100 tube-like struts that



snapped together. They also assembled and disassembled an upside-down pyramid frame using six 12-foot aluminum bars. After the second spacewalk, they pronounced themselves ready to build a space station.

Brewster Shaw commanded the flight with Bryan D. O'Connor as pilot. Mary Cleave was the third mission specialist and payload specialists were Charles Walker of McDonnell Douglas and Rudolfo Neri Vela of Mexico. Early in the flight, three satellites were deployed, one U.S., one Mexican and one Australian.

Columbia returned after a two-year refit, without its ejection seats (they had been disabled after the last test flight and removed during the overhaul) and with the agency anxious to get started on the 15 launches scheduled for 1986.

Weather and technical problems caused seven postponements before 61-C., Flight No. 24, was launched on Jan 12. Gibson commanded Columbia, with Pilot Charles Bolden, Mission Specialists George Nelson, Hawley and Franklin Chang-Diaz, and Payload Specialists Robert Cenker (an RCA engineer) and U.S. Rep. Bill Nelson.

Nelson represented the district that included Kennedy Space Center, and was chairman of the Subcommittee on Space Science and Applications. He participated on some experiments on the flight, which launched an RCA communications satellite.

With Columbia scheduled to launch again in early March and several experiments hampered by instrument failures, the flight was shortened from five days to four. But weather caused attempts to return to Kennedy on the new landing day and the day after that. With Florida weather still not cooperating on day 3, Columbia landed at Edwards.

On a cold, clear, bright Florida day, Jan. 28, 1986, Challenger launched at 11:38 a.m. local time. The spacecraft exploded 73 seconds after launch at an altitude of almost nine miles.

The seven crew members, Commander Francis R. "Dick" Scobee, Pilot Michael J. Smith, Mission Specialists Ellison S. Onizuka, Judith A. Resnik and Ronald E. McNair, and Payload Specialists Gregory Jarvis and Teacher in Space Sharon Christa McAuliffe, were killed.



STS-135: The Final Mission



Five astronauts and two payload specialists made up the Challenger crew in January of 1986. Crew members are (left to right, front row) astronauts Michael J. Smith, Francis R. (Dick) Scobee and Ronald E. McNair; Ellison S. Onizuka, Sharon Christa McAuliffe, Gregory Jarvis and Judith A. Resnik.

NASA REBOUNDS INTO SPACE

The first sign of trouble had been a puff of gray smoke from the aft field joint of the right solid rocket booster about half a second after Challenger's launch, the investigation revealed. It was followed by additional puffs, then flame and finally the explosion.

The temperature that Jan. 28 at 11:38 a.m. was 36 degrees Fahrenheit, about 15 degrees colder

than at any previous launch. No one really understood how the seals on the boosters' field joints worked, or how potentially serious the partial burn-through of O-ring seals seen in those joints after some previous flights had been.

Over the next three months, search teams recovered about 30 percent of the orbiter and parts of the boosters were recovered from the bottom of the Atlantic off Florida.

The banner features the STS-135 logo on the left, which includes a stylized shuttle and the text 'PERFORMANCE', 'PROGRESS', 'PROBATION', and 'PROBATION'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and red American flag with a yellow glow on the right side.

STS-135: The Final Mission

On Feb. 3, President Reagan named a commission to investigate the accident. It was chaired by former Secretary of State William P. Rogers. Among its 14 members were astronauts Neil Armstrong and Sally Ride, test pilot and retired Air Force Brig. Gen. Chuck Yeager, physicist and Nobel laureate Richard P. Feynman and other leading scientists and engineers.

Among its recommendations

- The faulty booster joint seal must be changed.
- The Shuttle Program management structure should be reviewed.
- NASA should encourage transition of qualified astronauts into management positions.
- NASA should establish an office of Safety, Reliability and Quality Assurance reporting directly to the administrator.
- Reliance on a single launch capability should be avoided and NASA must establish a flight rate consistent with its resources.

Eventually, after NASA and the National Transportation Safety Board had done a thorough evaluation of the Challenger debris, they were sealed in unused Minuteman missile silos not far from the spacecraft's launch pad.

Challenger had changed a lot. It was a very public disaster, watched on live TV by millions and millions more on subsequent newscasts. The space agency and its contractors changed in management and philosophy. And following the Rogers Commission recommendation, NASA was

forbidden, with certain exceptions, to launch commercial satellites.

Thirty-two months later, after overhauls that brought more than 450 changes to each of the remaining three orbiters, with redesigned solid rocket boosters, a plethora of changes in processes and management procedures and more, NASA was ready to fly again.

Discovery launched on STS-26, the Return To Flight mission, on Sept. 29, 1988. The orbiter carried a veteran five-man crew commanded by Frederick Hauk. The TDRS-C, a new Tracking and Data Relay Satellite replacing the one lost on Challenger, was in the cargo bay.

NASA had returned to the flight numbering system used until STS-9. The missions retained the assigned number even if the launch sequence changed.

Mission Specialists John Lounge and David Hilmers deployed the TDRS-C six hours into the flight. Scientific experiments and tests of the upgraded orbiter occupied other crewmen, Pilot Richard Covey and Mission Specialist George Nelson, during much of the four-day flight.

During a news conference from orbit the day before landing, crew members delivered moving tributes to the Challenger crew. Discovery landed on a dry-lakebed runway at Edwards Air Force Base. Managers had decided to end all missions there until the brake and landing system upgrades could be checked out.

A four-day, nine-hour STS-27 Department of Defense (DoD) mission with five crew members aboard Atlantis commanded by Robert Gibson was launched Dec. 2 as the last flight of 1988.

The banner features the STS-135 logo on the left, which includes a stylized shuttle and the text 'MISSION SPECIALIST' and '1981 2011'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom.

STS-135: The Final Mission

The TDRS-D was deployed on STS-29 shortly after Discovery's launch March 13, 1989, by Mission Specialists Robert Springer and James Bagian. With its predecessor, TDRS-A, the new satellite in its geosynchronous orbit was able, after its checkout, to provide communications with a shuttle about 85 percent of the time. The figure for ground stations was less than 20 percent.

Commander Michael Coats, Pilot John Blaha and Mission Specialist James Buchli worked with experiments during the five-day flight. They also captured extensive Earth views with a 70 mm IMAX camera. Discovery landed on Edwards' concrete runway.

While NASA generally could not launch commercial satellites, a backlog of other spacecraft, including government satellites and planetary probes, had accumulated while the shuttle was not flying.

Magellan was the first planetary mission to be launched by a space shuttle. Its flight to Venus began on STS-30 in Atlantis' cargo bay on May 4. Six hours later it was deployed.

Magellan's departure was the highlight of the four-day flight of Atlantis crew members, Commander David Walker, Pilot Ronald Grabe and Mission Specialists Norman Thagard, Mary Cleave and Mark Brown. The 15-month flight to Venus took it 1 1/2 times around the sun before it went into orbit around the target planet.

Like its explorer namesake, Ferdinand Magellan, the spacecraft did not make it home. But it was not supposed to. After radar mapping of 98 percent of Venus' surface and measuring its gravity field, Magellan was

intentionally crashed to gather information about its atmosphere.

The explorer did not fare as well – he was killed in the Philippines in 1521, but 18 of his 237 men returned to Spain, completing the first circumnavigation. The satellite circled Venus thousands of times, and sent back data that changed our ideas about the planet.

Another DoD mission, STS-28, commanded by Brewster Shaw, followed with an Aug. 8 launch. Next up was the shuttle's second planetary payload deployment

Atlantis, commanded by Donald Williams and piloted by Michael McCulley, launched on STS-34 Oct. 18 with the \$1.5-billion Galileo spacecraft. Mission Specialists Shannon Lucid, Ellen Baker and Franklin Chang-Diaz deployed Galileo a little over six hours after liftoff.

Galileo, managed by NASA's Jet Propulsion Laboratory in Pasadena, Calif., swung around Venus, then twice around Earth to gain momentum. En route to Jupiter, it captured images of two asteroids (one with the first asteroid moon discovered). It also observed fragments of Comet Shoemaker-Levy crashing into Jupiter in July 1994.

Galileo went into orbit around Jupiter Dec. 7, 1995, and dropped a probe into its atmosphere. Galileo itself was intentionally crashed into Jupiter on Sept. 21, 2003, but not before returning a wealth of information about the gas giant and four of its moons.

The fifth shuttle DoD mission and 1989's final flight, STS-33 by Discovery, was launched in darkness on Nov. 22 under command of Frederick Gregory.

The banner features the STS-135 logo on the left, which includes a stylized shuttle and the text 'NASA' and 'STS-135'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom.

STS-135: The Final Mission

An 11-day flight, the longest to that time, was commanded by Daniel Brandenstein and launched Jan. 9, 1990, as STS-32 in Columbia. It deployed a Navy communications satellite and retrieved the Long Duration Exposure Facility (LDEF).

LDEF, launched on April 6, 1984, on Flight 41-C, the 11th of the shuttle program, with 57 experiments expected to stay in orbit for a year. Its retrieval was first deferred to a later mission then delayed after the Challenger accident.

After the sixth DoD flight of the program, STS-36 on Atlantis commanded by John Creighton launched Feb. 28, 1990, perhaps one of the most meaningful payloads launched aboard a shuttle went into orbit aboard Discovery on April 24. The Hubble Space Telescope helped change the way we see, and think about, our universe.

It was the first of four NASA Great Observatories, three of them taken into orbit by space shuttles.

The Discovery crew on that STS-31 flight was Commander Loren Shriver, Pilot Charles Bolden and Mission Specialists Steven Hawley, Bruce McCandless and Kathryn Sullivan. They deployed Hubble about 24 hours after launch at an altitude of about 380 statute miles.

The deployment went flawlessly, but it soon became apparent that all was not well with Hubble. A mistake had been made in the grinding of its main mirror. The mirror had been ground to the wrong shape, but ground precisely so that correction was possible.

Some observations were possible, particularly those of bright objects, before the replanned first servicing mission was flown. Scientists were able to use image processing to improve results. But there was considerable criticism from the public, political figures and the scientific community.

That first servicing mission, STS-61, launched on Endeavour Dec. 2, 1993, with seven crew members. After five lengthy spacewalks, a reboosted Hubble was released with cleared vision, one new camera, new solar arrays, four (of six) new gyroscopes and some new electronics.

In early January, NASA declared the mission a success, and released the first of thousands of sharp, remarkable images Hubble has sent down over the years. The space telescope was functioning as advertised.

Four more servicing missions followed, the most recent in May 2009 on Atlantis. Each of those missions upgraded Hubble's capabilities and extended its life. (See related story.)

Ulysses, a joint NASA-European Space Agency mission, was launched Oct. 6, 1990, in Discovery's cargo bay on the STS-41 flight commanded by Richard Richards and piloted by Robert Cabana. Ulysses made a swing around Jupiter before entering a solar polar orbit.

Expected to have a lifetime of five years, Ulysses made almost three orbits around the sun and gathered information on most of two 11-year solar cycles. It was deactivated in mid-2009.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION SPECIALISTS' and '2011'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a yellow glow at the bottom right.

STS-135: The Final Mission

After a DoD mission in November 1990 and a science flight, the last of the year, the second of NASA's great observatories, the Gamma-Ray Observatory, was ready to go. Its STS-37 mission would see an unplanned spacewalk to free a stuck antenna on the spacecraft. It was the first spacewalk in almost six years.

Atlantis launched on the deployment mission on April 5, 1991. The observatory's high-gain antenna did not deploy correctly when commanded by the ground. Mission Specialists Jerry Ross and Jerome Apt freed the antenna during a 4 1/2-hour spacewalk.

They also completed a planned spacewalk of a little over six hours the following day to test ideas about how to move about and move equipment during space station assembly and maintenance.

After a science flight, a Spacelab Life Sciences mission, deployment of TDRS-D and deployment of an Upper Atmosphere Research Satellite, Atlantis on STS-44 wound up the 1991 flight year with a Nov. 24 launch to deploy a Defense Support Program satellite.

Discovery on STS-42 began 1992 with a Jan. 22 launch of an around-the-clock flight of the International Microgravity Laboratory in the Spacelab module. It was followed by a March launch of Atlantis with the Atmospheric Laboratory for Applications and Science, made up of 12 instruments from seven countries. It was mounted on Spacelab pallets in the cargo bay.

The first flight of Endeavour, the replacement for Challenger put together largely with available spare parts, launched May 7 on a dramatic communications satellite rescue attempt. The target of the STS-49 mission

commanded by Daniel Brandenstein and piloted by Kevin Chilton was the Intelsat VI, stranded in a useless orbit since its March 1990 launch on a Titan III.

On the flight's first spacewalk, Mission Specialists Pierre Thuot and Richard Hieb could not attach a capture bar to the satellite. A second attempt the next day also was unsuccessful.

After a day off and discussion with Mission Control, the spacewalk plan for the third spacewalk called for three spacewalkers, with the addition of Mission Specialist Thomas Akers. Perched on the payload bay sill, they would grab the satellite when Brandenstein maneuvered Endeavour close enough for them to reach it.

It worked. The new booster they attached sent Intelsat into its proper orbit. It was the first three-person spacewalk. The flight was a powerful argument for the value of humans in space. It also marked the first use of a drag parachute when Endeavour landed at Edwards.

The following microgravity laboratory flight launched in June 1992. STS-50, in Columbia, was the longest by a shuttle to that time, 13 days, 19 hours and 30 minutes. Atlantis, launched in July, tested a tethered satellite as a power generator.

Endeavour's second flight, STS-47 in September with Spacelab life sciences and materials processing experiments, boasted a number of shuttle firsts – the first Japanese astronaut, Mamoru Mohri; the first black woman astronaut, Mae Jemison; and the first married couple to fly together, Mission Specialists Mark Lee and N. Jan Davis.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION', 'DISCOVERY', 'COLUMBIA', and '2011'. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and red American flag with a yellow glow on the right side.

STS-135: The Final Mission

A science and satellite deployment mission, STS-52 on Columbia, followed in October. Next came the STS-53 mission on Discovery, the last of 1992 and the last of 11 dedicated DoD flights on shuttles. Endeavour began 1993 with the January launch of STS-54 to deploy the TDRS-F satellite.

STS-56 on Discovery took scientific experiments into orbit in March and STS-55 in Columbia followed with a Spacelab mission in April. Launched in June, STS-57 saw the first flight of a Spacehab module, a commercially owned pressurized module in the cargo bay, and a spacewalk rehearsal for the first Hubble Servicing Mission and for station construction. A Spacelab life science mission followed with an October launch on Columbia mission STS-58.

The long awaited Hubble flight followed. That mission, STS-61 on Endeavour, was followed by one that was a precursor of far-reaching changes in shuttle activities. One of the mission specialists on Discovery's STS-60 flight launched Feb. 3, 1994, was cosmonaut Sergei Krikalev of the Russian Space Agency.

Krikalev's flight seemed to have little direct connection with station-related activities. But, after a series of half-a-dozen mostly scientific shuttle missions, the flight of fellow cosmonaut Vladimir Titov certainly did.

As part of the Shuttle-Mir Program, he came within about 40 feet of the Russian space station on Discovery's STS-63 flight launched Feb. 3, 1995. After the rendezvous and approach to Mir (peace), Commander James Wetherbee and Pilot Eileen Collins (the first female shuttle pilot) guided Discovery on a fly-around of the station.

The mission, with Mission Specialists Michael Foale, Janice Voss and Bernard Harris, was a step toward development of the International Space Station. It was one of the things the space shuttle had been designed to do.

In the 1984 State of the Union Address, President Ronald Reagan had directed NASA to start working on a space station. That concept, an American orbiting outpost named Freedom, languished, particularly after the Challenger accident.

But in 1992, President George H.W. Bush and Russian President Boris Yeltsin signed an agreement for collaboration in space. Cosmonauts would fly on space shuttles and astronauts would serve on Mir. That was the beginning of the Shuttle-Mir Program.

After an intervening scientific shuttle mission, cosmonauts Anatoly Solovyez and Nikolai Budarin launched on STS-71 aboard Atlantis June 27 with Commander Robert Gibson, Pilot Charles Precourt and Mission Specialists Ellen Baker, Gregory Harbaugh and Bonnie Dunbar.

Atlantis brought water, tools and supplies to Mir and took home experiment results and a broken Mir computer.

Also coming home aboard Atlantis was Norman Thagard, who had launched to Mir on a Soyuz spacecraft four months before, and his fellow Mir crew members, cosmonauts Vladimir Dezhurov and Gennadiy Strekalov. The cosmonauts who had come to Mir in Atlantis got into a Soyuz to film Atlantis separating from Mir.

After Thagard's mission and the visit of Atlantis, things would never be the same.



FROM MIR TO THE INTERNATIONAL SPACE STATION

A total of nine space shuttle flights docked to the Russian space station Mir. Each brought equipment and supplies. Each provided new knowledge and new understanding among the U.S., Russians and other international partners.

Working together on those missions, their preparation and execution, created a respect among astronauts and cosmonauts, and among the people and programs supporting them. Shuttle-Mir also helped lay a firm foundation for development, construction and operation of the International Space Station.

The first Mir docking flight by Atlantis on STS-71 brought home on July 7, 1995, a wealth of information with astronaut Norman Thagard, who had served a pioneering four months aboard the Russian space station with two cosmonaut crewmates. It caused both sides to look at how the other did things in space and sometimes used that knowledge to improve their own methods or to develop new ways combining the best elements of both.

The next flight, STS-70 on Discovery, was the launch of TDRS G. It was notable, in part, for a delay caused by nesting Flicker Woodpeckers damaging the external tank – they made more than 70 holes ranging from four inches to half an inch in diameter over the Memorial Day weekend and caused a rollback for repairs. The flight finally launched July 13.

Atlantis launched to Mir again on Nov. 12, STS-74, with a new Russian-built docking module and Canadian astronaut Chris Hadfield. On Mir was European Space Agency astronaut Thomas Reiter of Germany. No crew members were exchanged.

It marked the first time representatives of those four agencies had been together in space. It would not be the last.

The flight brought water, equipment and supplies and returned scientific samples to Earth. The new docking module, which provided better clearance for shuttle dockings, remained on Mir.

Astronaut Shannon Lucid was aboard STS-76 on her way to become the second U.S. crew member on Mir. Launched March 22, 1996, with a Spacehab module containing equipment and supplies, the flight began a record-breaking stay for Lucid and two years of continuous U.S. astronaut presence on Mir.

A Spacehab double module with 4,000 pounds of equipment and supplies was aboard Atlantis on STS-79 when it brought astronaut John Blaha to Mir to replace Lucid. When she landed on Sept. 26, she had spent 188 days in space, a new U.S. record and a world record for a woman.

The first shuttle flight of 1997, STS-81 was launched on Atlantis Jan. 12, again with a Spacehab double module packed with water, supplies and equipment for Mir. Aboard was astronaut Jerry Linenger, Blaha's replacement.

During his increment, Linenger and his crewmates successfully fought a Feb. 23 fire that had broken out in an oxygen-generating "candle." It filled the station with smoke, but none of the six people aboard was badly hurt.

Atlantis launched May 15 on STS-84 with Linenger's replacement, Michael Foale, and about 7,500 pounds of material for the station. His increment, like Linenger's, was in many

The banner features the STS-135 mission logo on the left, which includes a shuttle, a Progress spacecraft, and a Mir module. The text "STS-135: The Final Mission" is written in a large, bold, white font against a background of a stylized American flag and a sunset over a horizon.

STS-135: The Final Mission

ways successful, but it too was punctuated by an accident.

An unpiloted Progress collided with Mir on June 25, causing a breach in the hull. One compartment was sealed off and internal and external spacewalks, including one by Foale, were done later to rectify and inspect damage.

Both accidents, and especially the weeks-long recovery from the collision, were learning experiences.

STS-86, again on Atlantis, launched on Sept. 25 and brought astronaut David Wolf to Mir along with a Spacehab double module with equipment and supplies, and returned home with Foale. Wolf's 119 days aboard Mir were relatively uneventful, in that his increment went largely as planned.

Endeavour became the first orbiter other than Atlantis to dock at Mir after its STS-89 launch on Jan. 22, 1998. It brought another 8,000 pounds of equipment and supplies, along with Andrew Thomas, the Australian-born U.S. astronaut, and cosmonaut Salizhan Sharipov.

The final flight of the Shuttle-Mir Program was STS-91 launched June 2 on Discovery. It delivered about 6,000 pounds of equipment and supplies and returned to Earth with Thomas and long-term U.S. experiments from Mir.

The Shuttle-Mir Program provided a foundation for the International Space Station. It gave U.S. astronauts extended time in orbit. The science program provided a basis for the more extensive International Space Station science activities.

It gave us valuable experience in training crew members from different nations, and showed us how to operate an international space program. It gave us experience in support of long-duration spaceflight and in dealing with unexpected challenges.

It helped develop the cooperation and trust we see each day on the International Space Station and in control centers around the world.

In addition to the woodpecker-plagued STS-70 flight on Discovery, total of 13 non-Mir shuttle flights took place between the time of the first and the final shuttle dockings to Mir. Each contributed to science, to development of techniques to build the International Space Station and/or to better spaceflight operational understanding and capability.

Among them were

- Endeavour's STS-69 flight in September 1995 which included the Spartan astronomy tool and a spacewalk to check out International Space Station assembly and maintenance tools and procedures.
- Endeavour's January 1996 mission, STS-72, with two spacewalks to evaluate International Space Station fixtures, tool holders and an umbilical holder.
- The STS-82 flight of Discovery in February 1997, the second Hubble Space Telescope servicing mission. (See related story.)

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION', 'ISS', and 'SPACE SHUTTLE'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

- The July 1997, STS-94 mission of Columbia with the first Microgravity Science Laboratory, in a Spacelab module in the orbiter's cargo bay.
- The Neurolab mission, STS-90, in April 1998, also in a Spacelab module in Columbia's cargo bay.

A single shuttle mission was flown between the final flight to Mir and the first shuttle launch of an International Space Station module. That single mission was STS-95 on Discovery, launched Oct. 29, 1998. Among its crew members was Payload Specialist John Glenn.

Glenn had become the first American to orbit the Earth on Feb. 20, 1962, in his Friendship 7 Mercury spacecraft, a flight of just under five hours. More than 36 years and a stint in the U.S. Senate later, he was back in space, this time for almost nine days on a largely scientific mission.

Assembly of the International Space Station began on the STS-88 mission of Endeavour, launched Dec. 4, 1998. With Commander Robert Cabana and Pilot Rick Sturckow were robotic arm operator Nancy Currie, spacewalkers Jerry Ross and James Newman, and cosmonaut Sergei Krikalev.

The Unity Node, Node 1, a connector module was mated late Dec. 6 with the Russian-built Zarya module, launched the previous Nov. 20 from the Baikonur Cosmodrome in Kazakhstan. Ross and Newman did three spacewalks to connect power and data cables.

Another rollback, this one caused by hail damage, delayed the start of Discovery's STS-96 flight, the first logistics flight to the station.

Launched May 27, 1999, the Spacehab double module in the cargo bay held supplies and internal outfitting equipment.

An Integrated Cargo Carrier held a Russian Strela crane and a U.S. crane, both installed on the station during a spacewalk.

The third of NASA's great observatories, the Chandra X-Ray Observatory, was launched on Columbia's STS-93 flight July 23. The flight was the first with a female commander, Eileen Collins.

Next up was Hubble Space Telescope Servicing Mission 3A, 1999's last mission launched Dec 19.

The Shuttle Radar Topography Mission provided mapping information of unprecedented accuracy covering about 80 percent of the Earth's land surface, home to 95 percent of its population. STS-99 launched on Endeavour Feb. 11, 2000. The around-the-clock mission gathered simultaneous radar images from an antenna in the cargo bay and another at the end of a 197-foot boom, providing strips of 3D images of the Earth below.

After that flight, the shuttle flight focus was on the space station.

Atlantis launched May 19 on STS-101, the first flight of the new glass cockpit, to take equipment and supplies to the station. A spacewalk by James Voss and Jeffery Williams made equipment changes before the arrival of the Zvezda Service Module.

Zvezda, the first fully Russian contribution to the ISS – Zarya was Russian built, but U.S. funded – launched from the Baikonur Cosmodrome and docked to the station July 25.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION 135' and 'FINAL MISSION'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

Atlantis went to the station again on STS-106, launched Sept. 8 with more than 5,000 pounds of equipment and supplies. The crew prepared the station for the arrival of the first crew, and a spacewalk by Edward Lu and Yuri Malenchenko connected cables between Zvezda and the adjacent Zarya module.

The Z-1 Truss with its four 600-pound attitude control gyroscopes was launched to the station by Endeavour Oct. 11 on STS-92, the 100th space shuttle mission. Four spacewalks, two by Leroy Chiao and William McArthur and two by Jeff Wisoff and Michael Lopez-Alegria, were devoted largely to making connections between the station and the new truss, and a new pressurized mating adaptor also brought to the station by Endeavour.

Endeavour flew again on STS-97, launched Nov. 30 on the final shuttle flight of 2000. It carried the P6 Truss and its 240- by 38-foot solar wings. They could provide almost 64 kilowatts of power for the station's Expedition One crew, Bill Shepherd, Yuri Gidzenko and Sergei Krikalev, which had arrived at the station Nov. 2.

Mission Specialists Joseph Tanner and Carlos Noriega made three spacewalks, hooking up the new P6 to the Z1 Truss and preparing for the arrival of the U.S. laboratory Destiny.

Destiny came to the space station on Atlantis' STS-98 mission, launched Feb. 7, 2001. Mission Specialists Thomas Jones and Robert Curbeam did three spacewalks to connect Destiny to the station, install a docking connector to its forward end and install an antenna.

The Expedition Two crew, Yury Usachev, Susan Helms and James Voss, came up on

Discovery, launched on STS-102 March 8. It was the first visit of the Multi-Purpose Logistics Module (MPLM) Leonardo to the station, and took home Expedition One.

Helms and Voss did one spacewalk to prepare a berthing port for Leonardo. Mission Specialists Paul Richards and Andy Thomas did a second spacewalk to help prepare the station for its own robotic arm.

Canadarm2, that 58-foot station robotic arm, and the cargo carrier Raffaello MPLM came to the station on Endeavour's STS-100 flight, launched April 19. Scott Parazynski and Chris Hadfield did two spacewalks to install the arm and an antenna.

Atlantis brought a new airlock to the station on STS-104, launched July 12. The airlock, named Quest, was installed by Helms with help from spacewalkers Michael Gernhardt and James Reilly.

The spacewalks installed four related high-pressure tanks, two oxygen and two nitrogen, on two subsequent spacewalks. The final spacewalk was the first to be made from the airlock itself.

The second station crew exchange saw Frank Culbertson, Vladimir Dezhurov and Mikhail Turin brought to the station and Expedition Two brought home by Discovery on STS-105, launched Aug. 10. It brought the cargo carrier Leonardo back to the station and included outfitting spacewalks by Daniel Barry and Patrick Forrester.

Endeavour, on STS-108, took a new station crew, Yuri Onufrienko, Daniel Bursch and Carl Walz, into orbit and took Expedition 3 home. The Raffaello MPLM came to the station

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION 28' and '28th Shuttle Mission'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

and spacewalkers Linda Godwin and Daniel Tani installed insulation on a P6 array rotating device.

Columbia's STS-109 flight was to the Hubble Space Telescope for Servicing Mission 3B.

The first segment of the station's main truss, the central Starboard Zero (S0), was brought up on STS-110 by Atlantis, launched April 8. The mobile transporter, which eventually would move along the truss rails, was part of the cargo.

Two teams, Steven Smith and Rex Walheim and Jerry Ross and Lee Morin, made a total of four spacewalks focusing on hooking up the new truss segment and station outfitting.

MPLM Leonardo was back for a third station visit on Endeavour's STS-111, which also brought up a new station crew, Expedition 5's Valery Korzun, Peggy Whitson and Sergei Treshev. The flight, launched June 5, also carried the mobile base system for the station's railroad.

Astronaut Franklin Chang-Diaz and Philippe Perrin of the French Space Agency did three spacewalks to install the mobile base system, continue outfitting the station's exterior and replace Canadarm2's wrist roll joint.

The next two flights each brought an additional truss segment. STS-112 by Atlantis launched Oct. 7 brought the Starboard One (S1) segment to the truss while STS-113 on Endeavour,

launched Nov. 23 on the final flight of 2002 brought the Port One (P1) piece and a new station crew.

Atlantis Mission Specialists Dave Wolf and Piers Sellers made three spacewalks from the station airlock to help install and to connect S1, install cameras and release restraints on a handcart for the station railway.

Endeavour launched to the station Expedition 6, Kenneth Bowersox, Nikolai Budarin and Donald Pettit. Its spacewalkers, Michael Lopez-Alegria and John Herrington, helped shuttle and station arm operators attach P1 and then installed connectors between it and S0, installed part of a wireless video system for spacewalks and attached ammonia tank lines.

On Jan. 16, 2003, Columbia launched on a long-planned and much anticipated science mission. It carried more than 80 experiments, most in a Spacehab research double module in the cargo bay. Crew members worked around the clock in two 12-hour shifts.

After what appeared to be a successful flight, Columbia was minutes away from its scheduled Feb. 1 landing when it broke apart.

The seven crew members, Commander Rick Husband, Pilot William McCool, Payload Commander Michael Anderson, Mission Specialists Kalpana Chawla, David Brown, Laurel Clark and Payload Specialist Ilan Ramon of Israel, were killed.



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Columbia crew members, seated in front from left, are astronauts Rick D. Husband, mission commander; Kalpana Chawla, mission specialist; and William C. McCool, pilot. Standing are (from the left) David M. Brown, Laurel B. Clark, and Michael P. Anderson, all mission specialists; and Ilan Ramon, payload specialist representing the Israeli Space Agency.

STATION ASSEMBLY COMPLETED AFTER COLUMBIA

Columbia's mission launched from Kennedy Space Center's Pad 39A at 10:39 a.m. EST that Jan. 16, 2003. A piece of foam that detached from the external tank's left bipod foam ramp later was determined to be perhaps 24 inches long and 15 inches wide.

When it struck the left wing's leading edge 82 seconds after launch, Columbia was at about 66,000 feet and traveling at 1,650 mph. The relative velocity of the foam to Columbia at impact was about 545 mph.

Columbia's mission went smoothly. But shortly after it began its Feb. 1 re-entry, problems began. The foam had struck the reinforced carbon-carbon heat shield on the left wing's leading edge. The damage allowed

The banner features the STS-135 logo on the left, which includes a stylized shuttle and the text 'MISSION' and 'RECOVERY'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and red sky with a bright light source on the right.

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superheated gases to penetrate the wing during re-entry, causing catastrophic failure.

Radar and video recordings indicate the orbiter was shedding debris beginning when it crossed California. The most westerly confirmed Columbia debris was found at Littlefield, Texas, northwest of Lubbock.

Videos showed the spacecraft breaking up south of Dallas-Fort Worth. The most easterly debris, heavy engine parts, was found at Fort Polk, La.

More than 25,000 people from 270 organizations spent 1.5 million hours searching an area almost as big as Connecticut looking for debris. They and the public found 84,000 pieces of Columbia, almost 85,000 pounds or 38 percent of the orbiter's dry weight.

The Columbia Accident Investigation Board (CAIB) was headed by Retired Navy Adm. Harold W. Gehman Jr. Among its 12 other eminently qualified members was former astronaut Sally Ride, who had served on the Rogers Commission investigating the loss of Challenger.

The CAIB found the immediate cause of the accident was foam from the external tank breaking free and breaking the reinforced carbon-carbon heat shield. That allowed superheated gases into the wing during re-entry and caused the loss of Columbia.

The report, issued in August 2003, gave equal weight to organizational causes, including management acceptance of the risk of damage from tank foam shedding because of previous experience.

The 29 recommendations of the CAIB included better preflight inspections, better shuttle imagery during ascent and in flight establishment of an independent technical engineering authority to better control hazards, and recertification of all shuttle components by 2010.

On Jan. 14, 2004, almost a year after the accident, President George W. Bush released the Vision for Space Exploration. Among its goals was to complete assembly of the International Space Station and then retire the space shuttle.

Two "Return to Flight" missions, each with a number of test activities, were scheduled for the resumption of shuttle flights. The first was STS-114 on Discovery, with Eileen Collins making her fourth shuttle flight and second as commander.

Discovery launched July 26, 2005. Changes were evident early in the mission.

A 50-foot extension of the shuttle's robotic arm with laser and video cameras at its end was deployed to examine the spacecraft's nose cap and wing leading edges on flight day two. The next day Discovery paused in its approach to the station to do a slow back flip.

That allowed station crew members to get numerous photos of the orbiter's thermal protection system. They were sent to experts on the ground for detailed analysis.

Both were among new procedures done on all subsequent shuttle flights.

Discovery brought the Multi-Purpose Logistics Module (MPLM) Raffaello filled with equipment and supplies to the station. On three spacewalks, Mission Specialists



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Stephen Robinson and Soichi Noguchi of Japan replaced one of the station's four 600-pound attitude control gyroscopes and restored power to another and installed a stowage platform and a materials experiment.

They also demonstrated repair procedures for the shuttle's heat shield. Robinson, at the end of the station arm, also pulled two protruding gap fillers from between heat-resistant tiles on the shuttle's belly.

Discovery landed at Edwards Air Force Base on Aug. 9 after a mission that generally went smoothly. But there had been an unexpected loss of foam from the external tank shortly after launch. While the orbiter had not sustained major damage, more work and testing on the foam-shedding issue was required.

The second Return to Flight mission, STS-121, again on Discovery, was launched July 4, 2006. It brought another MPLM, Leonardo, to the station with supplies and equipment, including a laboratory freezer. In the cargo bay, it brought a cargo carrier and a container with materials for tests of repair procedures for the shuttle's thermal control system.

During three spacewalks, Mission Specialists Piers Sellers and Michael Fossum fixed the mobile transporter base for the station arm on the main truss railroad, tested the shuttle arm extension as a work platform and tested the heat shield repair procedures.

The mission was important in several ways. Sellers said late in the flight that it showed the shuttle capable of flying without major problems, and that it left the station ready for continued assembly.

The next flight, STS-115 on Atlantis, launched Sept. 9, seemed to verify Sellers' observations. It brought port truss segments three and four and a second set of 240-foot solar wings. Two spacewalks by Mission Specialists Heidemarie Stefanyshyn-Piper and Joe Tanner and one by Dan Burbank and Steve MacLean of Canada focused on the truss segments' installation and related activities.

The spacewalks marked the first use of the "camp out" procedure, with spacewalkers spending the previous night in the airlock at a reduced pressure of 10.2 psi. That reduces the nitrogen content of the blood, to avoid the condition called the bends.

The final flight of 2006, STS-116 on Discovery, launched Dec. 9 on Discovery with port truss segment 5. Four spacewalks were done, three by Mission Specialists Robert Curbeam and Christer Fuglesang of Sweden and one by Curbeam and Sunita Williams, a new station crew member brought up by Atlantis.

The spacewalks helped install and connect the new truss segment. The fourth spacewalk by Curbeam and Fuglesang was added to help retract the P6 snagged solar array, which had been deployed for six years atop the station. That done, the new array brought up on STS-115 was extended and activated.

Hail delayed the launch of STS-117. The storm, on Feb. 26, 2007, was described as "a very dynamic event" by those at the pad. Hailstones, some as big as golf balls, damaged thermal protection tiles on Atlantis' left wing and caused 2,600 dings in the external tank foam.

After repairs, the flight launched June 8 with the Starboard three and four truss segments

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION SPECIALIST' and '2011'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white and yellow font against a background of a blue and white American flag and a bright orange and yellow glow at the bottom.

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and a third set of solar wings. Four spacewalks, two by Mission Specialists James Riley and Danny Olivas and two by Lee Archambault and Patrick Foster, helped install and hook up the truss segments.

They also helped complete retraction and prepare the P6 truss segment for relocation from atop the station to the end of the main station truss.

Endeavour returned after a four-year modernization program which included installation of a system to allow it to take power from the station enabling it to stay three extra days at the space station. Its STS-118 flight launched on Aug. 8 with the starboard 5 truss segment.

Four spacewalks were done by Mission Specialists Richard Mastracchio, Canadian Dave Williams and station Flight Engineer Clayton Anderson, rotating on two-person teams. They helped install and hook up the S5 segment. They also replaced one of the 600-pound attitude control gyroscopes.

On this mission, Barbara Morgan became the first mission specialist educator in space.

Station assembly continued at a brisk pace. The STS-120 flight of Discovery was launched Oct. 22, 2007, with the Italian-built Node 2 connecting module. Spacewalkers Scott Pasrazynski, Doug Wheelock and Daniel Tani (a station crew member who came up on Discovery) did four spacewalks.

They involved preparing and disconnecting the P6 truss from Z1 and helping with its installation at the end of the port truss, its new home. As the P6 solar wings were being deployed, one blanket was torn.

On the fourth spacewalk, Parazynski rode the station arm and the shuttle's arm extension to the area of the tear. There he cut a fouled wire and installed reinforcing "cuff links," the products of improvised fabrication from materials available inside the station the previous night. They enabled the P6 solar wing deployment to be completed.

For the first time, two female commanders, the shuttle's Pamela Melroy and ISS commander Peggy Whitson, met in space.

Europe's Columbus Laboratory was launched Feb. 7, 2008, on the STS-122 mission of Atlantis. The European Space Agency's largest contribution to the station added 2,648 cubic feet of pressurized volume to the station.

Three spacewalks helped install and set up Columbus. The spacewalkers, Rex Walheim, Stanley and ESA's Hans Schlegel, also swapped out a nitrogen tank and installed a European experiment outside Columbus.

Endeavour launched March 11 on STS-123 with the Japanese Experiment Logistics Module named Kibo and the Canadian Special Purpose Dexterous Manipulator, called Dextre.

The two-week flight saw a record five spacewalks, during which the Japanese module was installed in a temporary location and Dextre was assembled and installed. The spacewalkers also tested heat shield repair methods and installed a materials experiment.

Discovery carried the main section of the Kibo lab, the 32,558-pound Japanese Experiment Module, to the station on STS-124, launched May 31. Three spacewalks by Mission Specialists Michael Fossum and Ron Garan

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION', 'HUBBLE', 'KIBO', 'DISCOVERY', and 'FINAL MISSION'. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and red sky with a bright yellow sun on the right side.

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helped install and hook up Kibo, the largest pressurized module on the station.

Mission Specialists Karen Nyberg (who on STS-124 became the 50th woman in space) and Akihiko Hoshide of Japan used the station arm for Kibo installation, and later moved the pressurized logistics module, brought up on STS-123, to its permanent Kibo location.

Expansion of the station crew from three to six members was made possible by Endeavour on STS-126, which saw the 10th anniversary of station construction. Launched Nov. 14, 2008, the flight brought to the station the Leonardo MPLM with additional sleep stations, a new galley, a new bathroom and a water recovery system.

During four spacewalks, done in two-member teams by Heidemarie Stefanyshyn-Piper, Stephen Bowen and Robert Kimbrough, astronauts repaired and serviced Solar Alpha Rotary Joints (SARJs). The joints allow the station's 240-foot solar wing assemblies to track the sun.

The final piece of the station's 335-foot main truss was on Discovery's STS-119 flight launched March 15, 2009. The Starboard 6 (S6) segment, with the fourth set of solar wings, was installed by Canadarm2 with help from spacewalkers Steve Swanson and Richard Arnold, who also completed connections.

Joseph Acaba joined Swanson and Arnold in two additional spacewalks, installing an antenna and relocating a handcar on the station's main truss. When Discovery left, the station was more than 80 percent complete and the four solar wing assemblies had a total area of .9 acre, or 38,400 square feet.

Atlantis launched May 11 on STS-125, the final Hubble Space Telescope servicing mission. (See related story.)

A total of 13 spacefarers representing all partner nations, the most ever on one spacecraft, were aboard the station during Endeavour's STS-127 mission launched July 15. Crew members completed the construction of the Japanese Kibo science laboratory.

They added an external experiment platform called the exposed facility to Kibo. Crew members did five spacewalks, installing that platform and swapping out six 367-pound batteries on the P6 truss. Endeavour also delivered spare parts.

The Discovery crew delivered more than seven tons of laboratory facilities, exercise equipment, food, water and other supplies on its STS-128 mission, launched Aug. 28.

Mission Specialists Danny Olivas, Nicole Stott and Christer Fugelsang of ESA, paired up for three spacewalks, replacing an ammonia tank for station cooling and retrieving materials samples that could help in development of future spacecraft.

The STS-129 flight of Atlantis focused on delivery of spare parts too big and too massive to fly on other vehicles. Launched Nov. 16, it brought to the station about 14 tons of cargo in its payload bay, including two large carriers with heavy spare parts that were stored on the station's exterior.

Three two-man spacewalks by Mike Foreman, Robert Satcher and Randy Bresnik installed an antenna and cabling, payload attachment systems, a high-pressure oxygen tank and a materials experiment.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'PRESSURIZED MULTIPURPOSE MODULE' and '1974 2011'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

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The final U.S. pressurized station module, Node 3 Tranquility, came to the station on the STS-130 flight of Atlantis, launched Feb. 8, 2010, along with a Cupola robotics workstation with seven windows giving crew members a unique view of their home planet and the station.

Commander George Zamka, Pilot Terry Virts and Mission Specialists Kathryn Hire, Stephen Robinson, Nicholas Patrick and Robert Behnken left behind more than 36,000 pounds of hardware that included the Tranquility Node 3 and the redundant cupola.

Behnken and Patrick did three spacewalks, helping connect Tranquility to the station's Unity node and helped with relocation of the Cupola from the end of Tranquility to its Earth-facing port. Zamka dedicated the Cupola with a plaque containing four moon rocks that Parazynski had taken to the summit of Mount Everest and returned, along with a piece of rock from atop the world's highest mountain.

The Leonardo pressurized cargo module completed its last round trip to the station on the STS-131 flight of Discovery, launched April 5. But it was back after a refit to serve as a permanent station module.

Discovery brought more than 17,000 pounds of equipment and supplies to the station. Richard Mastracchio and Clayton Anderson did three spacewalks, replacing an ammonia tank, retrieving an experiment from Kibo and replacing a rate gyro assembly.

Four women were together for the first time in space, as were two Japanese astronauts, Mission Specialist Naoko Yamazaki and station Flight Engineer Soichi Noguchi.

Atlantis launched May 14 on the STS-132 mission to deliver a Russian research module,

six more 367-pound batteries for the P6 truss and other equipment and supplies for the station.

The flight included three spacewalks, two each by Mission Specialists Garrett Reisman and Steve Bowen. They installed a second high-data-rate Ku-band antenna and a spare parts platform for Dextre. They also completed the P6 battery replacement, leaving it with a full set of 12 new batteries.

Mission Specialists Piers Sellers and Reisman used Canadarm2 and a Russian language computer to install the Mini-Research Module 1, named Rassvet (Dawn) on the Earth-facing port of the station's Zarya module.

The refitted MPLM Leonardo, now a Pressurized Multipurpose Module, came to its permanent home on the station on Discovery's STS-133 mission, in 2011. With it came Robonaut 2, a legless robot, and an EXPRESS Logistics Carrier (ELC) with equipment and supplies.

MISSION CONTROL ROSES EXPRESS THANKS, SUPPORT

Traditions develop over the years in the course of activities as demanding, complex and rewarding as the Space Shuttle Program. Most originate internally, but one began more than 100 shuttle missions ago with a bouquet of roses sent to the Mission Control Center in Houston.

It happened during the STS-26 flight of Discovery launched in September 1988, the Return to Flight mission after the Challenger accident in January 1986. An accompanying card expressing congratulations and good wishes was signed, but no one recognized the name.



STS-135: The Final Mission



Image shows one set of roses among many sent to the MCC during missions.

Milt Heflin, then a flight director and now Johnson Space Center associate director, found contact information on the senders, Mark and Terry and their daughter MacKenzie Shelton who live in the Dallas area. He called to say thanks.

Mark Shelton said he was a long-time follower of the space program, and wanted to quietly and personally express his admiration and support. The Sheltons visited JSC in 1990. They came again in March 2009, to deliver their 100th bouquet of roses in person.

The roses kept coming, mission by mission, for more than 22 years, even as the shuttle program neared its end. Heflin said they mean so much because they had not been asked for and were not initially expected. They are an island of beauty in an otherwise very businesslike MCC.

The card on a recent bouquet said: "To our good friends at Mission Control," and the crews of the shuttle and the International Space station. "May God bless you all! God speed."

There were seven red roses, one for each shuttle crew member, and a pink rose for each station crew member. There was a white rose, too, for those who had given their lives to further space exploration.



SPACE SHUTTLE PROGRAM'S KEY STATISTICS (THRU STS-134)

- Total # of individual human spaceflights = 848 crew members launched; 834 crew members returned (14 crew members were lost in flight in the Challenger and Columbia accidents); 355 different individuals flown onboard the shuttle
 - Total # of human spaceflight hours on shuttle = 198,728.25 man-hours (approximately 8,280 man-days)
 - Total number of payloads deployed (i.e., satellites, International Space Station components, etc.) into space from the shuttle = 179
 - Total number of payloads (i.e., satellites, space station components) returned from space using the shuttle = 52
 - Total number of payloads serviced (retrieved, repaired, then deployed, i.e., HST, Solar Max) on shuttle missions = 7 (not accounted for in the deployed and returned numbers above)
 - Total usable cargo mass delivered into space = 3,513,638 pounds (This value is the total amount of cargo launched in the cargo bay and middeck. Some of this was deployed, some transferred, some returned.)
 - Total usable cargo mass returned from space = 229,132 pounds (This value is the total amount of cargo retrieved from space and returned, i.e., LDEF, middeck cargo returned from ISS; does not include cargo launched and returned such as Spacelab)
- Total time in flight = 1,310 days (31,440 hours, 59 minutes, 33 seconds)
 - Total # of orbits = 20,830
 - Total # of flights = 134
 - MIR Dockings = 9
 - International Space Station Dockings = 36

http://www.nasa.gov/mission_pages/shuttle/launch/orbiter_flights.html

THE ORBITER FLEET

Enterprise: Now a Museum Piece

Enterprise, the first space shuttle orbiter, was named after the spacecraft in the popular TV science fiction series Star Trek. Plans had called for it to be converted to an operational orbiter after ground and approach and landing tests, but it never flew in space.

Designated OV-101, Enterprise was delivered to NASA's Dryden Flight Research Facility at Edwards Air Force Base on Jan. 31, 1977, for the nine-month test series. Tests included ground tests atop the shuttle carrier aircraft.

They were followed by five captive flight tests of the unmanned Enterprise atop the carrier aircraft. Three more captive flights were flown with two-man crews aboard the orbiter to check Enterprise's flight controls and other systems.

In five subsequent free flights, two alternating astronaut crews separated the orbiter from the carrier aircraft and landed at Edwards. Four of the landings were on a dry lake bed, and the fifth was on the base's main concrete runway.

Four local ferry flight tests were followed by modifications for vertical ground vibration



tests. On March 13, 1978, Enterprise flew aboard the carrier aircraft to Marshall Space Flight Center in Huntsville, Ala., for those tests.

On April 10, 1979, Enterprise was ferried to the Kennedy Space Center. Mated with an external tank and solid rocket boosters, it was moved on the mobile launcher platform to Launch Pad 39A. There, it served as a practice and launch complex fit-check tool.

By then, it had been decided that it would be too expensive to convert Enterprise to a spaceflight vehicle. It was taken back to Rockwell's Palmdale final assembly facility. Some of its parts were refurbished for use on flight vehicles being assembled at Palmdale.

Though Enterprise never got to space, it did see Paris, for the air show there. It also visited Germany, Italy, England and Canada during that 1983 trip. It was in New Orleans for the 1984 World's Fair.

On Nov. 18, 1985, Enterprise was ferried to Dulles Airport in Washington, D.C. There it became the property of the Smithsonian Institution.

The recent announcement of orbiter placement after the fleet is retired means Enterprise will be relocated from the Virginia suburbs to the Intrepid, Sea, Air and Space Museum in New York City. That will clear the way for Discovery to take its place at the Smithsonian.

Enterprise Construction Milestones

- July 26, 1972 Contract Award
- June 6, 1974 Start structural assembly of Crew Module

- Aug. 26, 1974 Start structural assembly of aft-fuselage
- May 23, 1975 Wings arrive at Palmdale from Grumman
- Aug. 24, 1975 Start of Final Assembly
- March 12, 1976 Completed Final Assembly
- Sept. 17, 1976 Rollout from Palmdale
- Jan. 31, 1977 Overland transport from Palmdale to Edwards
- April 4, 1979 Delivery to Kennedy Space Center

Enterprise's Flights

Taxi Tests

- 1. Feb. 15, 1977 (Max speed 89 mph)
- 2. Feb. 15, 1977 (Max speed 140 mph)
- 3. Feb. 15, 1977 (Max speed 157 mph)

Captive-Inactive Flights

- 4. Feb. 18, 1977
- 5. Feb. 22, 1977
- 6. Feb. 25, 1977
- 7. Feb. 28, 1977
- 8. March 2, 1977

Captive-Active Flights

- 9. June 18, 1977
- 10. June 28, 1977
- 11. July 26, 1977



Free Flights

12. Aug. 12, 1977
13. Sept. 13, 1977
14. Sept. 23, 1977
15. Oct. 12, 1977

COLUMBIA: FIRST IN SPACE, FIRST IN SCIENCE

On April 12, 1981, with a bright coat of new white paint and a gleaming white external tank, Columbia launched from Kennedy Space Center on STS-1, the first shuttle flight and the first of four test flights that took the nation back into space.

Each of those flights was flown with just a commander and a pilot, and each was flown by Columbia. The third of those flights was made with an unpainted external tank, a practice that saved about 600 pounds and continued through the rest of the program.

More formally known as OV-102, Columbia also flew the first operational shuttle flight, STS-5, launched Nov. 11, 1982. That flight saw the first launch of a commercial communications satellite to be deployed by a shuttle.

Columbia was named after the first American ocean vessel to circle the globe, a name shared by the Apollo 11 command module for the first moon landing. On STS-9, launched Nov. 28, 1983, it flew the first Spacelab mission. The pressurized cylinder in the cargo bay hosted around-the-clock experiments.

Columbia also flew the laboratory on its last mission in 1998.

In 1991, Columbia was the first orbiter to undergo the scheduled inspection and retrofit program. At Rockwell's Palmdale, Calif., assembly plant it underwent about 50 upgrades, including the addition of carbon brakes and a drag chute, improved nose wheel steering and removal of instrumentation used during the test flights. It was back in action for STS-50, launched in June 1992.

In 1994, Columbia was in Palmdale again for its first major tear-down and overhaul. It took about a year and left Columbia in some respects better than new. A second overhaul completed in 2001 involved more than 100 modifications, including "glass cockpit" instrumentation.

Columbia deployed the Chandra X-ray Observatory, one of four NASA great observatories, during STS-93 on July 23, 1999.

Many lessons learned from Columbia contributed to design of subsequent orbiters, which were somewhat lighter and more capable, and thus more suitable for space station assembly missions. Columbia became more focused on science flights.

It was on a long-planned science mission, STS-107 with a Spacehab research double module, that Columbia and its crew were lost on Feb. 1, 2003. A piece of external tank foam insulation had damaged a wing leading edge shortly after launch. Just 16 minutes away from the conclusion of what had been a successful mission, Columbia disintegrated over Texas.



STS-135: The Final Mission

Columbia Construction Milestones

July 26, 1972	Contract Award
March 25, 1975	Start long-lead fabrication aft fuselage
Nov. 17, 1975	Start long-lead fabrication of crew module
June 28, 1976	Start assembly of crew module
Sept. 13, 1976	Start structural assembly of aft-fuselage
Dec. 13, 1976	Start assembly upper forward fuselage
Nov. 7, 1977	Start of final assembly
May 26, 1978	Upper forward fuselage mate
July 7, 1978	Complete mate forward and aft payload bay doors
Sept. 11, 1978	Complete forward RCS
Feb. 3, 1979	Complete combined systems test, Palmdale
March 8, 1979	Closeout inspection, final acceptance, Palmdale
March 8, 1979	Rollout from Palmdale to Dryden (38 miles)
March 12, 1979	Overland transport from Palmdale to Edwards
March 20, 1979	SCA ferry flight to Biggs AFB, Texas
March 22, 1979	SCA ferry flight to Kelly AFB, Texas

March 24, 1979	SCA ferry flight to Eglin AFB, Fla.
March 24, 1979	SCA ferry flight to KSC
Nov. 3, 1979	Auxiliary power unit hot fire tests, OPF KSC
Jan. 14, 1980	Orbiter integrated test complete, KSC
Feb. 20, 1981	Flight readiness firing
April 12, 1981	First flight (STS-1)

Columbia Numbers

Total miles traveled:	121,696,993
Days in orbit:	300 (7,217 hours, 44 minutes and 32 seconds)
Total orbits:	4,808
Total flights:	28
Total crew members:	160
Second Shuttle, Challenger Notched Firsts	

For a spacecraft initially not intended to fly, Challenger went a long way and chalked up some impressive firsts.

Challenger was built as a test vehicle for the Space Shuttle Program. NASA's quest for a lighter orbiter led to its construction. The idea was to see if the new design with its lighter airframe could handle the heat and stresses inherent in spaceflight.

Challenger was named for HMS Challenger, a British research vessel which sailed the Atlantic and the Pacific during the 1870s. It was



STS-135: The Final Mission

designated OV-99, reflecting in part its original designation as a test object.

In early 1979, NASA awarded orbiter manufacturer Rockwell a contract to convert what was then STA-099 to a space-rated orbiter. The vehicle's conversion began late that year.

That job was easier and less expensive than it would have been to convert NASA's first orbiter, Enterprise, to fly in space. It was still a major process that involved a lot of disassembly and replacement of many parts.

The new orbiter arrived at Kennedy Space Center in July 1982. Challenger was launched on its maiden voyage, STS-6, on April 4, 1983.

That mission saw the first spacewalk of the Space Shuttle Program, as well as the deployment of the first satellite in the Tracking and Data Relay System constellation. The orbiter launched the first American woman, Sally Ride, into space June 18 on mission STS-7 and was the first to carry two U.S. female astronauts on mission 41-G, launched Oct. 5, 1984.

The first orbiter to launch (Aug. 30, 1983) and land at night on mission STS-8, Challenger also made the first shuttle landing at Kennedy Space Center on Feb. 11, 1984, concluding mission 41-B.

Spacelabs 2 and 3 flew on missions 51-B and 51-F (launched April 29 and July 29, 1985), as did the first German-dedicated Spacelab, launched on 61-A. A host of scientific experiments and satellite deployments were done during Challenger's nine successful missions.

Challenger's service to America's space program ended in tragedy on Jan. 28, 1986. Just 73 seconds into mission 51-L, the 25th shuttle flight, a booster joint failure caused an explosion that resulted in the loss of Challenger and its seven-astronaut crew.

Construction Milestones, Test Article STA-99

July 26, 1972	Contract award
Nov. 21, 1975	Start structural assembly of crew module
June 14, 1976	Start structural assembly of aft-fuselage
March 16, 1977	Wings arrive at Palmdale from Grumman
Sept. 30, 1977	Start of final assembly
Feb. 10, 1978	Completed final assembly

Challenger Construction Milestones

Jan. 1, 1979	Contract award
Jan. 28, 1979	Start structural assembly of crew module
Nov. 3, 1980	Start of final assembly
Oct. 21, 1981	Completed final assembly
June 30, 1982	Rollout from Palmdale
July 1, 1982	Overland transport from Palmdale to Edwards
July 5, 1982	Delivery to Kennedy Space Center
Dec. 19, 1982	Flight readiness firing
April 4, 1983	First flight



Challenger Numbers

Total miles traveled: 23,661,990

Days in orbit: (1,495 hours, 56 minutes,
22 seconds)

Total orbits: 995

Total flights: 10

Total crew members: 60

Discovery, a Stalwart of the Shuttle Fleet

With 39 missions to its credit, Discovery has become the workhorse of the shuttle fleet. It was the Return to Flight orbiter after both the Challenger and Columbia accidents. It has visited the International Space Station a dozen times.

It was the first orbiter to carry a Russian cosmonaut aboard and, a year later, the first to visit the Russian space station Mir. On that flight to Mir, STS-63 launched Feb. 3, 1995, was the first female shuttle pilot, Eileen Collins. (She would later become the first woman to command a shuttle on STS-93, launched on Columbia July 23, 1999.)

Discovery deployed the Hubble Space Telescope on STS-31, launched April 24, 1990, and flew both the second and third Hubble servicing missions, STS-82 in February 1997 and STS-103 in December 1999.

It was the third orbiter to join the fleet, arriving at the Kennedy Space Center in Florida in November 1983. It launched on its first flight, 41-D (the 12th shuttle flight) Aug. 30, 1984, to deploy three communications satellites.

STS-133 was its 39th and final flight. It took to the station the Permanent Multi-Purpose Module, converted from the Multi-Purpose Logistics Module Leonardo. In addition to that storage and experiment area, Discovery also carried spare components and an ELC, which was mounted outside the station to hold large components for the station. It also brought Robonaut, a robot with a human-like upper torso, to the station.

Earlier, on STS-124 launched May 31, 2008, it had brought the Japanese Kibo laboratory to the station. On STS-119 launched March 15, 2009, it brought the final piece of the station's backbone main truss into orbit.

Discovery, OV-103, traces its name to two sailing vessels. One was the ship used in the early 1600s by Henry Hudson to explore Hudson Bay and search for a northwest passage from the Atlantic to the Pacific. The other was used by British explorer James Cook on his voyage in the Pacific, leading to the European discovery of the Hawaiian Islands in 1778.

Discovery benefited from lessons learned in the construction and testing of Enterprise, Columbia and Challenger. At rollout, its weight was some 6,870 pounds less than Columbia, which made it more suited for taking heavy components and equipment to the space station.

Discovery underwent modifications over the years. In 1999, it began a nine-month extensive maintenance period at Palmdale, Calif. Beginning in 2002, it began major modifications at Kennedy Space Center – including upgrades and safety modifications.



STS-135: The Final Mission

After 39 missions, Discovery has been retired and will be displayed in the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center near Washington Dulles International Airport in the Virginia suburbs.

Discovery Construction Milestones

Jan. 29, 1979	Contract award
Aug. 27, 1979	Start long-lead fabrication of crew module
June 20, 1980	Start fabrication lower fuselage
Nov. 10, 1980	Start structural assembly of aft-fuselage
Dec 8, 1980	Start initial system installation aft fuselage
March 2, 1981	Start fabrication/assembly of payload bay doors
Oct. 26, 1981	Start initial system installation, crew module
Jan. 4, 1982	Start initial system installation upper forward fuselage
Sept. 3, 1982	Start of final assembly
Feb. 25, 1983	Complete final assembly and closeout installation
May 13, 1983	Complete initial subsystems testing
July 26, 1983	Complete subsystems testing
Aug. 12, 1983	Completed final acceptance
Oct. 16, 1983	Rollout from Palmdale

Nov. 5, 1983	Overland transport from Palmdale to Edwards
Nov. 9, 1983	Delivery to Kennedy Space Center
June 2, 1984	Flight readiness firing
Aug. 30, 1984	First flight (41-D)

Discovery Numbers

Total miles traveled: 148,221,675

Days in orbit: 365

Total orbits: 5,830

Total crew members: 252

Atlantis: First Shuttle to MIR, Last to Hubble

Atlantis, NASA's fourth orbiter to fly in space, was named after the primary research vessel for the Woods Hole Oceanographic Institute in Massachusetts from 1930 to 1966. The two-masted sailing ship had a 17-member crew and accommodated as many as five scientists in two laboratories. It used the first electronic sounding devices to map the ocean floor.

Construction of Atlantis, OV-104, began on March 3, 1980. Thanks to lessons learned in construction and testing of previous orbiters, Atlantis was finished in about half the man-hours spent on Columbia. Large thermal protection blankets were used on its upper body, rather than individual tiles.

At 151,315 pounds on rollout at Palmdale, Calif., Atlantis was nearly 3.5 tons lighter than Columbia. The new orbiter arrived at Kennedy Space Center on April 9, 1985, to prepare for its maiden voyage, 51-J (the 21st shuttle flight)



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launched Oct. 3, 1985. After that classified Department of Defense mission, it flew three more dedicated DoD flights and carried a classified DoD payload on a later mission.

Atlantis deployed a number of noteworthy spacecraft, including planetary probes Magellan and Galileo, as well as the Compton Gamma Ray Observatory. An array of science experiments took place during most missions to further enhance space research in low Earth orbit.

On STS-71, launched June 27, 1995, Atlantis flew the first Shuttle-Mir mission, as well as the subsequent six missions to dock with the Russian space station. During those docked operations Atlantis and Mir formed what was then the largest spacecraft to orbit the Earth.

The missions to Mir included the first U.S. crew exchange. On STS-79, the fourth docking mission, Atlantis ferried astronaut Shannon Lucid back to Earth after her record-setting 188 days in orbit aboard Mir.

Atlantis has delivered a number of components to the International Space Station. Among them were the U.S. laboratory Destiny, the airlock Quest and several sections of the Integrated Truss structure that makes up the station's backbone.

It made the last servicing mission to the Hubble Space Telescope, STS-125 launched May 11, 2009, and delivered the Russian Mini Research Module to the space station on STS-132 launched May 14, 2010.

During overhauls, orbiter maintenance down periods, Atlantis received a number of upgrades and new features. They included a glass cockpit or multifunction electronic display

system, new electrical connections and plumbing to give Atlantis the capability for extended-duration missions, improved nose wheel steering, a drag chute and many more.

Once it has completed its 33rd and final mission in the summer of 2011, Atlantis will retire down the road to the Kennedy Space Center Visitor Complex.

Atlantis Construction Milestones

Jan. 29, 1979	Contract Award
March 30, 1980	Start structural assembly of crew module
Nov. 23, 1981	Start structural assembly of aft-fuselage
June 13, 1983	Wings arrive at Palmdale from Grumman
Dec. 2, 1983	Start of Final Assembly
April 10, 1984	Completed final assembly
March 6, 1985	Rollout from Palmdale
April 3, 1985	Overland transport from Palmdale to Edwards
April 13, 1985	Delivery to Kennedy Space Center
Sept. 12, 1985	Flight Readiness Firing
Oct. 3, 1985	First Flight (51-J)

Atlantis Numbers (through STS-132)

Total miles traveled: 120,650,907

Days in orbit: 294

Total orbits: 4,648

The banner features the STS-135 logo on the left, which includes a shuttle and the text 'PERFORMANCE', 'PROGRESS', and 'PROUDLY SERVING'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white and yellow font against a background of a stylized American flag and a sunset over a horizon.

STS-135: The Final Mission

Total flights: 32

Total crew members: 191

Endeavour: Spare Parts Help Push Orbiter Design

A spacecraft that was partly a collection of spare parts, Endeavour also featured advanced new hardware that helped improve safety and performance of other orbiters when it was later incorporated into them.

Endeavour was authorized by Congress in August 1987 as a replacement for Challenger, lost in a Jan. 28, 1986, accident just after launch. Structural assembly of Endeavour's crew compartment had begun more than five years before the contract to build NASA's newest orbiter was awarded.

Spare parts made during the construction of Discovery and Atlantis, to be used in repairs if they became necessary, eventually were used in Endeavour. The new spacecraft came together pretty well.

Endeavour, OV-105, was named through a national competition of elementary and secondary school students. The name chosen was from a ship of Capt. James Cook used in a 1768 voyage to the South Pacific to observe a transit of Venus at Tahiti. That provided a more accurate knowledge of the distance between the sun and Earth. Other advances, ranging from the discovery of new plant and animal species to the accurate charting of New Zealand, also resulted.

The new shuttle's first mission was STS-49, launched May 7, 1992. A highlight was capture and repair of the Intelsat VI communications satellite whose booster rocket had failed. It took three spacewalks, one involving three

astronauts, but the satellite eventually was caught, fitted with a new booster rocket and successfully redeployed. A then-record fourth spacewalk was done to evaluate space station assembly methods.

Endeavour flew a number of high-profile missions. Highlights included STS-61, the first Hubble Space Telescope servicing mission, launched Dec. 2, 1993; the first space station assembly mission, STS-88 launched Dec. 4, 1998; and installation of the P6 truss with the first set of U.S. solar arrays on STS-97, launched Nov. 30, 2000.

The first Japanese component of the space station was taken by Endeavour to the station in March 2008 and the orbiter brought the final piece of the Japanese segment to the station in July 2009. It also delivered Node 3, Tranquility, and the Cupola, the robotic workstation, to the station in February 2010, completing its U.S. segment.

On STS-99, launched Feb. 11, 2000, Endeavour flew the Shuttle Radar Topography Mission. The around-the-clock work by the orbiter and crew resulted in remarkably accurate topographical maps of most of the Earth's surface.

Endeavour underwent extensive modifications, including the addition of all of the Return to Flight safety upgrades added to both Discovery and Atlantis after the Columbia accident. Endeavour's STS-118 launch on Aug. 8, 2007, was first in four years after a lengthy modernization.

Endeavour will be displayed at the California Science Center, Los Angeles – not too far from the assembly plant where all shuttles were built.



Endeavour Construction Milestones

Feb. 15, 1982	Start structural assembly of crew module
July 31, 1987	Contract award
Sept. 28, 1987	Start structural assembly of aft-fuselage
Dec. 22, 1987	Wings arrive at Palmdale, Calif., from Grumman
Aug. 1, 1987	Start of final assembly
July 6, 1990	Completed final assembly
April 25, 1991	Rollout from Palmdale
May 7, 1991	Delivery to Kennedy Space Center
April 6, 1992	Flight readiness firing
May 7, 1992	First flight (STS-49)

Endeavour Numbers (through STS-134)

- Total miles traveled: 122,883,151
- Days in orbit: 299
- Total orbits: 4,671
- Total flights: 25
- Total crew members: 166
- Mir dockings: 1
- ISS dockings: 11

SHUTTLE UPS AND DOWNS: LAUNCH, LAND AND LAUNCH AGAIN

The most dynamic phases of a space shuttle flight are at the beginning and the end – the

launch and the re-entry and landing. But a lot happens when the shuttle is on the ground.

The flights begin at Kennedy Space Center’s Launch Complex 39. With a single exception, all landings have taken place at KSC or at Edwards Air Force Base in California.

The exception was the third shuttle flight, Columbia’s STS-3. It landed at White Sands Space Harbor in New Mexico on March 30, 1982, because rains had left normally dry lake-bed runways at Edwards AFB unusable.

Of the 134 shuttle launches from KSC, 81 were from Pad 39A, from which Atlantis is scheduled to launch on STS-135. The remaining 53 were from Pad 39B.

The first from 39B was the ill-fated Challenger launch on flight STS-51-L Jan. 28, 1986. The last was Discovery’s STS-116 flight to the International Space Station launched Dec. 9, 2006. Disassembly of shuttle launch structures at Pad 39B began in 2010.

Every journey requires a first step. For the stacked space shuttle, the orbiter with its external tank and solid rocket boosters, that first step is from KSC’s Vehicle Assembly Building to the launch pad. It’s about 3.5 miles to Pad 39A, but the move takes six to eight hours.

Once in orbit, the shuttle will cover an equivalent distance in less than a second.

For the trip to the pad, the shuttle rides atop its mobile launcher platform, mounted on one of two KSC crawler transporters. That steel mobile launcher platform, 25 feet high, 160 feet long and 135 feet wide, weighs more than 8.2 million pounds. Three of the platforms used

The banner features the STS-135 logo on the left, which includes a stylized shuttle and the text 'NASA', 'SHUTTLE', and 'MISSION'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a yellow glow at the bottom right.

STS-135: The Final Mission

in the Apollo Program were modified for shuttle use.

The platform has three openings, two for the booster exhausts and one for the shuttle main engine exhaust. On each side of the hole for main engine exhaust are tail service masts.

The masts are 15 feet long, nine feet wide and rise 31 feet above the platform deck. They have umbilical connections to the orbiter for liquid hydrogen, liquid oxygen, gases, electrical power and communications.

One of the platforms is moved into the huge VAB. The two solid rocket boosters are assembled atop it. Then the large external tank is lowered between the boosters and attached to them.

Only then is the orbiter moved to the VAB and bolted to the external tank. Extensive testing follows. Together the unfueled shuttle and the platform weigh about 11 million pounds.

The crawler transporters are remarkable machines. Built for the Apollo Program under a contract awarded in March 1963, they were then the largest tracked vehicles in existence. Some modifications were needed for use with the shuttle, but they continue to function well. They seem ready for whatever new challenges may be presented to them.

They have twin double-tracked crawlers at each corner. Each track is 10 feet high and 41 feet long. Each track has 57 shoes, measuring 7.5 by 1.5 feet. Each of those shoes weighs more than a ton.

The crawler transporters which carry the platform and the shuttle to the pad are 114 feet long and 131 feet wide. Height is variable, from

20 to 26 feet. That allows it to maneuver under the platform and then lift it.

Each crawler transporter weighs about 5.5 million pounds. They have a 90- by 90-foot flat area in the top deck. Operator control cabs are at each end.

During rollout, the crawler transporter keeps the shuttle stack vertical to within plus or minus 10 minutes of arc – about the diameter of a basketball at the tip of the external tank – even while moving up the ramp to the pad surface.

Propulsion is like that of a diesel-electric railroad locomotive. Two 2,750 diesel engines drive four 1,000 kilowatt generators, which power 16 traction motors. Fuel capacity is 5,000 gallons. Consumption is about 42 feet per gallon, or about 125.7 gallons per mile – not bad with a gross weight of 17 million pounds or more.

Speed, loaded, is about one mile per hour. Without a load, the crawler transporters can race along at about double that rate.

Two additional diesel engines, of 1,065 horsepower each, drive four 1,000 kilowatt electric motors for jacking, steering, lighting and ventilation.

The crawler transporters run along a crawlerway. It has two 40-foot-wide lanes separated by a 50-foot median. The first stretch, linking the VAB with Pad 39A, was finished in August 1965.

The crawlerway lanes are made up of four layers with a total thickness of about eight feet. The top layer is between four and eight inches of river gravel. Then comes four feet of graded,



crushed stone, more than 2.5 feet of fill and a foot of compact fill.

The VAB is a substantial structure. Construction began in July 1963, and it was finished in 1966. By enclosed volume it was then the world's largest building. It covers 8 acres and is 716 feet long and 518 feet wide. It is more than 525 feet tall and encloses 129.4 million cubic feet.

It contains 98.6 tons of steel, 65,000 cubic yards of concrete and is anchored by 4,225 open-ended steel pipe piles 16 inches in diameter driven 160 feet down into bedrock.

A U.S. flag 209 feet long and 110 feet wide, then the largest anywhere, was painted on its side in 1976. The flag and a bicentennial emblem also added that year required 6,000 gallons of paint. The emblem has since been replaced with a king-size NASA meatball.

KSC's Launch Control Center is a four-story facility attached to the VAB. It does much of the space shuttle checkout. It also is responsible for the countdown and launch.

The LCC has handled all space shuttle launches. Its first use was on Nov. 9, 1967, for the unpiloted Apollo 4 launch with the first Saturn V. The facility's construction had started in March 1964. Completed in May 1965, it won that year's Architectural Award for Industrial Design of the year.

In addition to its prerollout duties, once the shuttle is at the pad, the LCC takes control of operations there. That continues through a terminal countdown demonstration test in which the crew and launch team simulate the final hours of countdown and through the

countdown itself beginning about two days before launch.

Two firing rooms on the LCC's third floor are configured for full control of launch operations. The firing rooms have a number of consoles staffed with specialists in various areas. The launch director faces the consoles and is responsible for launch operations.

Once the countdown is resumed after a scheduled 10-minute hold at T - 9 (nine minutes before launch) a ground launch sequencer puts the final countdown under computer control, subject to human intervention.

When the shuttle clears the launch tower, control shifts to Houston.

The shuttle flight control room at Johnson Space Center's Mission Control Houston has been responsible for all shuttle flights. It replaced the Mercury Control Center at Cape Canaveral in 1965 and was responsible for all but one of the Gemini missions as well as the Apollo flights.

A new five-story MCC wing was built in the early 1990s. The original flight control room was gradually replaced by one in the new facility. The new FCR supported orbital operations of the STS-70 mission in July 1995. For STS-77 in May 1996, it supported ascent and entry as well.

The shuttle flight director leads a team on more than 15 consoles, each supported by additional specialists called a "backroom." Three teams of flight controllers work around the clock through the mission. Additional teams serve for ascent and entry.



As the space station program began, a new flight control room was established a few steps from the shuttle FCR. It was replaced when Flight Control Room 1, established in 1965, was updated and upgraded. FCR 1 was recommissioned in October 2006.

With the shuttle's focus almost entirely on the station and with the station growing in complexity and to virtual completion, it remains important for the two flight control rooms to work together.

Assuming a landing at its 15,000-foot-long, 300-foot-wide concrete runway, KSC takes over again. A specialized convoy of 25 or more vehicles and perhaps 150 trained individuals make sure the area around the shuttle is safe to approach. Ground support umbilicals are attached and the crew leaves the spacecraft, generally for a walk around. When the crew leaves the orbiter, formal control returns to KSC.

Within about four hours of landing, the shuttle is towed to the Orbiter Processing Facility. If the shuttle landing is at Edwards, as more than 50 have been, or elsewhere and returns on one of the Boeing 747 shuttle transport aircraft, it is dismantled and towed to the OPF as promptly as possible.

There, the refurbishment and processing process began anew, the process that saw the orbiter eventually towed to the VAB, attached to a new external tank and finally rolled out to the pad for its subsequent mission.

THREE LANDING SITES USED, MANY MORE AVAILABLE

With a single exception, all space shuttle landings have been at Kennedy Space Center in

Florida or at Edwards Air Force Base in California. Columbia on STS-3, the third flight of the program, landed March 30, 1982, at White Sands Space Harbor in New Mexico.

Of the 132 landings through STS-134, 77 have been at KSC and 54 at Edwards. Of the Edwards landings, 19 were on lakebed runways and one, Endeavour's STS-126 flight on Nov. 23, 2008, was on a temporary asphalt runway.

The remaining 34 Edwards landings were on concrete runways. The New Mexico landing, STS-3 on March 30, 1982, was on a dry gypsum lakebed.

A total of 24 landings have been at night. Eighteen of those were at KSC and six were at Edwards.

Kennedy Space Center

KSC is the preferred landing site. Its 15,000-foot concrete runway is 300 feet wide and has 1,000-foot overruns at each end.

The single runway, designated runway 15 or runway 33 depending on the direction of landing, is grooved and 15 inches thick at its center.

At about the midpoint of the runway's length and just east of it is a recovery convoy staging area. There trailers, mobile units and other specially designed vehicles await the orbiter. They safe the orbiter just after landing, help get the crew off and transfer the spacecraft to the orbiter processing facility. Typically a returning orbiter can be in the OPF about four hours after landing.

Adjacent to the runway is a 490- by 550-foot parking apron with a mate/demate device at

The banner features the NASA logo on the left, a stylized shuttle launch in the center, and the text "STS-135: The Final Mission" in a large, bold, yellow font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

one corner to raise and lower the orbiter from atop the shuttle carrier aircraft.

The parking area is connected by a two-mile tow way to the Orbiter Processing Facility. An Edwards landing and return of the orbiter atop its carrier aircraft adds perhaps a week to the spacecraft's reaching the OPF.

Construction of the shuttle landing facility was completed in 1976. The first shuttle landing there was on Feb. 11, 1984, by Challenger on STS-41-B, the 10th shuttle flight. Two subsequent landings by Discovery were made there on the 14th and 16th shuttle flights, STS-51-A on Nov. 16, 1984, and STS-51-D April 19, 1985.

Brake and tire damage caused suspension of KSC shuttle landings. The next orbiter landing there was Atlantis on STS-38 on Nov. 20, 1990.

The facility has a number of advance navigation aids to help shuttles land, as do other actual and potential landing sites.

Edwards Air Force Base

Edwards is in the Mojave Desert about 100 miles east of Los Angeles. Its Rogers Dry Lake bed was used for landings in early space shuttle test, and it was the primary landing site for the shuttle until late 1990. The lakebed has been used by military aircraft since the early 1930s.

There are seven runways drawn on the lakebed, crisscrossing one another. The longest extends 7.5 miles. The main Edwards concrete runway is next to the dry lakebed. With its 15,000-foot length with a 9,000-foot lakebed overrun, it is among the world's longest runways.

Edwards and NASA's Dryden Flight Research Center, a base tenant, were important in approach and landing tests with Enterprise, the prototype orbiter that never flew in space. Dryden also contributed to development of the shuttle thermal protection system, solid rocket booster recovery system, flight control system computer software and the orbiter drag chutes.

Edwards remains the preferred shuttle backup landing site and serves as an emergency landing site for the shuttle.

White Sands Space Harbor

Located on White Sands Missile Range in southern New Mexico, the White Sands Space Harbor remains a backup shuttle landing site and is the primary training area for shuttle pilots flying practice approaches and landings in the shuttle training aircraft and T-38 chase aircraft.

The White Sands Test Facility, part of the Johnson Space Center, operates White Sands Space Harbor (WSSH), the WSSH complex built on a dry gypsum lakebed to simulate actual shuttle landing facilities in United States and abroad. It is a shuttle backup landing facility and was used during the landing of STS-3 in March 1982.

Two operational runways are 35,000 feet long and 300 feet wide. Both are 15,000 feet long with 10,000-foot overruns on each end. In 1989, a third runway was constructed to allow pilots to practice Transatlantic Abort Landings (TAL). The TAL runway is 12,800 feet long and 150 feet wide, smaller and narrower than the primary runways.

It is an abort-once-around landing facility. It was primary for high inclination launches and



secondary for International Space Station missions. All three runways are prepared continuously for training missions, and the north-south and east-west runways are laser leveled to a tolerance of plus or minus an inch in 1,000 feet to be ready for shuttle landings.

Contingency Landing Sites

Contingency sites are identified for each shuttle mission, depending on the inclination of launch (the angle to the equator), the nature of the potential problem and the availability of possible landing sites.

Each shuttle mission has at least two TAL sites in its contingency plan. They are selected shortly before launch, based on weather forecasts.

Shuttle missions to the space station have focused on TAL sites at Istres, France, and Zaragoza and Morón, Spain. For lower inclination flights, Ben Guerir, Morocco, and Banjul in the Gambia had been used.

Banjul was discontinued as a TAL site in November 2002 and Ben Guerir was last used in that capacity in June 2002. Earlier, Dakar Senegal had been used, but was replaced by Banjul in 1988. Casablanca, Morocco, had been used until January 1986.

A number of emergency landing sites, which could be used in the event of a sudden problem necessitating return to Earth, have been selected. In practice, the shuttle could land on any paved runway at least 9,800 feet long, as are runways of most large commercial airports. A military landing facility would be preferred, because of security and to avoid disruption of a civilian airport.

ASTRONAUT CORPS MARKS CHANGES IN SPACE, SOCIETY

The space shuttle brought marked changes to space activities, helping to move our approach from exploration toward utilization. It also reflected and in many ways contributed to societal change, and it helped make space an arena of international cooperation rather than competition.

The makeup of the astronaut corps and other shuttle crew members reflects each of those changes. Without the shuttle, those developments would have been much slower in coming.

The initial emphasis, beginning with the seven Mercury astronauts, had been on selection of the best test pilots. The space shuttle made space access available to people who did not have to be in top physical condition and in the prime of life.

Only one of the Mercury 7 flew aboard the space shuttle. John Glenn became the first American to orbit the Earth and a national hero on the Feb. 20, 1962, flight of a Mercury capsule named Friendship 7.

On Oct. 29, 1998, Glenn, then 77 and a U.S. senator nearing the end of his fourth and final term, launched as a payload specialist on the nine-day STS-95 flight of Discovery. He was the oldest human to fly in space. Among his six fellow crew members were a female Japanese astronaut and a Spanish astronaut representing the European Space Agency.

In the more than 36 years between his two flights, the first American woman to fly in space, Mission Specialist Sally Ride, had flown on Challenger on STS-7 launched June 18, 1983.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION SPECIALIST' and 'STS-135'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

Mission specialists work with the commander in shuttle systems, planning, and experiment and payload operations. The first mission specialist was Joe Allen on Columbia's STS-5 flight, launched Nov. 11, 1982.

The flight after Ride's, STS-8 launched Aug. 20, 1983, also on Challenger, had among its crew Mission Specialist Guion S. Bluford Jr., the first U.S. African American in space. Ulf Merbold of Germany flew on Columbia on STS-9 as the first payload specialist, a new crew category, and the first European in orbit.

Payload specialists are crew members who are not NASA astronauts and who have specialized duties on the spacecraft, often focusing on payloads.

Culturally diverse and international crew members, each with distinguished backgrounds and the products of exhaustive training, continued to fly and to contribute to missions during those 36 years between Glenn's two flights and to the present.

The right stuff had been redefined.

International Space Station assembly and maintenance has been among the major accomplishments of the Space Shuttle Program. In preparation for it, the shuttle flew 10 missions to the Russian space station Mir.

Shuttle crew members began assembly of the station in December 1998, attaching the Unity node to the previously launched Russian-built Zarya module. Cosmonaut Sergei Krikalev and Discovery Commander Robert D. Cabana entered the infantile station together.

Since that time, the shuttle has delivered new modules, new crew members, equipment and supplies to the station. It would have been

difficult to launch some of those cargos by other means, and impossible to bring the cargos it returned from the station to Earth by other means.

International crew members have included cosmonauts, European Space Agency astronauts, Japanese astronauts, Canadian astronauts, and more.

Well before station assembly began, payload specialists from many countries had flown aboard the shuttle.

During the early days, the first three groups of astronauts selected were pilot astronauts. Members of the fourth group, selected in June 1965, were science astronauts. All six had Ph.D. or M.D. degrees.

After the fifth group of pilot astronauts selected in April 1966, another group of science astronauts, all 11 with doctorates or M.D. degrees, was named in August 1997, additional evidence of the space pendulum continuing its swing from exploration to utilization.

When the Air Force Manned Orbiting Laboratory program was canceled in mid-1969, seven astronaut trainees transferred to NASA. All subsequently flew on the space shuttle.

One, Robert Crippen, was pilot of the first shuttle flight and subsequently commanded three others. Another, Richard H. Truly, flew on two shuttle flights and from 1989 to 1992 served as NASA administrator.

The first group of astronaut candidates for the Space Shuttle Program was selected in Group 8 in January 1978. Its 20 mission specialists, the first selected under that designation, and 15 pilots, included Michael Coats, who flew three shuttle missions and who, in

The banner features the STS-135 logo on the left, which includes a stylized shuttle and the text 'NASA', 'STS-135', and 'ORION'. To the right, the title 'STS-135: The Final Mission' is written in a large, bold, white font against a background of a blue and red sky with a bright light source on the right.

STS-135: The Final Mission

November 2005, became director of Johnson Space Center. Group 8 was the largest astronaut class up to that time. It was equaled only in May 1996 by group 16, also with 35 members.

Group 9 included another astronaut turned agency administrator, Charles F. Bolden Jr. He flew as pilot on two shuttle missions, and commanded two others. He became NASA administrator July 17, 2009.

Eleven groups of pilots and mission specialists have been selected since then: 19 in 1980, 17 in 1984, 13 in 1985, 15 in 1987, 23 in 1990, 19 in 1992, 19 in 1995, 35 in 1996, 25 in 1998, 17 in 2000, 11 in 2004 and nine in the most recent group in 2009.

Among members of the 1985 group was Cabana, who flew four shuttle missions, including that first station assembly flight, Discovery's STS-88 mission in December 1998. He later served as director of Stennis Space Center and since October 2008, he has served as director of Kennedy Space Center.

The 2004 group was notable because it included three candidates designated educator mission specialists. Two of them, Joseph M. Acaba and Richard R. Arnold, flew on Discovery's STS-119 mission launched March 15, 2009, under the designation mission specialist/educator astronaut. The third, Dorothy Metcalf-Lindenburger, served as a mission specialist on Discovery's STS-131 flight launched April 5, 2010.

The three followed Barbara Morgan, who had been selected as a mission specialist and educator astronaut in 1998. She flew on Endeavour's STS-118 flight launched Aug. 8, 2007.

She had been a backup to Christa McAuliffe, NASA's first teacher in space, and trained with the STS-51L crew. McAuliffe and her six crewmates were killed in the Challenger explosion Jan. 28, 1986.

"Astronaut" comes from a Greek word meaning space sailor. Things have become a little more complicated since the days of the Odyssey.

Currently, candidates for pilot NASA astronauts (shuttle or space station) must have a bachelor's degree in engineering, biological or physical sciences or math. An advanced degree is desirable. At least 1,000 hours as pilot-in-command of jet aircraft is required, and test pilot experience is desirable. They also have to pass a NASA space physical. Requirements include vision correctable to 20/20 in each eye, blood pressure no higher than 140/90 sitting, and height between 62 and 75 inches.

Mission specialist candidates must have the same type of bachelor's degree, plus at least three years of related and progressively responsible professional experience. A master's degree can substitute for one year of that experience, a doctorate for three years. Physical requirements are similar.

A total of 330 NASA astronaut candidates have been selected, beginning with the Mercury 7 in 1959. Today, 61 current astronauts serve in the corps.

Competition is fierce. For example, applications for the most recent astronaut class, the 20th, totaled more than 3,500. Of those who applied, only the nine were selected as astronaut candidates. Three are test pilots, three are women and two are flight surgeons.

None of them will fly on the space shuttle.



HUBBLE AND THE SHUTTLE: NEW VIEWS OF OUR UNIVERSE

The space shuttle has been instrumental in the success of the Hubble Space Telescope, launching the orbiting observatory and performing repairs and upgrades during five servicing missions.

Discovery launched on STS-31 with Hubble aboard on April 24, 1990. The crew, including Pilot Charles F. Bolden (who became NASA administrator July 17, 2009), deployed Hubble 384 statute miles above Earth on April 25.

Two months later, on June 25, Hubble's main mirror was discovered to be flawed. Later that year, the Corrective Optics Space Telescope Axial Replacement, a complex package of five optical mirror pairs to rectify the mirror problem, was approved.

The package was launched on Endeavour's STS-61 flight Dec. 2, 1993. On five spacewalks, crew members on the planned Servicing Mission 1 installed a new device, as well as the Wide Field Planetary Camera 2, new solar arrays, new gyroscopes and electronic equipment.

Servicing Mission 2 brought two new and advanced instruments to Hubble, the Near Infrared Camera and the Multi-Object Spectrometer. During that STS-82 flight of Discovery launched Feb. 11, 1997, crew members also installed a refurbished fine guidance sensor, a solid state recorder, and a refurbished spare reaction wheel assembly which helps point the telescope.

After three of Hubble's six gyroscopes failed (three are required for observations), NASA split the next Hubble flight into Servicing Mission 3A and Servicing Mission 3B. Before

Discovery launched on 3A on Dec. 19, 1999, a fourth Hubble gyroscope had failed on Nov. 13, causing the telescope to be put into safe mode.

During three spacewalks 3A crew members replaced all six gyroscopes and one of Hubble's fine guidance sensors. They also installed a transmitter, an advanced central computer, a digital data recorder and other electronic equipment.

Columbia launched on the 3B mission, STS-109, on March 1, 2002, to install Hubble's new Advanced Camera for Surveys. It could capture the most distant images of the universe and collect data much more quickly than its predecessor.

On five spacewalks, 3B astronauts also replaced the telescope's solar arrays with smaller and more powerful panels, replaced the power control unit and one of the four reaction wheel assemblies. They also installed a new cooling system for an infrared camera, which had been out of action since 1999.

On the final shuttle flight to Hubble, Servicing Mission 4, Atlantis launched May 11, 2009, on STS-125. On five spacewalks astronauts installed two new instruments, the Wide Field Camera and the Cosmic Origins Spectrograph and repaired two others, the Advanced Camera for Surveys which had ceased functioning in 2007 and the Space Telescope Imaging Spectrograph, which had not worked since 2004. They also replaced gyroscopes and batteries.

Hubble is better than ever with greater capabilities – with six complementary science instruments – and supporting equipment that is expected to help extend its operational life to at least 2014. Without the space shuttle, that could not have happened.



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STS-135: The Final Mission

STS-135 MISSION OVERVIEW



Dawn approaches after space shuttle Atlantis completed its historic final journey to Launch Pad 39A from NASA Kennedy Space Center's Vehicle Assembly Building. Atlantis was secured, or "hard down," at its seaside launch pad at 3:29 a.m. (EDT) on June 1, 2011. The milestone move, known as "rollout," paves the way for the launch of the STS-135 mission to the International Space Station, targeted for July 8. STS-135 will be the 33rd flight of Atlantis, the 37th shuttle mission to the space station and the 135th and final mission of NASA's Space Shuttle Program.

January 5, 1972. President Richard M. Nixon announced the initiative for a new space vehicle for the United States..... "I have decided today that the United States should proceed at once with the development of an entirely new type of space transportation system designed to help transform the space frontier of the 1970s into familiar territory, easily accessible for human endeavor in the 1980s and '90s."

April 21, 1972. On the lunar surface at the Plains of Descartes, Apollo 16 Commander John Young and Lunar Module Pilot Charles Duke receive a call from Spacecraft Communicator Anthony England at Mission Control, Houston.

England: *"This looks like a good time for some good news here. The House (of Representatives) passed the space budget yesterday, 277 to 60, which includes votes for the (space) shuttle."*

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'PERSONALITY', 'MISSION', and 'ADAPTABILITY'. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

STS-135: The Final Mission

Duke: *"Beautiful. Wonderful. Beautiful."*

Young: *"The country needs that shuttle mighty bad. You'll see."*

Almost four decades after that exchange, and three decades after its engines and solid rocket boosters first flashed to life to send humans into orbit on April 12, 1981, the space shuttle is poised to fly one final time as Atlantis sits on Launch Pad 39A at the Kennedy Space Center, Fla., ready to blast off on July 8 at 11:26 a.m. EDT to send four American astronauts aloft on its 33rd mission since it first flew in October 1985 and the 135th and last flight in the storied history of the Space Shuttle Program.

This 37th and final visit of a space shuttle to the International Space Station is solely designed to stock the complex with as many supplies and spare parts as possible for sustenance of the outpost and its crews in the post-shuttle era.

Commanding the final flight of the space shuttle is veteran NASA astronaut Chris Ferguson, 49 (Capt., USN, Ret.), who will be making his third flight into space, all to the International Space Station. He was Atlantis' pilot on the STS-115 mission in September 2006 and commanded Endeavour on the STS-126 mission to the station in November 2008.

Atlantis' last pilot is Doug Hurley, 44 (Col., USMC). Hurley is making his second flight into space, having flown to the station aboard Endeavour in July 2009 on the STS-127 mission that completed the Japanese segment of the International Space Station.

Mission specialist 1 is Sandra Magnus, 46, a veteran of two spaceflights. Magnus visited the station on Atlantis in October 2002 on the STS-112 mission to deliver one of the truss

segments for the complex and returned as an Expedition 18 long-duration crew member, launching on Endeavour as part of Ferguson's crew on STS-126 in November 2008 and returning to Earth with the STS-119 crew on Discovery in March 2009 after 134 days in space and 132 days on the station.

Mission specialist 2 and flight engineer is Rex Walheim, 48 (Col., USAF, Ret.). Walheim is making his third flight into space, all on Atlantis. Walheim first flew in April 2002 on the STS-110 mission and returned to the complex in February 2008 on the STS-122 mission that delivered the European Space Agency's Columbus science laboratory.

Atlantis' final crew is limited to four astronauts since there is no shuttle available anymore to serve as a "rescue" vehicle in the unlikely event Atlantis would incur damage to its thermal protection heat shield during launch that would prevent it from coming back to Earth. In that case, the four crew members would have to rely on Russian Soyuz vehicles to bring them home in a staggered fashion over the course of several months. The four crew members will transport custom-made Soyuz seat liners to the station to protect for that possibility.

In its 30 years of flights, the space shuttle has served as the ride for 355 different individuals from 16 countries.

Housed in Atlantis' payload bay will be the Raffaello Multi-Purpose Logistics Module (MPLM), the large cargo carrier that will be filled with 8,640 pounds of supplies for the station and its six crew members. Raffaello will be making its fourth delivery trip to the station, having first flown in April 2001 on Endeavour on the STS-100 mission. Its last flight was on the Return to Flight mission of Discovery on STS-114 in 2005.



STS-135: The Final Mission



NASA astronauts, from left, Sandra Magnus, Doug Hurley, Chris Ferguson and Rex Walheim walk to dinner after an informal gathering for the STS-135 Crew Equipment Interface Test (CEIT) at the Fish Lips restaurant near NASA's Kennedy Space Center in Florida on April 7, 2011.

Raffaello will be unberthed from the payload bay by the station's Canadarm2 robotic arm on the fourth day of the mission and mated to the earth-facing port of the Harmony module. Raffaello will be parked next to the Leonardo Permanent Multi-Purpose Module that was permanently attached to the station's Unity module nadir port in March to serve as a storage closet for the station's residents.

Atlantis' launch will be timed to occur when the Earth's rotation places the Kennedy Space Center in the plane, or corridor, of the space station's orbit. The launch also will serve as the

first act in the carefully choreographed rendezvous that will later use the shuttle's orbital maneuvering engines to position Atlantis and fine-tune its path to track down and catch up to the station for docking two days later.

Once they reach orbit on launch day, Ferguson and his crewmates will set up their ship for in-orbit operations, opening Atlantis' payload bay doors and downlinking video and digital still imagery of the last external fuel tank that housed the half million gallons of liquid hydrogen and liquid oxygen for the shuttle's



STS-135: The Final Mission

main engines for the 8 ½-minute ride to orbit. The crew will then unfurl Atlantis's robotic arm and conduct a brief survey of the payload bay and its cargo.

The next day, the crew will use the arm to reach over to the starboard sill of the payload bay to grapple and unberth the 50-foot-long Orbiter Boom Sensor System (OBSS) that will use its laser imaging device and high-fidelity cameras

to inspect the reinforced carbon-carbon along the leading edges of Atlantis' wings and the shuttle's thermal protection heat shield. The inspection should take about six hours to complete. All of that imagery plus launch day imagery and that to be collected by the station crew of Atlantis on its approach for docking will be pored over by analysts at the Johnson Space Center in Houston to ensure that Atlantis is fit for its final entry back to Earth.



NASA astronauts Doug Hurley (left), STS-135 pilot, and Rex Walheim and Sandra Magnus, both mission specialists, attired in training versions of their shuttle launch and entry suits, participate in a post insertion/deorbit training session on the flight deck of the crew compartment trainer (CCT-2) in the Space Vehicle Mock-up Facility at NASA's Johnson Space Center. STS-135 is planned to be the final mission of the Space Shuttle Program.



STS-135: The Final Mission

The crew will also gear up for its arrival at the station the next day, checking out rendezvous tools and powering up the docking mechanism that will latch up with the station's docking port.

On Flight Day 3, two days after launch, Atlantis will take center stage as it links up to the station for the final time.

About three hours before docking, Atlantis' orbital maneuvering system engines will fire as the shuttle is about nine miles behind the station in the "terminal initiation burn" that will put Atlantis on a final intercepting path to reach a point about 1,000 feet below the complex on the radial vector, or "R-bar," an imaginary line drawn between the station and the Earth.

From there, Ferguson will take a position at the shuttle's aft flight deck to fly Atlantis up the R-bar in a stair step approach to about 600 feet directly below the station where he will apply the brakes.

Within minutes, Ferguson will command Atlantis to begin a three-quarter of a degree per minute rotational back flip called the R-bar Pitch Maneuver (RPM). This will present Atlantis' heat shield to Expedition 28 Flight Engineers Mike Fossum of NASA and Satoshi Furukawa of the Japan Aerospace Exploration Agency, who will be inside the station's Zvezda Service Module armed with digital cameras equipped with 800 mm and 400 mm lenses to document the shuttle's condition. Those images will be downlinked almost immediately for analysis on the ground. Fossum and Furukawa launched to the station on June 8 on a Russian Soyuz spacecraft with cosmonaut Sergei Volkov and docked to the

complex on June 10 to join station Commander Andrey Borisenko, Alexander Samokutyaev and NASA astronaut Ron Garan, who have resided on the station since April.

Ferguson will then guide Atlantis to a point about 400 feet directly in front of the station on the "V-bar," or velocity vector, the direction of travel for both the shuttle and the station. Ferguson will slowly fly Atlantis down a narrow corridor, aligning the extended docking mechanism ring with its target, Pressurized Mating Adapter 2. Contact and capture to complete the rendezvous should occur just minutes later.

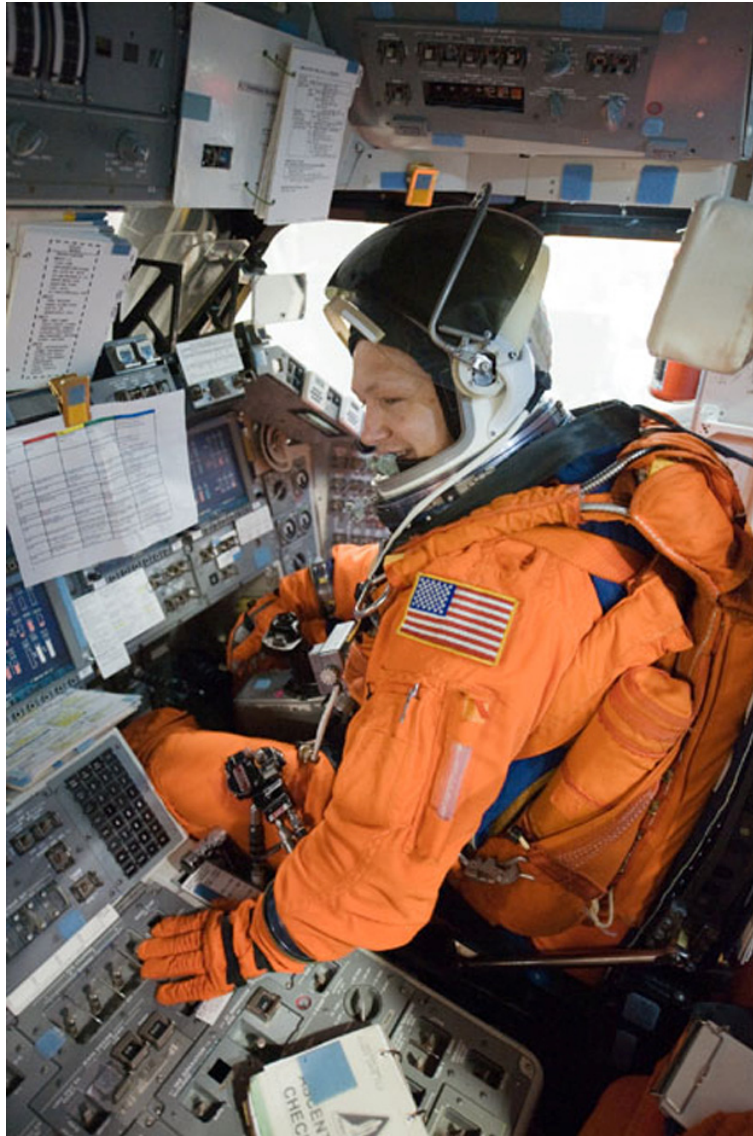
After about 90 minutes, or one orbit of the Earth, to enable crews on both sides of the docking interface to conduct leak checks, hatches between Atlantis and the station will swing open and the crews will greet one another to begin more than a week of joint operations.

The first order of business will see Garan and Furukawa use Canadarm2 to reach over and unberth the orbiter boom extension for a handoff to the shuttle arm operated by Ferguson and Hurley. The boom will be used a few days later for yet another set of inspections of Atlantis' heat shield.

Flight Day 4 will be devoted to the unberthing and installation of the Raffaello MPLM to Harmony. Hurley and Magnus will be at the controls of the Canadarm2 to lift the 12.5-ton module out of Atlantis' payload bay and slowly maneuver it for installation at the nadir port of the Harmony module where a series of bolts will secure it to Harmony's berthing mechanism.



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While seated at the pilot's station, NASA astronaut Doug Hurley, STS-135 pilot, participates in a post insertion/de-orbit training session on the flight deck of the Crew Compartment Trainer (CCT-2) in the Space Vehicle Mock-up Facility at NASA's Johnson Space Center. Hurley is wearing a training version of his shuttle launch and entry suit. STS-135 is planned to be the final mission of the Space Shuttle Program.

The crew will conduct leak checks and pressurize a small passageway between Harmony and Raffaello before opening of its hatch to begin the critical transfer of cargo that will keep the station stocked for up to a year.

At the end of the day, the shuttle crew will join station crew members Fossum and Garan to review procedures for the one spacewalk of the mission that Fossum and Garan will conduct the next day on Flight Day 5. The final

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION OVERVIEW' and '2010-2011'. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and white American flag with a yellow glow at the bottom right.

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spacewalks using shuttle crew members were conducted in May on the STS-134 mission.

Rather than the “campout” procedure used on a number of station-based spacewalks, a new, less time-consuming procedure was successfully employed on the STS-134 mission called ISLE, for In-Suit Light Exercise. It is a protocol that requires fewer consumables for the spacewalkers and requires less time to purge nitrogen from their bloodstreams to avoid decompression sickness when they leave the Quest airlock to work in the vacuum of space. The ISLE technique that was inaugurated by spacewalkers Drew Feustel and Mike Fincke before their third spacewalk in May on STS-134 will be used by Fossum and Garan on the morning of Flight Day 5. It is best illustrated by the spacewalkers flexing their legs and performing small squats to increase the flow of their blood while suited in their extravehicular mobility units.

The spacewalk out of Quest by Fossum and Garan will be the 160th devoted to space station assembly and maintenance. It will be the seventh spacewalk for Fossum, who has logged 42 hours and 1 minute of spacewalking time on two previous flights. Garan has conducted three previous spacewalks totaling 20 hours and 32 minutes. Ironically, the duo performed three spacewalks together on the STS-124 mission in June 2008 on the mission that delivered the Japanese Experiment Module, “Kibo,” to the station.

Fossum and Garan will first make their way from Quest to a spare parts platform called the External Stowage Platform-2 on the side of the

airlock. Bolted to ESP-2 is the ammonia pump module that suddenly shut down on July 31, 2010, taking down half of the station’s cooling capability. The failed component, which is mounted on a bracket, will be removed from ESP-2 by Garan whose feet will be planted in a portable foot restraint at the end of the Canadarm2 operated by Hurley and Magnus.

With the assistance of Fossum, Garan will be lowered toward the rear of Atlantis’ payload bay where he will install the failed pump onto a payload carrier called the Lightweight Multi-Purpose Experiment Support Structure Carrier, or LMC. The International Space Station Program Office is eager to return the pump so the exact cause of its failure can be determined and the pump can be refurbished.

With that task completed, Fossum and Garan will swap places at the end of the Canadarm2. Fossum then will remove a device from the LMC called the Robotic Refueling Mission, or RRM. The experimental payload, which resembles a washing machine, is 43 inches by 33 inches by 45 inches and weighs 550 pounds on Earth.

The RRM is an experiment designed to demonstrate new technology to robotically refuel satellites in space, particularly satellites that were never designed to be refueled. Fossum will be transported on Canadarm2 over to the Canadian Space Agency’s Dextre robot, where the RRM will be transferred to Dextre’s Enhanced Orbital Replacement Unit Temporary Platform, or EOTP, a high-tech stowage area for tools and experiments.



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NASA astronaut Chris Ferguson, STS-135 commander, uses a computer during a training session in a space station mock-up in the Space Vehicle Mock-up Facility at NASA's Johnson Space Center.

At a later date after Atlantis' departure, the RRM will be moved by Dextre to the ExPRESS Logistics Carrier-4, or ELC-4, a spare parts carrier on the starboard truss to allow Dextre to conduct various dexterous tasks on its activity boards to test experimental refueling components.

The two spacewalkers will also move a payload from a material experiment mounted on the station's truss to ELC-2 to wrap up the final task of the planned 6.5-hour excursion.

If required, a more detailed inspection of Atlantis' heat shield could be accommodated on Flight Day 6 by the four shuttle crew

members using the OBSS attached at the end of the shuttle's robotic arm. But if mission managers deem that unnecessary, the crew members will instead begin several days of transfer activities of the cargo brought to the station in the Raffaello module and from lockers in Atlantis' middeck. This final transfer of items to stock the station is considered one of the most critical objectives of the mission.

On the final day of the last visit of a shuttle to the station on Flight Day 10, the crew will complete the final transfer of cargo from Raffaello to the complex, close the MPLM's hatch, depressurize the vestibule passageway to

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'INTERNATIONAL SPACE STATION' and '2011'. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and white American flag with a glowing orange and yellow light effect at the bottom right.

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Harmony and prepare for its demating from the nadir port of the connecting node.

Operating the Canadarm2 robotic arm, Hurley and Magnus will grapple Raffaello and, after it is unbolted from Harmony, the cargo module filled with items to be returned to Earth will be removed from the station and lowered down into Atlantis' payload bay where it will be latched in place for the ride back home.

Then, it will be time for Atlantis' astronauts to say farewell to the Expedition 28 crew. Late on Flight Day 10, hatches will be closed between the station's Pressurized Mating Adapter-2 docking port and Atlantis, and preparations will begin for undocking the following day.

On the morning of Flight Day 11, 12.5 years after assembly of the International Space Station began with Endeavour's arrival to mate the Unity module with the Zarya control module on STS-88, Atlantis will pull away from the Harmony module for the final time.

With Hurley at the controls at Atlantis' aft flight deck, the shuttle will slowly back away from the complex, leaving behind almost a million pounds of international hardware and a fully supplied world-class science laboratory expected to function for at least another decade.

Hurley will conduct a final flyaround of the station as his crewmates collect digital images and high-definition video of the complex, the final views a space shuttle crew will ever have of the orbital outpost. After a little more than an hour of precision flying around the station at a radial distance of about 600 feet, Hurley will fire Atlantis' jets to depart the complex for the final time.

Later that day, Ferguson, Hurley and Magnus will conduct one last inspection of Atlantis' heat shield with the OBSS before it is berthed back on the starboard sill of Atlantis' payload bay. It will be the last time the shuttle's robotic arm will ever be used, dating back to its inaugural flight on the shuttle Challenger in April 1983 on the STS-7 mission, operated by the first American woman to fly in space, Sally Ride.

Flight Day 12 will see Ferguson and Hurley activate one of Atlantis' hydraulic power systems to conduct the traditional checkout of the shuttle's flight control surfaces followed by the firing of its steering jets to ensure the orbiter is ready to support its last descent back to Earth the next day.

Right after the flight control system checkout is complete, the crew will send commands to deploy a small 5" x 5" x 10" technology demonstration satellite called PicoSat from a canister in Atlantis' cargo bay. PicoSat will relay data back to investigators on the performance of solar cells that cover the nanosatellite for analysis and possible use on future space hardware.

The crew will then pack up items used during the mission, stow the Ku-band communications antenna for the final time and complete landing preparations.

On Flight Day 13, the crew will climb into their launch and entry suits, close Atlantis' payload bay doors for the last time, and with approval from Entry Flight Director Anthony Ceccacci at Mission Control in Houston, fire the shuttle's orbital maneuvering system engines to begin its last journey home.



STS-135: The Final Mission

Landing is scheduled on July 20, the 42nd anniversary of Apollo 11's historic landing on the moon, on the Shuttle Landing Facility at the Kennedy Space Center around sunrise. The space shuttle's 30-year quest to push the boundaries of exploration, provide a new vision of the universe and construct an international way station in the sky, will be over.

"We're really not too far – the human race isn't – from going to the stars, and I'm mighty proud to be part of it."

– John Young; April 14, 1981, at Edwards Air Force Base, Calif., after landing the space shuttle Columbia to complete STS-1.



NASA astronauts Rex Walheim (right) and Sandra Magnus, both STS-135 mission specialists, participate in an Extravehicular Activity (EVA) hardware training session in the Neutral Buoyancy Laboratory near NASA's Johnson Space Center. EVA instructors John Ray (left foreground) and Art Thomason assist Walheim and Magnus.



STS-135 TIMELINE OVERVIEW

Flight Day 1

- Launch
- Payload Bay Door Opening
- Ku-Band Antenna Deployment
- Shuttle Robotic Arm Activation and payload bay survey
- Umbilical Well and Handheld External Tank Photo and TV Downlink

Flight Day 2

- Atlantis' Thermal Protection System heat shield survey with Shuttle Robotic Arm/Orbiter Boom Sensor System (OBSS)
- Centerline Camera Installation
- Orbiter Docking System Ring Extension
- Rendezvous tools checkout

Flight Day 3

- Rendezvous with the International Space Station
- Rendezvous Pitch Maneuver Photography of Atlantis' Thermal Protection System by Expedition 28 crew members Fossum and Furukawa
- Docking to Harmony/Pressurized Mating Adapter-2
- Hatch Opening and Welcoming
- Canadarm2 robotic arm handoff of OBSS to Shuttle robotic arm

Flight Day 4

- Canadarm2 robotic arm unberth of the Raffaello Multi-Purpose Logistics Module from Atlantis' payload bay and installation on the nadir port of Harmony
- Ingress into Raffaello for the start of cargo transfer operations
- Spacewalk procedure review

Flight Day 5

- In-Suit Light Exercise (ISLE) Preparation and Pre-Breathe by Fossum and Garan
- Spacewalk by Fossum and Garan (Transfer of failed Pump Module from External Stowage Platform-2 (ESP-2) to Atlantis' cargo bay; transfer of the Robotic Refueling Mission hardware from Atlantis's payload bay to the Enhanced Orbital Replacement Unit Temporary Platform on the DEXTRE robot; installation of the MISSE-8 Optical Reflector Materials Experiment Ram/Wake hardware on ESP-2)
- Cargo transfer from Raffaello to ISS

Flight Day 6

- If required, focused inspection of Atlantis' thermal protection system heat shield with the OBSS
- Cargo transfer from Raffaello and Atlantis' middeck to ISS



Flight Day 7

- Cargo transfer from Raffaello to ISS
- Crew off-duty time

Flight Day 8

- Cargo transfer from Raffaello to ISS
- Joint Crew News Conference

Flight Day 9

- Cargo transfer from Raffaello to ISS
- Crew off-duty time

Flight Day 10

- Egress from Raffaello and demate preparations
- Demate of Raffaello from the nadir port of Harmony and berthing in Atlantis' payload bay
- Final Farewells and Hatch Closure
- Centerline Camera Installation
- Rendezvous Tools Checkout

Flight Day 11

- Final Space Shuttle Undocking and flyaround of ISS
- Late inspection of Atlantis' thermal protection system heat shield with the OBSS
- OBSS berth

Flight Day 12

- Cabin stowage
- Flight Control System checkout
- Picosat deployment
- Reaction Control System hot-fire test
- Deorbit Preparation Briefing
- Crew Tribute to Atlantis and the end of the Space Shuttle Program
- Ku-band antenna stowage

Flight Day 13

- Deorbit preparations
- Payload Bay Door closing
- Deorbit burn
- KSC Landing and the end of the 30-year Space Shuttle Program



STS-135 MISSION PROFILE

CREW

Commander: Chris Ferguson
Pilot: Doug Hurley
Mission Specialist 1: Sandra Magnus
Mission Specialist 2: Rex Walheim

Space Shuttle Main Engines:

SSME 1: 2047
SSME 2: 2060
SSME 3: 2045
External Tank: ET-138
SRB Set: BI-146
RSRM Set: 114

LAUNCH

Orbiter: Atlantis (OV-104)
Launch Site: Kennedy Space Center,
Launch Pad 39A
Launch Date: July 8, 2011
Launch Time: 11:26:46 a.m. EDT (preferred
in-plane launch time)
Launch Window: 10 Minutes
Altitude: 122 Nautical Miles
(140 Miles) Orbital Insertion;
188 nautical miles
(216 statute miles)
rendezvous
Inclination: 51.6 Degrees
Duration: 11 days, 19 hours, 30 minutes

SHUTTLE ABORTS

Abort Landing Sites

RTLS: Kennedy Space Center Shuttle
Landing Facility
TAL: Primary – Zaragoza, Spain
Alternates – Morón, Spain and
Istres, France
AOA: Primary – Kennedy Space Center
Shuttle Landing Facility
Alternate – White Sands Space
Harbor

VEHICLE DATA

Shuttle Liftoff Weight: 4,521,143
pounds
Orbiter/Payload Liftoff Weight: 266,090
pounds
Orbiter/Payload Landing Weight: 226,375
pounds
Software Version: OI-34

LANDING

Landing Date: July 20, 2011
Landing Time: 7:06 a.m. EDT
Primary landing Site: Kennedy Space Center

PAYLOADS

ULF7



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STS-135 MISSION OBJECTIVES

These tasks, listed in order of International Space Station Program priority, are to be executed during this flight.

1. Dock shuttle Flight ULF7 to Pressurized Mating Adaptor-2 port and perform mandatory crew safety briefing for all crew members.
2. Install Multi-Purpose Logistics Module (MPLM) to space station Harmony nadir port using space station robotic arm.
 - Perform minimal MPLM activation and checkout to preserve module and cargo.
 - Perform MPLM Passive Common Berthing Mechanism sealing surface inspection.
3. Transfer critical cargo items.
4. Return MPLM to shuttle payload bay using space station robotic arm.
5. Transfer remaining ascent cargo items and transfer return cargo items to meet minimum MPLM return.
6. Remove failed pump module from External Stowage Platform 2 and install on Lightweight MPRESS Carrier (LMC) in payload bay using space station robotic arm.
7. Remove robotics refueling payload from the LMC in the payload bay and install on the Special Purpose Dexterous Manipulator Enhanced ORU Temporary Platform (EOTP) using station arm.
8. Deploy the Materials International Space Station Experiment-8 ORMatE-III R/W.
9. Perform daily station payload status checks, as required.
10. Transfer O₂ from the orbiter to the station airlock High-Pressure Gas Tanks (HPGTs).
11. Transfer N₂ from the orbiter to the ISS Airlock HPGTs.
12. Perform daily middeck activities to support payloads.
13. Transfer remaining return cargo items.
14. Perform station payload research operations tasks.
15. Perform payload operations to support Pico-Satellite Solar Cell (PSSC) deployment.
16. Transfer water from orbiter to station.
17. Perform Program-approved EVA get-ahead tasks.
18. Perform imagery survey of the station port and starboard exterior surfaces during orbiter flyaround after undock with the station.
19. Reboost the station with the orbiter if mission resources allow and are consistent with station trajectory analysis and planning.
20. Deploy one Zero-gravity Stowage Racks (ZSRs) in the Permanent Module.



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21. Perform Program-approved IVA get-ahead tasks. The following IVA get-ahead tasks do not fit in the existing IVA timelines; however, the IVA Team will be trained and ready to perform should the opportunity arise.
 - Perform HDTV 3D imagery.
 - Remove Ultrasound 1 from Human Research Facility 1 and replace with Ultrasound 2 and four 4-panel unit (4-PU) drawers.
22. Perform TriDAR Autonomous Rendezvous and Docking (AR&D) Sensor DTO-701A activities.
23. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during MPLM berthing and unberthing.
24. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during Orbiter Docking (IWIS required).
25. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during Mated Orbiter Reboost (IWIS required).
26. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during Orbiter undocking (IWIS highly desired).
27. Perform payloads of opportunity operations if propellant available.
 - RAM Burn Observations - 2 (RAMBO-2)
 - Maui Analysis of Upper Atmospheric Injections (MAUI)
 - Shuttle Exhaust Ion Turbulence Experiments (SEITE)
 - Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX)



MISSION PERSONNEL

KEY CONSOLE POSITIONS FOR STS-135

	<u>Flt. Director</u>	<u>CAPCOM</u>	<u>PAO</u>
Ascent	Richard Jones	Barry Wilmore Charlie Hobaugh (Wx)	Rob Navias
Orbit 1 (Lead)	Kwatsi Alibaruho	Steve Robinson	Rob Navias
Orbit 2	Rick LaBrode	Megan McArthur	Josh Byerly
Planning	Paul Dye	Shannon Lucid	Brandi Dean
Entry	Tony Ceccacci	Barry Wilmore Charlie Hobaugh (Wx)	Rob Navias
Shuttle Team 4	TBD	N/A	N/A
ISS Orbit 1	Jerry Jason	Ricky Arnold	N/A
ISS Orbit 2 (Lead)	Chris Edelen	Rob Hayhurst	N/A
ISS Orbit 3	Courtenay McMillan	Kathy Bolt	N/A
Station Team 4	TBD		

JSC PAO Representative at KSC for Launch – Nicole Cloutier-Lemasters/Kyle Herring/Dan Huot

KSC Launch Commentator – George Diller

KSC Launch Director – Mike Leinbach

NASA Launch Test Director – Jeff Spaulding



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STS-135 ATLANTIS CREW



STS-135 Mission Patch

The STS-135 patch represents the space shuttle Atlantis embarking on its mission to resupply the International Space Station. Atlantis is centered over elements of the NASA emblem depicting how the space shuttle has been at the heart of NASA for the last 30 years. It also pays tribute to the

entire NASA and contractor team that made possible all the incredible accomplishments of the space shuttle. Omega, the last letter in the Greek alphabet, recognizes this mission as the last flight of the Space Shuttle Program.



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Attired in training versions of their shuttle launch and entry suits, these four astronauts take a break from training to pose for the STS-135 crew portrait. Pictured are NASA astronauts Chris Ferguson (center right), commander; Doug Hurley (center left), pilot; Rex Walheim and Sandra Magnus, both mission specialists.

Short biographical sketches of the crew appear in this package.

More detailed biographies are available at <http://www.jsc.nasa.gov/Bios/astrobio.html>



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CREW BIOGRAPHIES



Chris Ferguson

Veteran astronaut and retired captain in the U.S. Navy, Chris Ferguson will be making his third trip into space as commander on STS-135. In his role as commander, he has overall responsibility for the safety and execution of the mission, orbiter systems operations and flight operations, including landing. In addition, he will fly Atlantis through its rendezvous and docking to the International Space Station.

Ferguson reported to the Johnson Space Center in August 1998. Following the completion of

two years of training, he was assigned technical duties in the Spacecraft Systems Branch associated with the shuttle main engine, external tank, solid rocket boosters and software. He also served as spacecraft communicator (CAPCOM) for the STS-118, 120, 128 and 129 missions. Ferguson was the pilot of STS-115 and commanded STS-126. He has logged more than 28 days in space. From November 2009 to September 2010, Ferguson served as deputy chief of the Astronaut Office.



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Doug Hurley

Doug Hurley, a colonel in the U.S. Marine Corps, will be making his second trip into space as pilot on STS-135. In July 2009, he completed his first spaceflight as pilot on STS-127. He has logged more than 376 hours in space.

Following the completion of two years of training and evaluation, he was assigned technical duties in the Astronaut Office which have included Kennedy operations support as a "Cape Crusader" where he was the lead

astronaut support personnel for shuttle missions STS-107 and STS-121. He worked shuttle landing and rollout, served on the Columbia Reconstruction Team at Kennedy Space Center and in the Exploration Branch in support of the selection of the Orion Crew Exploration Vehicle. He also served as the NASA director of operations at the Gagarin Cosmonaut Training Center in Star City, Russia. Most recently, Hurley served as chief of the Astronaut Office Safety Branch.



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Sandra Magnus

Sandra Magnus will be making her third trip into space as a mission specialist on STS-135. Dr. Magnus first worked in the Astronaut Office Payloads/Habitability Branch. Next, she was assigned as a “Russian Crusader,” which involved traveling to Russia in support of hardware testing and operational products development. Dr. Magnus served as a CAPCOM for the International Space Station.

Dr. Magnus flew aboard STS-112 logging 10 days, 19 hours and 58 minutes in space.

Following STS-112, Dr. Magnus was assigned to work with the Canadian Space Agency to prepare the Special Purpose Dexterous Manipulator robot for installation on the International Space Station. In 2008, she flew to the space station with the crew of STS-126, spent 4.5 months aboard the space station and returned to Earth with the crew of STS-119. Next, Dr. Magnus served six months at NASA Headquarters in Washington, D.C., working in the Exploration Systems Mission Directorate.



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Rex Walheim

Rex Walheim, a retired colonel in the U.S. Air Force, will be making his third trip to space as a mission specialist on STS-135. Walheim served as a flight controller and operations engineer at the Johnson Space Center from October 1986 to January 1989. He was selected by NASA and reported back to the Johnson Space Center in 1996. After completing two years of training and evaluation, he qualified for flight assignment as a mission specialist. Walheim has been assigned technical duties in the

Astronaut Office Space Station Operations Branch, where he helped develop the initial procedures and displays used on the space station, served as a CAPCOM in the Mission Control Center, and was chief of the EVA branch.

A veteran of two spaceflights, he has logged more than 565 hours in space, including more than 36 hours in five spacewalks. Walheim previously served on the crews of STS-110 and STS-122.



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PAYLOAD OVERVIEW

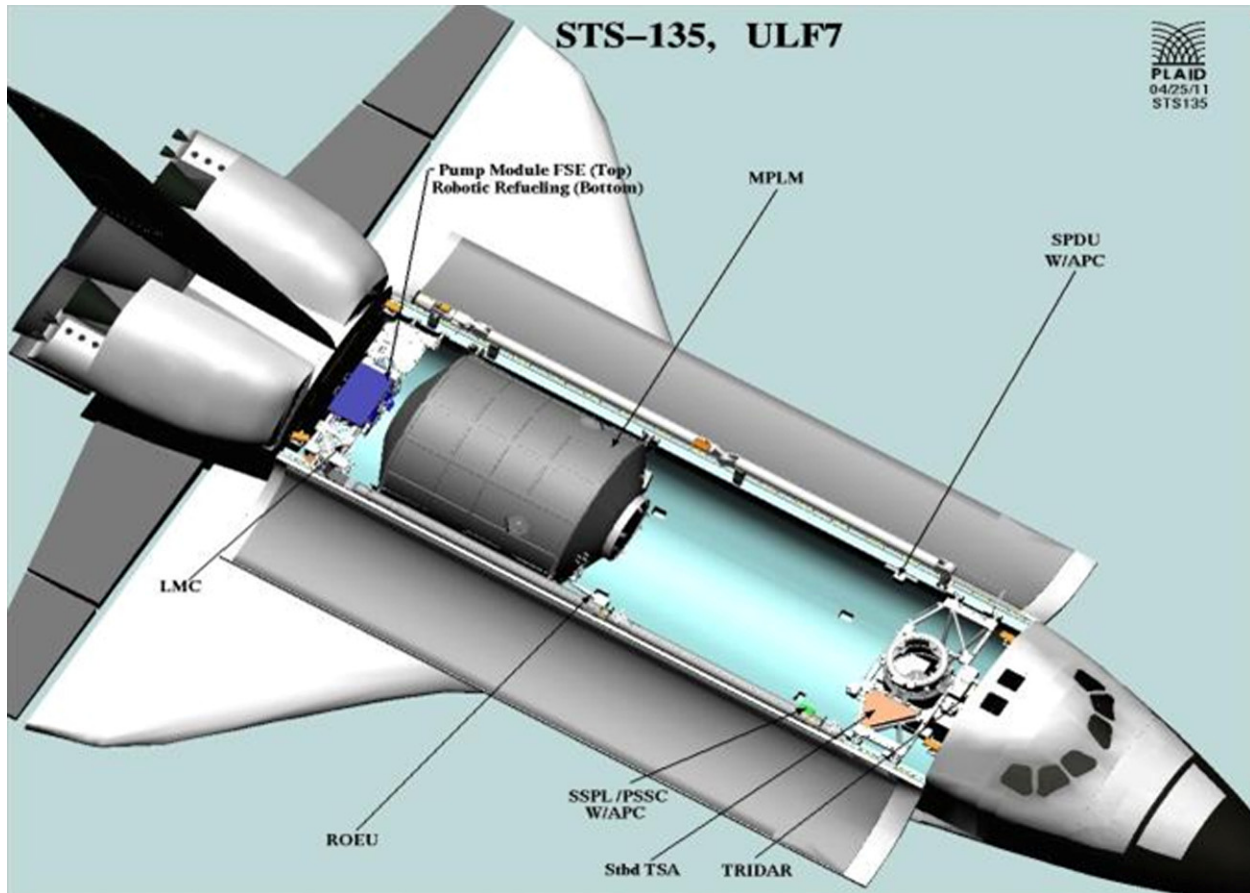


Image depicting the layout of the payloads on STS-135.

Space shuttle Atlantis' STS-135/ULF7 payload includes the Raffaello Multi-Purpose Logistics Module (MPLM) and a Lightweight Multi-Purpose Carrier (LMC). The MPLM will carry supplies, logistics and spare parts to the International Space Station. The LMC will be used to return a failed Ammonia Pump for troubleshooting and analysis to help NASA better understand the failure mechanism and improve pump designs for future systems. The total payload launch weight, not counting the middeck, is 31,015 pounds. The return weight is expected to be 28,606 pounds. The MPLM will be temporarily attached to Node 2 nadir.

On the middeck of the space shuttle, it will carry GLACIER, which is a freezer designed to provide cryogenic transportation and preservation capability for samples. The unit is a double locker equivalent unit capable of transport and operation in the middeck and in-orbit operation in the ExPRESS (Expedite the Processing of Experiments to the Space Station) rack. The space shuttle will carry on its middeck (ascent) a variety of experiments and hardware.

One of the more interesting items that will be carried in the space shuttle's middeck is called



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the Advanced Recycle Filter Tank Assembly (ARFTA). The ARFTA consists of a tank, three types of filter assemblies, a Compressor Adapter, a Rodnik/ATV adapter and several hose assemblies. The ARFTA replaces the Recycle Filter Tank Assembly (RFTA). The ARFTA tank is a metal bellows tank. The tank housing is made of titanium and the bellows are made of Hastelloy. These are the only metals that are known to withstand the corrosive effects of the concentrated pretreated urine/brine. The function of the RFTA is to

collect the residue left over from extracting water from the astronaut urine. The RFTA is at the heart of the International Space Station Urine Processing Assembly (UPA). The UPA is an integral part of the station's Water Recovery System (WRS). The UPA produces purified product water from crew urine that is combined with crew member hygiene wastes and cabin condensate for final treatment by the Water Processing Assembly (WPA) to potable water quality specifications.



The Advanced Recycle Filter Tank Assembly (ARFTA) consists of a tank, three types of filter assemblies, a Compressor Adapter, a Rodnik/ATV adapter and several hose assemblies. The ARFTA replaces the Recycle Filter Tank Assembly (RFTA) as a key element of the International Space Station Urine Processing Assembly (UPA). The UPA is an integral part of the station's Water Recovery System.



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Space shuttle Atlantis' STS-135 crew is standing in front of the Raffaello MPLM, which is packed with supplies, logistics and spare parts for their mission to the International Space Station. Shown from the left are Commander Chris Ferguson, Mission Specialists Sandra Magnus and Rex Walheim, and Pilot Doug Hurley.

To learn more about experiments on the International Space Station, please visit http://www.nasa.gov/mission_pages/station/science/coolstation.html

RAFFAELLO MULTI-PURPOSE LOGISTICS MODULE (MPLM) FLIGHT MODULE 2 (FM2)

The Raffaello Multi-Purpose Logistics Module (MPLM) is one of three differently named large, reusable pressurized elements, carried in the space shuttle's cargo bay, used to ferry cargo back and forth to the station. Raffaello

includes components that provide life support, fire detection and suppression, electrical distribution and computers when it is attached to the station. The cylindrical logistics module acts as a pressurized "moving van" for the Space Station, carrying cargo, experiments and supplies for delivery to support the six-person crew on board the station. The module also returns spent Orbital Replacement Units (ORUs) and components. Each MPLM module is 21 feet long and 15 feet in diameter – the same size as the European Space Agency's (ESA's) Columbus module.



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On the STS-135 mission, Raffaello will carry eight Resupply Stowage Platforms (RSPs), two Intermediate Stowage Platforms (ISPs), and six Resupply Stowage Racks (RSRs) and one Zero Stowage Rack. There are no system or express racks flying up on this MPLM. All the racks are stowage racks (RSRs, RSPs, ISPs) so NASA can carry the maximum cargo (spare units, spare parts, food, etc.) up to keep the station stocked up for one year.

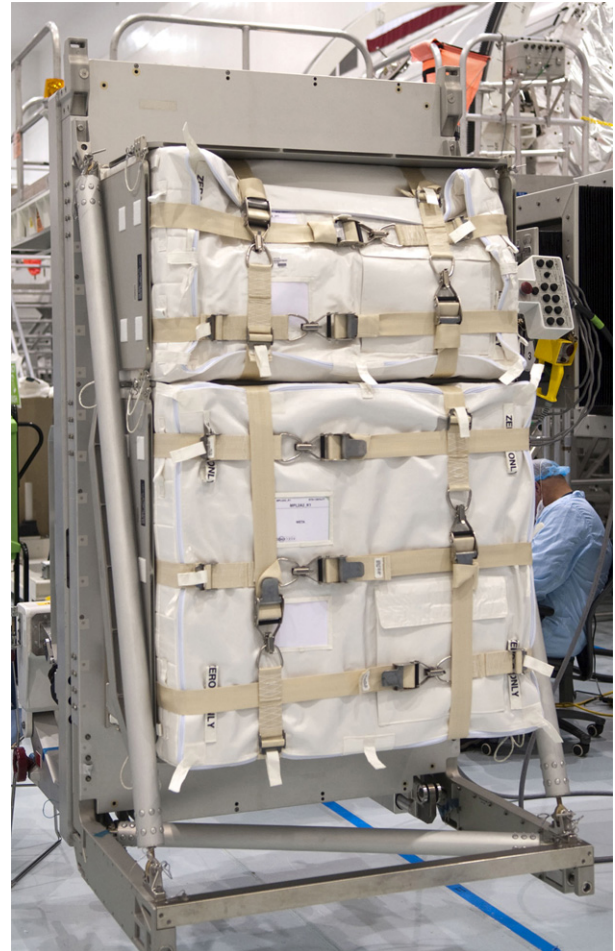
Special modifications were made to the RSPs and the Raffaello MPLM Structure so additional stowage/cargo could be carried. The RSPs were modified so they could carry an additional 200 pounds (an additional M02 cargo bag) on the front side of the rack. In addition, the MPLM structure was modified by drilling and adding an Aft End Cone Stowage Frame so an additional 400 pounds (12 bags worth) of stowage could be carried.

RAFFAELLO SPECIFICATIONS	
Dimensions:	Length: 21 feet Diameter: 15 feet
Payload Mass (launch):	25,500 pounds
Payload Mass (return):	9,5600 pounds
Empty Weight:	9,865 pounds

MPLM BACKGROUND INFORMATION

The Italian-built, U.S.-owned logistics modules are capable of ferrying more than 7.5 tons (15,000 pounds) of cargo, spares and supplies. This is the equivalent of a semi-truck trailer full of station gear bringing equipment to and from the space station. Equipment such as container racks with science equipment, science experiments from NASA and its international partners, assembly and spare parts and other hardware items for return, such as completed experiments, system racks, station hardware

that needs repair and refuse from the approximately 220 mile-high outpost can be ferried to and from the station in the MPLM. Some of these items are for disposal on Earth while others are for analysis and data collection by hardware providers and scientists.



Eight Resupply Stowage Platforms (RSPs) will be carried on board Raffaello.

The MPLM Module Leonardo is named after the Italian inventor and scientist Leonardo da Vinci. It was the first MPLM to deliver supplies to the station. For STS-133, FM1, formerly known as Leonardo, was modified to become a permanent module attached to the International Space Station during the STS-133 mission.



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The two other modules are named Raffaello, after master painter and architect Raffaello Sanzio, and *Donatello*, for one of the founders of modern sculpture, Donato di Niccolo Di Betto Bardi. *Leonardo* has flown the most because it is equipped with programmable heater thermostats on the outside of the module that allow for more mission flexibility. *Donatello* has not flown because it was built to fly active experiments up the space station and back down to Earth. Those active flights were cancelled following the Columbia accident due to reduction in the planned number of space shuttle flights.

Leonardo was the first MPLM to fly to the station on STS-102 (March 8, 2002) and there have been 10 flights total for the two modules. Raffaello has flown three missions and STS-135 will be its fourth mission. The space shuttle flies logistic modules in its cargo bay when a large quantity of hardware has to be ferried to the orbiting habitat at one time.

The modules are attached to the inside of the bay for launch and landing. When in the cargo bay, the module is independent of the shuttle cabin, and there is no passageway for shuttle crew members to travel from the shuttle cabin to the module. After the shuttle has docked to the outpost, typically on the fourth flight day after shuttle launch, Raffaello will be mated to the station using the station's robotic arm to the Node 2 nadir port. In the event of a failure or issue which may prevent the successful latching of the MPLM to the nadir port, the Zenith port can be used in mating the MPLM to the station. Nodes are modules that connect the elements to the station. For its return trip to Earth,

Raffaello will be detached from the station and positioned back into the shuttle's cargo bay.

NASA solely owns the modules which were acquired in a bartered agreement between NASA and the Italian Space Agency for using the modules in exchange for allowing the Italians to have crew time on board the station.

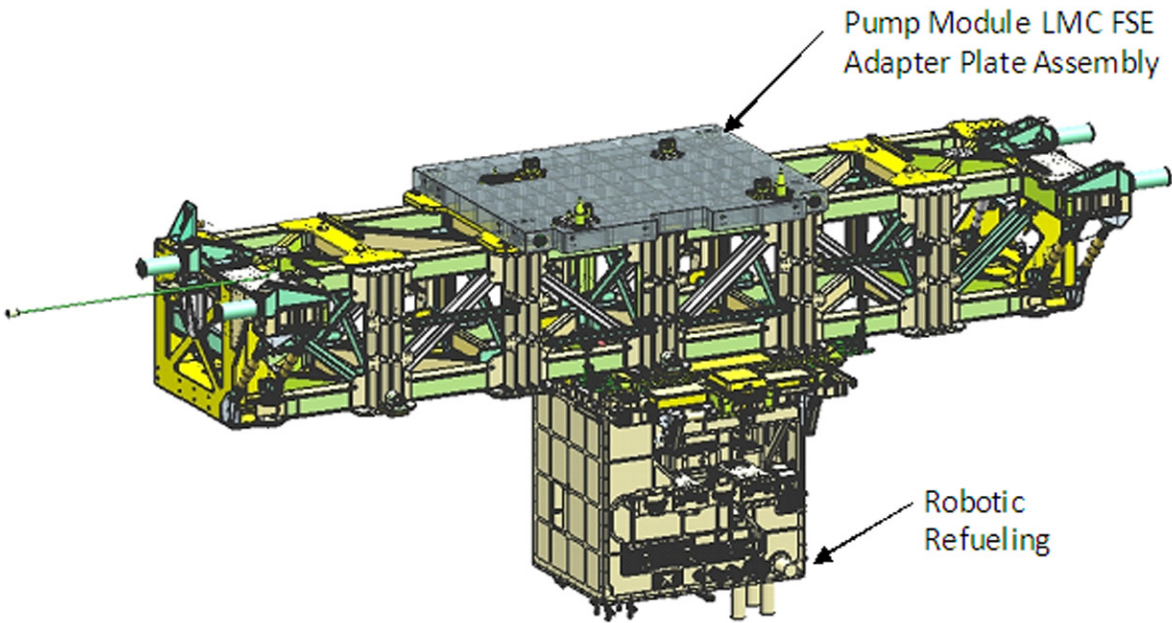
Boeing has the responsibility under its Checkout, Assembly and Payload Processing Services (CAPPS) contract with NASA, for payload integration and processing for every major payload that flies on each space shuttle flight. The Boeing MPLM processing team provides all engineering and hands-on work including payload support, project planning, receiving of payloads, payload processing, maintenance of associated payload ground systems, and logistics support. This includes integration of payloads into the space shuttle, test and checkout of the payload with the orbiter systems, launch support and orbiter post-landing payload activities including destow of the module.

THE LIGHTWEIGHT MULTI-PURPOSE EXPERIMENT SUPPORT STRUCTURE CARRIER (LMC)

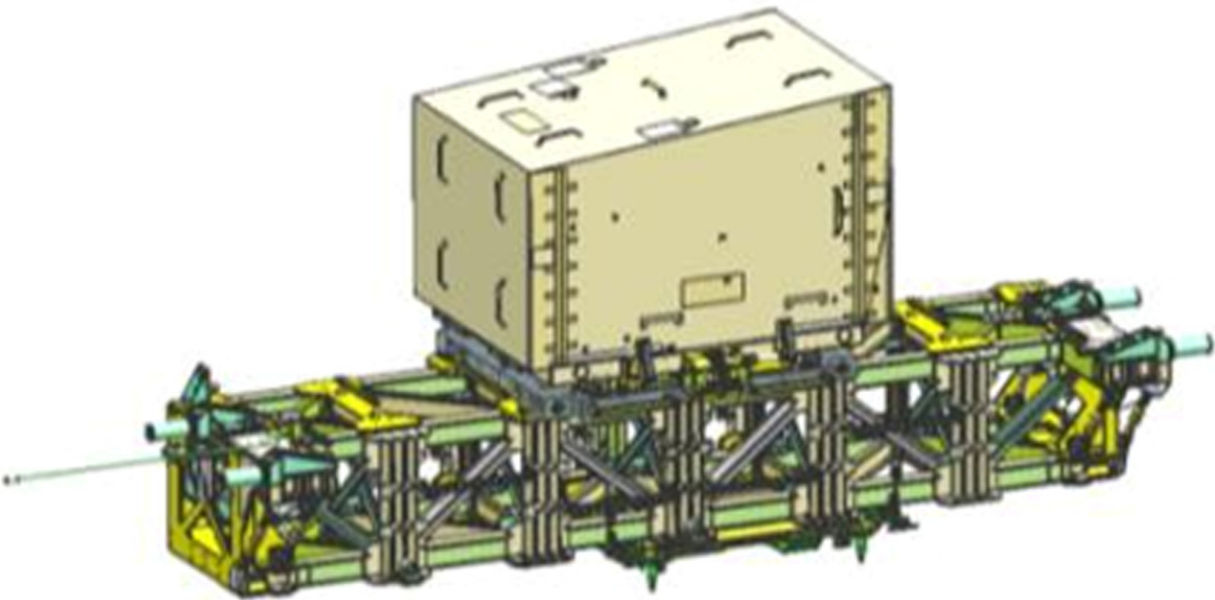
Located behind Raffaello in the space shuttle payload bay is the Lightweight Multi-Purpose Experiment Support Structure Carrier (LMC), a nondeployable cross-bay carrier providing launch and landing transportation. The LMC is a light-weight shuttle stowage platform that only weighs 946 pounds. The launch weight of the LMC is 2,918 pounds and the return weight with the pump module will be 3,530 pounds.



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LMC launch configuration



LMC return configuration with Pump Module Assembly



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The top of the LMC is shown here with the special adapter plate installed to accommodate the Pump Module Assembly.

STS-135 will be the last of seven missions for the workhorse LMC carriers. The LMCs were developed for use by station from existing Space Shuttle Multi-Purpose Equipment Support Structure, MPES, hardware to carry Launch-On-Need, LON, and Orbital Replacement Units, ORUs, for space station. GSFC and ATK have provided the sustaining engineering support for all the LMC missions,

including carrier management, refurbishment, analysis, documentation and safety.

During ascent, the LMC will be carrying a Robotic Refueling Mission (RRM) on the bottom. During descent, the LMC will be carrying an ammonia pump that will be analyzed to determine its cause for failure. A special adapter plate, built by Boeing, had to be



installed on the LMC so the large pump could be carried on the top of the LMC. Additional modifications had to be made to accommodate the Pump Module Assembly (PMA) which included removing the aft winch, the wireless video antenna, and all handrails in the aft bulkhead of the space shuttle cargo bay. This will be first time that a pump module has been carried on an LMC. The PMA will be removed from External Storage Platform 2 where it has been stored.

ROBOTIC REFUELING MISSION (RRM)

NASA's Robotic Refueling Mission (RRM) is an external International Space Station experiment designed to demonstrate and test the tools, technologies and techniques needed to robotically refuel and repair satellites in space, especially satellites that were not designed to be serviced. A joint effort between NASA and the Canadian Space Agency (CSA), RRM will be the first in-orbit attempt to test robotic refueling and repair techniques for spacecraft not built with in-orbit servicing in mind. It is expected to reduce risks and lay the foundation for future robotic servicing missions. RRM also marks the first use of Dextre beyond the planned maintenance of the space station for technology research and development.

After Atlantis docks with station, RRM will be transferred during a spacewalk to Dextre's Enhanced Orbital Replacement Unit Temporary Platform (EOTP). Following the shuttle's departure, RRM will remain on the EOTP, and Dextre and Canadarm2 will transfer RRM to its permanent location ExPRESS Logistics Carrier 4 (ELC-4). The ELC will provide command, telemetry and power support for the experiment. RRM operations will be entirely remotely controlled by flight controllers at NASA's Goddard Space Flight Center in Greenbelt, Md., Johnson Space Center in Houston, Marshall Space Flight Center in Huntsville, Ala., and the CSA's control center in St. Hubert, Quebec.

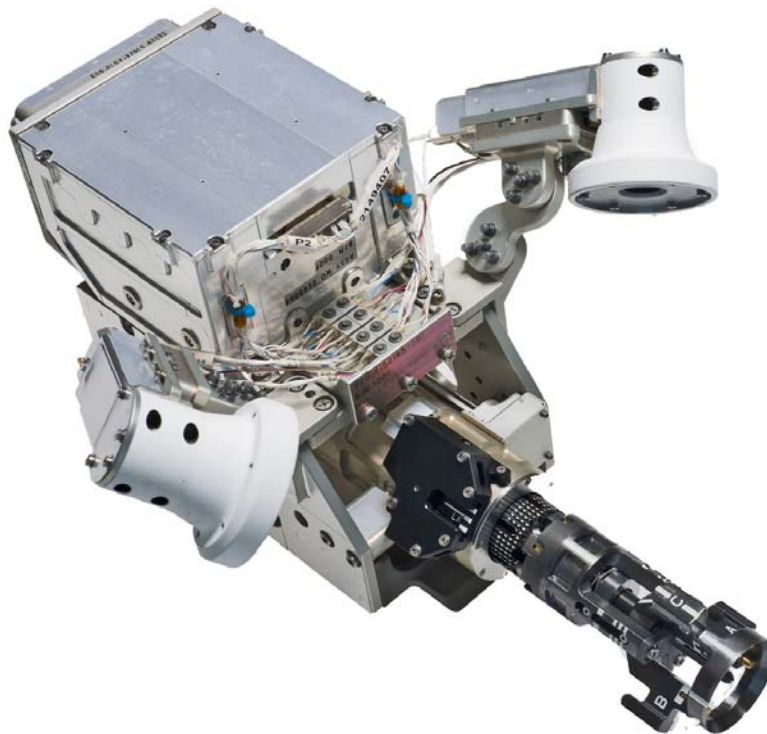
To meet the challenge of robotic refueling, the RRM development team assessed what tasks would be necessary for a robot to access the triple-sealed fuel valve of an orbiting satellite and refuel it. They then developed the cube-shaped RRM module that breaks down each refueling activity into distinct, testable tasks and provides the components, activity boards, and tools to practice them. The RRM module is about the size of a washing machine and weighs approximately 550 pounds, with dimensions of 43" by 33" by 45". RRM includes 0.45 gallon (1.7 liters) of ethanol that will be used to demonstrate fluid transfer in orbit.



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The RRM module, hanging from the Lightweight Multi-Purpose Carrier, is prepared at KSC for launch to the International Space Station.



RRM's Multifunction Tool with Plug Manipulator Adapter attached.
Note the two integral cameras.

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'PAYLOAD OVERVIEW' and 'REPAIRS' around a central figure. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and white American flag with a yellow glow on the right side.

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Once the RRM module is securely mounted to the space station's ELC-4 platform, mission controllers will direct the Dextre robot, the space station's Canadian, twin-armed "handyman," to retrieve RRM tools from the module and perform a full set of refueling tasks. Dextre will use the RRM tools to cut and manipulate protective blankets and wires, unscrew caps and access valves, transfer fluid, and leave a new fuel cap in place. At one stage of the mission, Dextre will use RRM tools to open up a fuel valve, similar to those commonly used on satellites today, and transfer liquid ethanol across a robotically mated interface via a sophisticated robotic fueling hose. Each task will be performed using the components and activity boards contained within and covering the exterior of the RRM module. The experiment will also demonstrate general space robotic repair and servicing operations. Completing the demonstration will validate the tool designs (complemented with cameras), the fuel pumping system, and robotic task planning, all of which will be used during the design of a potential future refueling spacecraft.

RRM will launch to the space station with four unique tools developed at Goddard: the Wire Cutter and Blanket Manipulation Tool, the Multifunction Tool, the Safety Cap Removal Tool and the Nozzle Tool. Each tool will be stored in its own storage bay in the RRM module until Dextre retrieves it for use. To give mission controllers the ability to see and control the tools, each tool contains two integral cameras with built-in LEDs.

One of the secondary goals of RRM is to collect performance data from all RRM operations conducted on the space station and use this information to validate "tool-to-spacecraft"

simulations of contact dynamics. The Goddard Satellite Servicing Demonstration Facility (GSSDF) was developed in parallel with the RRM flight hardware. One objective is to validate that GSSDF accurately simulates the dynamic space environment of the space station. Such a confirmation would validate Goddard's capability to develop and test any future space robotic servicing and assembly missions with a very high degree of accuracy.

Drawing upon 20 years of experience servicing the Hubble Space Telescope, the Satellite Servicing Capabilities Office (SSCO) at NASA's Goddard Space Flight Center initiated the development of RRM in 2009. Atlantis, the same shuttle that carried tools and instruments for the final, astronaut-based Hubble Space Telescope Servicing Mission 4, will now carry the first step to robotic refueling and satellite servicing on the last shuttle mission to space.

Robotic refueling and satellite servicing were targeted as a technology demonstration because these capabilities could extend the lifetimes of satellites, potentially offering satellite owners and operators years of additional service and revenue, more value from the initial satellite investment, and significant savings in delayed replacement costs. There are numerous commercial and government-owned satellites in orbit today that could benefit from such services.

In-orbit robotic refueling and satellite servicing have been identified by several nations and space agencies as critical capabilities that could support overarching autonomy and expansion in space. If applied in conjunction with a fuel depot, robotic refueling would minimize the need for space explorers and satellites to launch with heavy amounts of fuel, thus freeing up



weight for other mission-critical equipment and capabilities. Robotic refueling has the potential to allow human and robotic explorers to reach distant destinations more efficiently and effectively.

SSCO's prime contractor base consists of Lockheed Martin, Stinger Ghaffarian Technologies, Orbital Sciences Corporation, Alliant Techsystems, Jackson and Tull, and Arctic Slope Regional Corporation.

PUMP MODULE (PM)

The Pump Module (PM) is part of the station's complex Active Thermal Control System (ATCS), which provides vital cooling to avionics, crew members and payloads. The station has two independent cooling loops. The external loops use an ammonia-based coolant and the internal loops use a water-based coolant. At the heart of the ATCS is the Pump Module, which provides circulation, loop pressurization, and temperature control of the ammonia. The PM pumps the ammonia through the external system to provide cooling. Heat is generated by the electronic boxes throughout the station and eventually rejected into space via the radiators.

The major components in the PM include a Pump and Control Valve Package (PCVP), an accumulator, isolation and relief valves, and

temperature, flow, and pressure sensors. The accumulator within the PM works in concert with the Ammonia Tank Assembly (ATA) accumulators to compensate for expansion and contraction of ammonia caused by the temperature changes and keeps the ammonia in the liquid phase via a fixed charge of pressurized nitrogen gas on the backside of its bellows. Manufactured by Boeing, the pump module weighs 780 pounds and measures approximately 5 1/2 feet (69 inches) long by 4 feet (50 inches) wide with a height of 3 feet (36 inches).

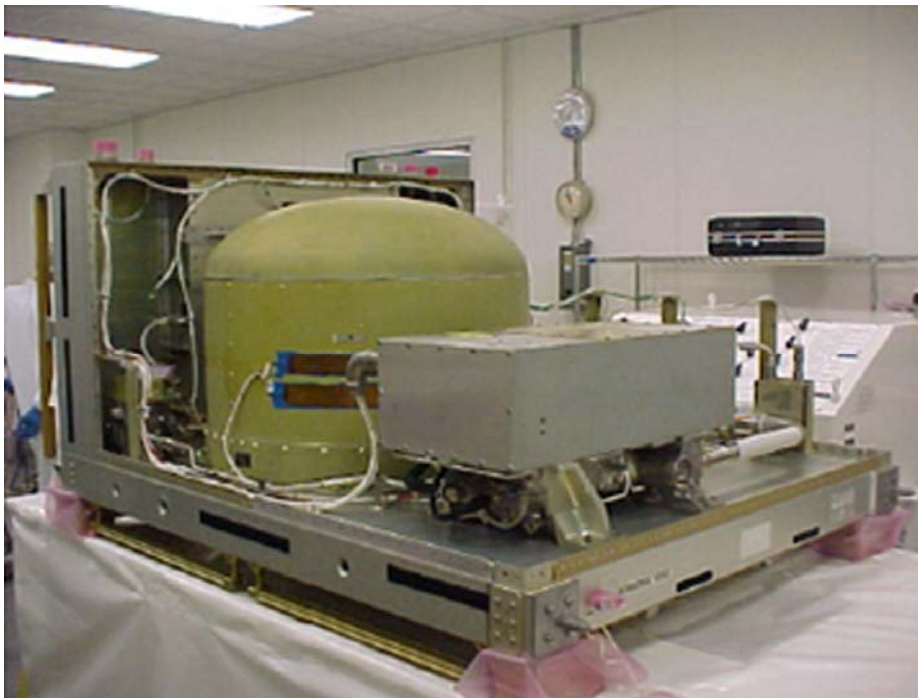
On this mission, the PM is being returned for further analysis and investigation of the failure that occurred on July 31, 2010. A new PM was installed on Aug.16, 2010, and has been performing well. The failed PM will undergo extensive testing and evaluation in Houston. The PCVP will be sent to Hamilton Sundstrand for thorough testing and evaluation. The current theory for the cause of the failure is an electrical issue within the PCVP unit. After the root cause is determined to be either systemic to the PM or specific to this unit, NASA will determine the follow-on actions, if any. The space station has three spare pump modules in orbit.



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The PM with the cover in place.



The PM with the cover removed.



RENDEZVOUS & DOCKING

Atlantis's launch for the STS-135 mission is timed to lead to a link up with the International Space Station about 220 miles above Earth. A series of engine firings during the first two days of the mission will bring the shuttle to a point about 50,000 feet behind the station. Once there, Atlantis will start its final approach. About 2.5 hours before docking, the shuttle's jets will be fired during what is called the terminal initiation burn. The shuttle will cover the final miles to the station during the next orbit.

As Atlantis moves closer to the station, its rendezvous radar system and trajectory control sensor will provide the crew with range and closing-rate data. Several small correction burns will place the shuttle about 1,000 feet below the station.

Commander Chris Ferguson, with help from Pilot Doug Hurley and other crew members, will manually fly the shuttle for the remainder of the approach and docking.

Ferguson will stop Atlantis about 600 feet below the station. Timing the next steps to occur with proper lighting, he will maneuver the shuttle through an approximate eight-minute back flip called the Rendezvous Pitch Maneuver, also known as the R-bar Pitch Maneuver since Atlantis is in line with an imaginary vertical R-bar directly below the station. During this maneuver, station crew members Mike Fossum and Satoshi Furukawa will photograph Atlantis's upper and lower surfaces through windows of the Zvezda Service Module. They will use digital cameras

equipped with an 800 mm lens to provide up to one-inch resolution and a 400 mm lens providing three-inch resolution.

The photography is one of several techniques used to inspect the shuttle's thermal protection system for possible damage. Areas of special interest include the thermal protection tiles, the reinforced carbon-carbon panels along the wing leading edges and the nosecone, landing gear doors and the elevon cove. The photos will be downlinked through the station's Ku-band communications system for analysis by imagery experts in Mission Control.

When Atlantis completes its back flip, it will be back where it started with its payload bay facing the station. Ferguson then will fly the shuttle through a quarter circle to a position about 400 feet directly in front of the station. From that point, he will begin the final approach to docking to the Pressurized Mating Adapter 2 at the forward end of the Harmony node.

The shuttle crew members will operate laptop computers that process the navigational data, the laser range systems and Atlantis' docking mechanism.

Using a video camera mounted in the center of the Orbiter Docking System, Ferguson will line up the docking ports of the two spacecraft. If necessary, he will pause the shuttle 30 feet from the station to ensure proper alignment of the docking mechanisms. He will maintain the shuttle's speed relative to the station at about one-tenth of a foot per second, while both



Atlantis and the station are moving at about 17,500 mph. Ferguson will keep the docking mechanisms aligned to a tolerance of three inches.

When Atlantis makes contact with the station, preliminary latches will automatically link the two spacecraft. The shuttle's steering jets will be deactivated to reduce the forces acting at the docking interface. Shock absorber springs in the docking mechanism will dampen any relative motion between the shuttle and station.

Once motion between the shuttle and the station has been stopped, the docking ring will be retracted to close a final set of latches between the two vehicles.

UNDOCKING, SEPARATION AND DEPARTURE

At undocking time, the hooks and latches will be opened and springs will push the shuttle away from the station. Atlantis's steering jets

will be shut off to avoid any inadvertent firings during the initial separation.

Once the shuttle is about two feet from the station and the docking devices are clear of one another, Hurley will turn the steering jets back on and will manually control Atlantis within a tight corridor as the shuttle separates from the station.

Atlantis will move to a distance of about 450 feet, where Hurley will begin to fly around the station. Atlantis will circle the shuttle around the station at a distance of about 600 feet. The shuttle crew will take detailed photographs of the external structure of the station, which serves as important documentation for the ground teams in Houston to monitor the orbiting laboratory.

Once the shuttle completes 1.5 revolutions of the complex, Hurley will fire Atlantis's jets to leave the area. Nearly two hours after undocking a second firing of the engines will take Atlantis farther away from the station.



SPACEWALKS

The last spacewalk to be performed by space shuttle crew members took place on STS-134, but not the last spacewalk to be performed during a space shuttle mission.

Although STS-135 was not originally intended to include a spacewalk, the desire to return a pump module that failed on the International Space Station in 2010 to the Earth for analysis made one necessary, and over time other tasks were added to it as well. With only four people, however, the STS-135 crew was too small to perform a spacewalk on top of all of its other work. So members of the Expedition 28 crew were recruited for the job, though the shuttle crew members will still support the spacewalk from inside the space station.

Flight Engineers Michael Fossum and Ron Garan will perform one 6.5-hour spacewalk on the fifth day of the mission. It will not be their first time to go outside the station together – they were partnered for the three spacewalks of the STS-124 mission in June 2008, as well. Those three spacewalks left Garan with a total of 20 hours and 32 minutes of spacewalk experience. Fossum also performed three spacewalks during the STS-121 mission in July of 2006, giving him a total of more than 40 hours spent spacewalking.

Fossum will be the lead spacewalker for the mission, and wear a spacesuit marked with a solid red line. Garan will wear an all-white suit.

When a spacewalk – also called Extravehicular Activity, or EVA for short – is going on outside, one crew member inside the International Space Station is assigned the job of Intravehicular (IV) officer, or spacewalk choreographer. In this case, Mission Specialist Rex Walheim, who performed five spacewalks during STS-110 and STS-122, will act as the intravehicular officer for that spacewalk. The spacewalk will also require astronauts inside the station to be at the controls of the station's 58-foot-long robotic arm; Mission Specialist Sandy Magnus and Pilot Doug Hurley will be given that responsibility for this mission, and each of the spacewalkers will take a turn riding on the end of the arm for various tasks.

Fossum and Garan will prepare for this spacewalk using a new practice tried out for the first time during STS-134. Aimed at cutting down the amount of oxygen used in spacewalk preparations, Fossum and Garan will wait until the morning of their spacewalk to begin getting ready, rather than spending the night inside the Quest at a low air pressure, as they would have previously done. They will breathe pure oxygen through air masks for an hour as the air pressure inside the Quest is lowered to 10.2 pounds per square inch. After that, they will be able to put on their spacesuits and perform light exercise (moving their legs inside of their spacesuits) for 50 minutes to raise their metabolic rate and purge nitrogen from their bloodstream.



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Photos of the EVA 1 Spacewalkers

EVA 1

Duration:	6 hours, 30 minutes
EVA Crew:	Fossum and Garan
IV Crew:	Walheim
Robotic Arm Operators:	Magnus

EVA Operations:

- Retrieve failed pump module for return
- Install Robotic Refueling Mission experiment
- Deploy Materials International Space Station Experiment 8 segment

Fossum and Garan will begin the STS-135 spacewalk with the highest priority task – retrieval of the failed pump module. The equipment was prepared for return to Earth during previous spacewalks, and is stored on external stowage platform 2 at the Quest

airlock. Fossum will make his way to the platform and install two backup tools, called Contingency Operations Large Adapter Assembly Tools – or COLTs – onto the hardware that holds the pump module in place. The COLTs will allow the crew to access contingency bolts on the back of the hardware, in case the spacewalkers run into problems using the primary bolt to install the pump module in the shuttle’s cargo bay.

While Fossum works with the COLTs, Garan will meet the station’s robotic arm at the stowage platform, and install a foot restraint on it so that he can climb into it and free up his hands to carry the pump module back to Atlantis.

To remove the pump module from the stowage platform, Garan will grab onto the pump module, while Fossum releases the bolt holding it in place. That will allow Garan to lift the



module off of the stowage platform and fly it to the shuttle's cargo bay.

Once there, Garan will drive the same bolt to attach the module to the carrier inside the cargo bay, securing it for the return to Earth.

Fossum and Garan will then switch places, giving Fossum a turn on the end of the robotic arm. Then Fossum will hold the Robotic Refueling Mission experiment, while Garan releases the bolt attaching it to the cargo bay. Fossum will lift it out, and fly it via robotic arm to the Special Purpose Dexterous Manipulator, or Dextre, as the robot is called, on the Destiny laboratory. He will bolt the experiment onto platform on Dextre used to hold equipment and spare parts that Dextre is working with. Garan will assist.

With those major tasks done, Fossum will climb off of the robotic arm and remove the foot restraint that Garan installed, while Garan

deploys a segment on the Materials International Space Station Experiment 8 (or MISSE 8), which was installed during STS 134. Because that experiment is situated near the Alpha Magnetic Spectrometer (AMS), which was also installed on STS-134, and the thermal covers on the AMS were expected to need some time to air out once the experiment was installed, the STS-134 crew was asked not to expose this segment of the experiment until the gases in the AMS cover had some time to dissipate. To deploy it now, Garan will install an Optical Reflector Materials Experiment that was brought up on Endeavour's middeck during STS-134 into a socket on MISSE 8 and remove its protective cover.

Whatever time remains in the spacewalk after these items are completed will be used to work on get-ahead tasks.



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STS-135 EXPERIMENTS

STS-135/ULF7 RESEARCH AND TECHNOLOGY DEVELOPMENT

STS-135 experiments will range from microscopic cell research to macroscopic technology development equipment deliveries to the International Space Station. In addition, both plants and animals will be the subject of microgravity tests.

For a joint project of NASA and the Canadian Space Agency (CSA), hardware for the Robotic Refueling Mission (RRM) will be delivered and installed on the station's Express Logistics Carrier 4 for future demonstrations that will test the tools, technologies and techniques needed to robotically refuel satellites in space – even satellites not designed to be serviced. The tests, using Candarm2, its Dexterous Manipulator System and a variety of specialized tools, will be the first on-orbit tests of techniques to refuel spacecraft not built with on-orbit servicing in mind. The RRM hardware will be installed during the flight's only spacewalk.

Another facility being delivered to the station is Ultrasound-2, a cardiovascular ultrasound system that will replace and upgrade a 10-year-old ultrasound unit that stopped operating earlier this year. The device will be used for general crew health assessment, and in NASA investigations such as Integrated Cardiovascular, which looks at the weakening of heart muscles associated with long-duration spaceflight, and the Integrated Resistance and Aerobic Training Study (Sprint), which looks at high-intensity, low-volume exercise

training to minimize loss of muscle, bone and cardiovascular performance in astronauts. A European Space Agency experiment called Vascular Echography (Vessel Imaging) will use the device to evaluate changes in central and peripheral blood vessel wall properties (thickness and compliance) and cross sectional areas of station astronauts during and after long-term exposure to microgravity.

Commercial Biomedical Test Module (CBTM-3) experiments will use a validated mouse model to examine the effectiveness of experimental drug therapies against bone loss that results from prolonged life in low gravity. One investigation will look at whether the use of a sclerostin antibody can induce bone formation and thereby prevent skeletal deterioration, while another will examine whether changes in the blood supply to the bones and bone forming tissues may contribute to bone loss in low gravity.

Plant experiments will look at terrestrial food supply issues, and provide educational opportunities for students on Earth. The NASA-sponsored Biological Research in Canisters Symbiotic Nodulation in a Reduced Gravity Environment (BRIC-SyNRGE), will look at how microgravity affects the infectiousness of bacteria in plants. The symbiotic relationships of plants and bacteria affect a large portion of human and livestock food production on Earth. The CSA-sponsored Tomatosphere-III will carry 400,000 tomato seeds to the station and back to Earth, where students in 10,000 classrooms throughout



Canada will measure germination rates, growth patterns and vigor of the seeds as they grow.

A Department of Defense experiment will study the effects of tissue regeneration and wound healing in space. Space Tissue Loss-Regeneration-Keratinocytes experiments will look at how cellular degeneration and decreased immune response associated with traumatic wounds and unused limbs, with potential application in the treatment of both military and civilian injuries and immune response on Earth.

Two distinct types of smart phones also will fly to the station, where they will be tested for potential use as navigation aids and as mobile assistants for astronauts.

SHORT-DURATION RESEARCH TO BE COMPLETED ON STS-135/ULF7

Biology and Biotechnology

Biological Research in Canisters Symbiotic Nodulation in a Reduced Gravity Environment (BRIC-SyNRGE) investigates microgravity effects associated with microbe-host interactions and cell-cell communication using a plant-bacteria model system. It directly addresses the impact of the space environment on microbial virulence in a constructed ecosystem. Plant-bacteria symbiosis accounts for a large percentage of human and livestock food production on Earth, particularly in nitrogen-depleted soil. BRIC-SyNRGE adds to the knowledge base of this plant-bacteria mechanism. (NASA)

Commercial Biomedical Testing Module-3: Assessment of sclerostin antibody as a novel bone forming agent for prevention of spaceflight-induced skeletal fragility in mice (CBTM-3-Sclerostin Antibody) investigates a novel anabolic therapy for prevention of space flight-induced skeletal fragility in mice. CBTM-3-Sclerostin Antibody is part of a team of investigations designed to determine if administering a therapeutic agent preflight to mice reduces the loss of bone associated with space flight. Humans and animals have been observed to lose bone mass during the reduced gravity of space flight. The sclerostin antibody is designed to inhibit the action of “sclerostin”, a protein that is a key negative regulator of bone formation, bone mass and bone strength. (NASA)

CBTM-3-Vascular Atrophy Commercial Biomedical Testing Module-3: STS-135 space flight's affects on vascular atrophy in the hind limbs of mice (CBTM-3-Vascular Atrophy) examines the effects of space flight on the skeletal bones of mice and the efficacy of a novel agent that may mitigate the loss of bone associated with space flight. Humans and animals have been observed to lose bone mass during the reduced gravity of space flight. CBTM-3-Vascular Atrophy specifically determines if there is a correlation between space flight induced altered blood supply to the bones and surrounding tissues with a resultant loss of bone mass. (NASA)

Gravitational Effects on Biofilm Formation During Space Flight (Micro-2) studies how gravity alters biofilm (aggregation of microorganisms) formation with the goal of developing new strategies to reduce their impact on crew health and to minimize the harmful effects of biofilms on materials in space and on Earth. (NASA)



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National Lab Pathfinder – Cells – 7 (NLP-Cells-7) is a commercial payload serving as a pathfinder for the use of the International Space Station (ISS) as a National Laboratory after ISS assembly complete. It contains several different experiments that examine cellular replication and differentiation of cells. This research is investigating the use of space flight to enhance or improve cellular growth processes utilized in ground based research. (NASA)

Recombinant Attenuated Salmonella Vaccine (RASV) evaluates the ability of the space flight platform to accelerate recombinant attenuated Salmonella vaccine development against pneumococcal pneumonia – which causes life-threatening diseases (pneumonia, meningitis, bacteremia) that kill more than 10 million people annually, particularly children and elderly who are less responsive to current vaccines. RASV will use space flight to facilitate design and development of next-generation vaccines with improved efficacy and protective immune responses while minimizing unwanted side effects by providing novel gene targets for vaccine improvement and development, and re-formulating existing vaccines. (NASA)

Space Tissue Loss – The Effects Microgravity on Stem Cell-Based Tissue Regeneration: Keratinocyte Differentiation in Wound Healing (STL-Regeneration-Keratinocytes) is a Department of Defense (DoD) Space Test Program payload flying both NASA and DoD science that uses cell and tissue cultures in microgravity to study the effects of tissue regeneration and wound healing in space. Cellular microgravity experiments are used to research methods of treating Earth-bound injuries where cellular degeneration and

decreased immune response can occur in traumatic wounds and unused limbs. The application spans across both military and civilian injuries and immune response on Earth. (NASA)

Education

NanoRacks-CubeLabs Module-8 processes biological samples in microgravity. The science goals for NanoRacks-CubeLabs Module-8 are proprietary. (NASA)

Japan Aerospace Exploration Agency – Commercial Payload Program (JAXA-Commercial Payload Program) consists of commercial items sponsored by JAXA sent to the space station to experience the microgravity environment. (JAXA)

Tomatosphere-III will send 400,000 tomato seeds to the International Space Station (ISS) for exposure to the space environment. The seeds will be returned to Earth for use in 10,000 classrooms throughout Canada as a learning resource. Students will measure the germination rates, growth patterns and vigor of growth of the seeds. (CSA)

Technology

The Forward Osmosis Bag (FOB) system is designed to convert dirty water into a liquid that is safe to drink using a semi-permeable membrane and a concentrated sugar solution. FOB looks at the forward osmosis membrane in a space flight environment and compares its performance against ground reference controls. A small forward osmosis device could be incorporated into new long-exposure EVA suits in order to recycle metabolic wastewater (i.e., sweat and urine) into drinkable fluid. Determining the effect of mechanical mixing on membrane performance may help inform suit



designers in the placement of a device to maximize permeate production. (NASA)

RESEARCH TO BE DELIVERED TO STATION ON SHUTTLE

Biology and Biotechnology

Plant Signaling studies the effects of microgravity on the growth of plants. The experiment is performed on board the International Space Station (ISS) in collaboration with the European Space Agency (ESA). Images of the plants are captured and down-linked to Earth. Samples of the plants are harvested and returned to Earth for scientific analysis. The results of this experiment can lead to information that will aid in food production during future long duration space missions, as well as data to enhance crop production on Earth. (NASA)

Education

Japan Aerospace Exploration Agency Education Payload Observation 7 (JAXA EPO 7) includes artistic experiments and cultural activities. JAXA implements these activities to enlighten the general public about microgravity utilization and human space flight. JAXA understands that International Space Station's Japanese Experiment Module (JEM), Kibo, is useful for scientists and engineers as well as writers, poets, teachers and artists. (JAXA)

Human Research

Astronaut's Energy Requirements for Long-Term Space Flight (Energy) will measure changes in energy balance in crew members following long-term space flight. Energy also will measure adaptations in the components of

the total energy expenditure to derive an equation for astronaut energy requirements. (ESA)

Sleep-Wake Actigraphy and Light Exposure During Spaceflight-Short (Sleep-Short)

examines how spaceflight affects astronauts sleep patterns during Space Shuttle missions. Advancing state-of-the-art technology for monitoring, diagnosing and assessing treatment of sleep patterns is vital to treating insomnia on Earth and in space. The success and effectiveness of manned spaceflight depends on the ability of crewmembers to maintain a high level of cognitive performance and vigilance while operating and monitoring sophisticated instrumentation. (NASA)

Physical Science

Materials Science Laboratory – Columnar-to-Equiaxed Transition in Solidification Processing and Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions (MSL-CETSOL and MICAST) are two investigations that support research into metallurgical solidification, semiconductor crystal growth (Bridgman and zone melting), and measurement of thermo-physical properties of materials. This is a cooperative investigation with the European Space Agency and NASA for accommodation and operation aboard the International Space Station. (NASA/ESA)

Technology

Moisture Removal Amine Swing-bed (CAMRAS) technology uses an amine sorbent to remove both CO₂ and water vapor from the atmosphere. The system vents absorbed CO₂ and moisture when exposed to vacuum,



regenerating the capability of the amine sorbent to absorb CO₂ and moisture from cabin atmosphere. (NASA)

Preliminary Advanced Colloids Experiment – Light Microscopy Module: Biological Samples (PACE-LMM-Bio) is a NASA Rapid Turn Around (RTA) engineering proof-of-concept proposal in preparation for the Advanced Colloids Experiment (ACE). In Bio, crewmembers image three-dimensional biological sample particles, tissue samples and live organisms. The goal of this experiment is to indicate the microscope’s capabilities for viewing biological specimens. (NASA)

Pico-Satellite Solar Cell Experiment (PSSC) is a picosatellite designed to test the space environment by providing a testbed to gather data on new solar cell technologies. This capability will allow for gathering spaceflight performance data before the launch of new satellites with the new solar cell technology as the primary power source. Presently, the two U.S. solar cell manufacturers, Spectrolab and Emcore, are starting production of a new generation of High Efficiency Solar Cells on a two to three year cycle. (NASA)

Robonaut (Robonaut) serves as a spring board to help evolve new robotic capabilities in space. Robonaut demonstrates that a dexterous robot can launch and operate in a space vehicle, manipulate mechanisms in a microgravity environment, operate for an extended duration within the space environment, assist with tasks, and eventually interact with the crew members. (NASA)

Robotic Refueling Mission (RRM) demonstrates and tests the tools, technologies and techniques needed to robotically refuel satellites in space, even satellites not designed

to be serviced. RRM is expected to reduce risks and lay the foundation for future robotic servicing missions in microgravity. Robotic refueling extends the lifetime of satellites, allowing owners and operators to gain additional years of use from assets already operating in space. Technology spinoffs have the potential to benefit humankind in yet-undiscovered ways. (NASA)

NanoRacks Smartphone-1 will test Apple’s gyroscope-equipped iPhone 4 and an application as a potential space navigation tool. The experiment will use the phone’s camera and an Earth limb tracker to test its capabilities to estimate altitude, calibrate spacecraft instruments and update navigation state vectors. The experiment also will characterize the effects of radiation on the device. The experiment is part of a long-term effort to test off-the-shelf products, including the latest in consumer platforms, in the spaceflight environment. (NASA).

Human Exploration Telerobotics-Smartphone will equip small, free-flying satellites called Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) with a Samsung Electronics Nexus S™ handset that features Google’s open-source Android™ platform. The experiment will use the smartphone-enhanced SPHERES as remotely operated robots to conduct interior surveys and inspections, capture mobile camera images and video, and to study how robots can support future human exploration. (NASA)

RESEARCH OF OPPORTUNITY

Maui Analysis of Upper Atmospheric Injections (MAUI), a Department of Defense experiment, observes the space shuttle engine



exhaust plumes from the Maui Space Surveillance Site in Hawaii when the space shuttle fires its engines at night or twilight. A telescope and all-sky imagers will take images and data while the space shuttle flies over the Maui site. The images are analyzed to better understand the interaction between the spacecraft plume and the upper atmosphere of Earth. (NASA)

Ram Burn Observations – 2 (RAMBO-2) is an experiment in which the Department of Defense uses a satellite to observe space shuttle orbital maneuvering system engine burns. Its purpose is to improve plume models, which predict the direction the plume, or rising column of exhaust, will move as the shuttle maneuvers on orbit. Understanding the direction in which the spacecraft engine plume, or exhaust flows could be significant to the safe arrival and departure of spacecraft on current and future exploration missions. (NASA)

Shuttle Exhaust Ion Turbulence Experiments (SEITE), a Department of Defense experiment, uses space-based sensors to detect the ionospheric turbulence inferred from the radar observations from previous Space Shuttle Orbital Maneuvering System (OMS) burn experiments using ground-based radar. (NASA)

Shuttle Ionospheric Modification with Pulsed Localized Exhaust Experiments (SIMPLEX) investigates plasma turbulence driven by rocket exhaust in the ionosphere using ground-based radars. (NASA)

RESEARCH TO BE RETURNED ON SPACE SHUTTLE

Biology and Biotechnology

Dynamism of Auxin Efflux Facilitators, CsPINs, Responsible for Gravity-regulated Growth and Development in Cucumber (CsPINs) uses cucumber seedlings to analyze the effect of gravity on gravimorphogenesis (peg formation) in cucumber plants. (JAXA)

Mycological evaluation of crew exposure to ISS ambient air (Myco) evaluates the risk of microorganisms' via inhalation and adhesion to the skin to determine which fungi act as allergens on the ISS. (JAXA)

Education

Commercial Generic Bioprocessing Apparatus Science Insert – 05: Spiders, Fruit Flies and Directional Plant Growth (CSI-05) examines the long duration orb weaving characteristics of a *Nephila clavipes* (golden orb-web spiders), the movement behavior of fruit flies, and the thigmotropic (directional plant growth in response to a stimulus of direct contact) and phototropic (directional plant growth in response to a light source) responses that occur during seed germination in microgravity. CSI-05 utilizes the unique microgravity environment of the International Space Station (ISS) as part of the K-12 classroom to encourage learning and interest in science, technology, engineering and math. (NASA)

Japan Aerospace Exploration Agency Education Payload Observation 6 (JAXA EPO 6) includes artistic experiments and cultural activities. JAXA implements these activities to enlighten the general public about microgravity utilization and human space



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flight. JAXA understands that International Space Station (ISS), Japanese Experiment Module (JEM), Kibo, is useful for scientists and engineers as well as writers, poets, teachers and artists. (JAXA)

Human Research

Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss (Bisphosphonates) determines whether antiresorptive agents (help reduce bone loss), in conjunction with the routine in-flight exercise program, protects International Space Station (ISS) crewmembers from the regional decreases in bone mineral density documented on previous ISS missions. The purpose of this study is not to test one dosing option versus the other. Rather, the intent is to show that bisphosphonates plus exercise will have a measurable effect versus exercise alone in preventing space flight induced bone loss. (NASA)

Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capability and Risk for Cardiac Arrhythmias (Integrated Cardiovascular) quantifies the extent, time course and clinical significance of cardiac atrophy (decrease in the size of the heart muscle) associated with long-duration space flight. This experiment identifies the mechanisms of this atrophy and the functional consequences for crewmembers that will spend extended periods of time in space. (NASA)

Validation of Procedures for Monitoring Crew Member Immune Function (Integrated Immune) will assess the clinical risks resulting from the adverse effects of space flight on the human immune system and will validate a

flight-compatible immune monitoring strategy. To monitor changes in the immune system, researchers collect and analyze blood, urine and saliva samples from crewmembers before, during and after space flight. There are no procedures currently in place to monitor immune function or its influence on crew health. Immune dysregulation has been demonstrated to occur during space flight, yet little in-flight immune data has been generated to assess this clinical problem. (NASA)

Evaluation of Maximal Oxygen Uptake and Submaximal Estimates of VO₂max Before, During, and After Long Duration International Space Station Missions (VO₂max) documents changes in maximum oxygen uptake for crewmembers on board the International Space Station (ISS) during long-duration missions. The data obtained from this study provides valuable insight into the aerobic capacity of teams in closed environments on Earth, such as arctic bases and submarines. (NASA)

Physical Science

Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions – 2 (InSPACE-2) obtains data on magneto-rheological fluids (fluids that change properties in response to magnetic fields) that can be used to improve or develop new brake systems and robotics. (NASA)

Chaos, Turbulence and its Transition Process in Marangoni Convection-Exp (Marangoni-Exp) analyzes the behavior of a surface-tension-driven flow in microgravity. Marangoni-Exp is a fluid physics experiment to observe Marangoni convection which is a surface-tension-driven flow. A liquid bridge of silicone oil with 30mm or 50mm in diameter is



formed into a pair of disks. Convection is induced by imposing the temperature difference between disks because of the surface tension gradient. (JAXA)

Growth of Homogeneous SiGe Crystals in Microgravity by the TLZ Method (Hicari) experiment aims to verify the crystal-growth theory, and to produce high-quality crystals of silicon-germanium semiconductor. (JAXA)

Technology

IntraVenous Fluid Generation for Exploration Missions (IVGEN) demonstrates the capability to purify water to the standards required for intravenous administration. This hardware is a prototype that will allow flight surgeons more options to treat ill or injured crew members during future long-duration exploration missions. IVGEN utilizes a deionizing resin bed to remove contaminants from feedstock water to a purity level that meets the standards of the United States Pharmacopeia (USP), which is chartered by the United States Food and Drug Administration to function as the governing body for pharmaceuticals in the United States. IVGEN technology could be used on Earth to generate IV fluid in Third World countries where medical resources are limited. (NASA)

Lab-on-a-Chip Application Development-Portable Test System (LOCAD-PTS) is a handheld device for rapid detection of biological and chemical substances on surfaces aboard the space station. Astronauts will swab surfaces within the cabin, mix swabbed material in liquid form to the LOCAD-PTS, and obtain results within 15 minutes on a display screen. The study's purpose is to

effectively provide a rapid indication of biological cleanliness to help crew monitor microorganisms in the ISS cabin environment. (NASA)

For more information on the research and technology demonstrations performed on the International Space Station, visit:

http://www.nasa.gov/mission_pages/station/science/

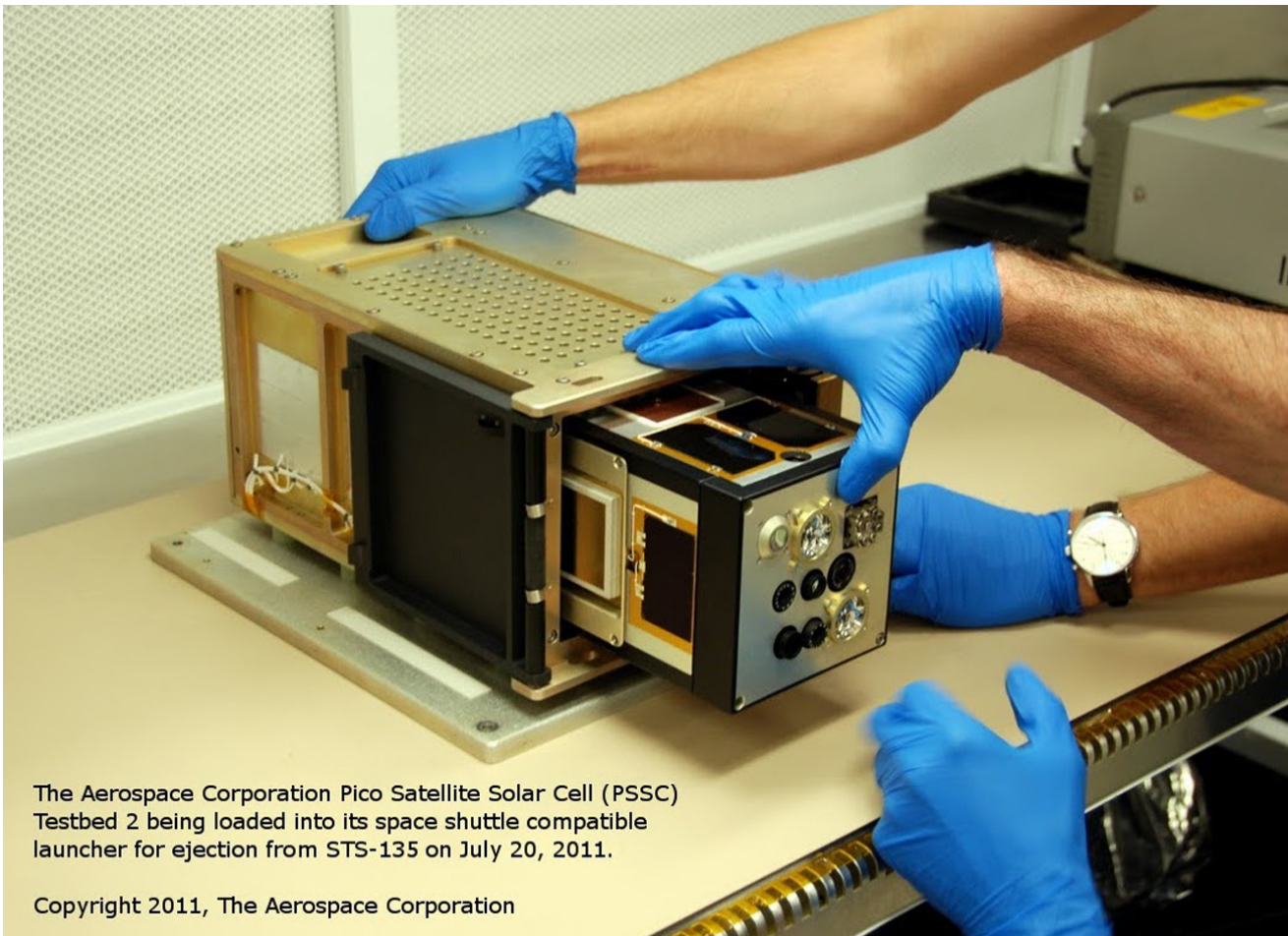
PICO-SATELLITE SOLAR CELL TESTBED

The Pico-Satellite Solar Cell (PSSC 2) testbed is scheduled to be deployed after Atlantis undocks from the International Space Station during STS-135/ULF7, becoming the last satellite ever deployed by the Space Shuttle Program.

The satellite, also known as "PicoSat," will perform two DoD experiments during its in-orbit lifetime. First, the Miniature Tracking Vehicle (MTV) experiment goal is to demonstrate the capability of a nano-satellite to serve as an orbiting reference for ground tracking systems while demonstrating 3-axis attitude control, solid rocket propulsion for orbit modification, adaptive communications and active solar cell performance monitoring in a nanosatellite platform. An on-board Global Positioning System (GPS) receiver will provide accurate time and position information to facilitate tracking error analyses. The second experiment, Compact Total Electron Content Sensor (CTECS), will demonstrate a CubeSat form factor space weather sensor with the capability to detect ionospheric density. It uses a modified commercial GPS receiver to detect differences in radio signals generated by occulting GPS satellites.



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The Aerospace Corporation Pico Satellite Solar Cell (PSSC) Testbed 2 being loaded into its space shuttle compatible launcher for ejection from STS-135 on July 20, 2011.

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Photo depicting an image of the PSSC Testbed

The PicoSat is 5" x 5" x 10" and weighs 3.7 kg. It is integrated onto Atlantis for the STS-135 mission under the management and direction of the DoD Space Test Program's Houston office at NASA's Johnson Space Center. PicoSat will be ejected shortly before shuttle re-entry into a low (less than 360-km altitude) orbit with an expected orbital lifetime of three to nine months, depending on solar activity. Multiple on-board megapixel cameras will image Atlantis as the satellite departs, thus supplying the last in-orbit photos of NASA's workhorse human space transportation system for the last few decades.

After the satellite's orbit lowers for approximately one month, four ammonium perchlorate solid rocket motors will provide 40 Ns of impulse each and could extend orbital lifetime by an additional two months or alternatively, actively deorbit the satellite. The PSSC 2 bus, MTV and CTECS experiments will be controlled by a primary ground station at The Aerospace Corporation in El Segundo, Calif., and secondary stations that comprise the Aerospace Corporation Internet-based Picosatellite Ground Station Network.



DEVELOPMENT TEST OBJECTIVES (DTO) AND DETAILED SUPPLEMENTARY OBJECTIVES (DSO)

Development Test Objectives (DTOs) are aimed at testing, evaluating or documenting systems or hardware or proposed improvements to hardware, systems and operations.

The following DTO will be conducted:

DTO 701A TriDAR Sensor (Triangulation and LIDAR Automated Rendezvous and Docking)

STS-135 will be the third space shuttle flight for the TriDAR sensor and the first time Atlantis has flown the system. Space shuttle Discovery carried the TriDAR DTO to ISS on two previous occasions (STS-128 and STS-131) where TriDAR capabilities were successfully demonstrated.

TriDAR provides critical guidance information that can be used to guide a vehicle during rendezvous and docking operations. Unlike current technologies, TriDAR does not rely on any reference markers, such as reflectors, positioned on the target spacecraft. To achieve this, it relies on a laser-based 3D sensor and a thermal imager. Geometric information contained in successive 3D images is matched against the known shape of the target object to calculate its position and orientation in real time.

On its maiden test flight (STS-128), TriDAR successfully demonstrated 3D sensor-based tracking in real time during rendezvous and docking to the International Space Station. During TriDAR's second test flight (STS-131) the program successfully demonstrated improved performance, tumbling target tracking, enhanced pilot displays as well as improved long range acquisition capabilities using passive thermal imaging. The third flight of the system is set to continue demonstration of the core real-time 3D tracking technology as well as demonstrate new functionality including real-time tracking from 2D thermal data and demonstration of advanced user interfaces. The system is also set to collect 3D and thermal imagery from the last space shuttle-based station flyaround developed by Canada's Neptec Design Group, winner of the 2010 George M. Low Award in the Small Business Product Category. TriDAR's 3D sensor is a dual sensing, multi-purpose scanner that builds on Neptec's Laser Camera System (LCS) technology currently used to inspect the space shuttle's thermal protection tiles. TriDAR's shape tracking technology is a key enabling technology for satellite servicing and it is a flexible tool that can be applied to diverse tasks including: automated rendezvous, robotic operations, planetary landing as well as rover navigation.



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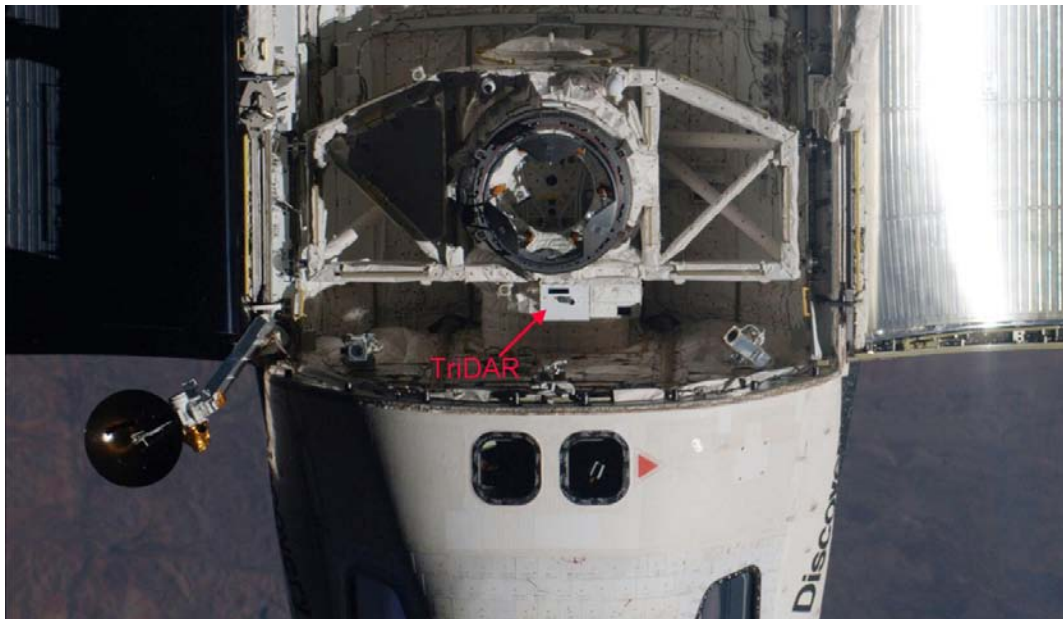


Image depicting the location of the TriDAR

Detailed Supplementary Objectives (DSOs) are space and life science investigations. Their purpose is to determine the extent of physiological deconditioning resulting from spaceflight, to test countermeasures to those changes and to characterize the space environment relative to crew health.

DSO 640 Physiological Factors

Exposure to the microgravity conditions of spaceflight causes astronauts to experience alterations in multiple physiological systems. These physiological changes include sensorimotor disturbances, cardiovascular deconditioning and loss of muscle mass and strength. These changes might affect the ability of crew members to perform critical mission tasks immediately after landing on a planetary surface following prolonged spaceflight.

To understand how changes in physiological function affect functional performance, an

interdisciplinary pre- and post-flight testing regimen called a Functional Task Test (FTT) has been developed that systematically evaluates both astronaut postflight functional performance and related physiological changes. The overall objective of the FTT is to identify the key underlying physiological factors that contribute to performance of functional tests that are representative of critical mission tasks.

This study will identify which physiological systems contribute the most to impaired performance on each functional test. This will allow us to identify the physiological systems that play the largest roles in decrements in overall functional performance. Using this information, we can design and implement countermeasures that specifically target the physiological systems most responsible for the altered functional performance associated with spaceflight.



DSO-641 Risk of Orthostatic Intolerance During Re-exposure to Gravity

One of the most important physiological changes that may negatively impact crew safety is post-flight orthostatic intolerance. Astronauts who have orthostatic intolerance are unable to maintain a normal systolic blood pressure during head-up tilt, have elevated heart rates and may experience presyncope or syncope with upright posture. This problem affects about 30 percent of astronauts who fly short-duration missions (4 to 18 days) and 83 percent of astronauts who fly long-duration missions. This condition creates a potential hazard for crew members during re-entry and after landing, especially for emergency egress contingencies.

Two countermeasures are currently employed to ameliorate post-flight orthostatic intolerance; fluid loading and an anti-gravity suit. Unfortunately, neither of these are completely effective for all phases of landing and egress, thus, continued countermeasure development is important. Preliminary evidence has shown that commercial compression hose that

include abdominal compression can significantly improve orthostatic tolerance. These data are similar to clinical studies using inflatable compression garments.

Custom-fitted, commercial compression garments will be evaluated as countermeasures to immediate and longer-term post-flight orthostatic intolerance. These garments will provide a continuous, graded compression from the foot to the hip, and a static compression over the lower abdomen. These garments should provide superior fit and comfort as well as being easier to don. Tilt testing will be used as an orthostatic challenge before and after spaceflight.

For more information about this and other DSOs, visit

https://rlsda.jsc.nasa.gov/scripts/experiment/exper.cfm?exp_index=1448

and

https://rlsda.jsc.nasa.gov/docs/research/research_detail.cfm?experiment_type_code=35&research_type=



STUDENT EXPERIMENTS

Peoria, Arizona

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 525 grade 5 through grade 8 students

SSEP Community-wide Engagement Program: 1,060 grade K through grade 8 students participating

Number of participating schools: 1, Parkridge Elementary School

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

Participation in the Student Spaceflight Experiments Program will help The Parkridge Elementary School meet its STEM education needs. Participating in this program is a perfect way to help tie STEM lessons into the different grade levels. Parkridge strongly believes in allowing all students the opportunity to get involved with activities such as SSEP to better prepare students for their futures. The motto at Parkridge is “College Ready.” They believe that it is their role here to prepare students for college. SSEP is also beneficial because it gives students a glimpse into future career options and what it is like to work as a scientist. The school will also use this program in partnership with the school-wide science fair. Not only will all grade levels benefit from the SSEP, the community will be made aware of this opportunity. Parents and the community will be able to visit their science fair and learn about the SSEP. The school knows that by allowing its students to participate in STEM activities will not only broaden their knowledge in different areas of science, technology, engineering, and math, but also better prepare them for their futures.

Partner Institutions

Lead: [Peoria Unified School District](#)
[John F. Long Properties LLLP](#)
[Vernier Software & Technology](#)
[NAU/NASA Space Grant](#)

SSEP Mission Participation

STS-135

SSEP Community Program Director

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School District
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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Hartford, Connecticut

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 150 grade 5 through grade 8 students
SSEP Community-wide Engagement Program: 364 grade K through grade 8 students participating
Number of participating schools: 1

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

The Annie Fisher STEM Magnet School is among the shining stars of Hartford Public Schools – with the Choose, Achieve, and Succeed motto of educational reform. The school highlights the core philosophy that science, technology, engineering, and mathematics are the norm for all students – kindergarten through the eighth grade. Through various established partnerships, the Student Spaceflight Experiments Program allows students the opportunity to work collaboratively with high school, college and industry-level professionals. These opportunities are not only unique, but incorporate inquiry-based educational programming along with the integration of 21st Century Skills. The idea of bringing all levels of academic learners to work collaboratively on a joint experiment fosters an amazing educational experience. This real-world experience will inspire students to continue their education within science, technology, engineering and mathematics fields.

Partner Institutions

Lead: [Annie Fisher STEM Magnet School](#)
[Hamilton Sundstrand](#)
[Connecticut Space Grant College Consortium](#)
[University High School of Science and Engineering](#)
[Hartford Public Schools](#)
[Travelers Insurance](#)

SSEP Mission Participation

STS-135

SSEP Community Program Director

Rachael Manzer
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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Chicago, Illinois

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 355 grade 4 through grade 8 students
SSEP Community-wide Engagement Program: 700 grade K through grade 8 students participating
Number of participating schools: 1, Skinner West Classical, Fine Arts & Technology School

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

Chicago is the headquarters for many of the country's most technologically advanced firms, research laboratories, and universities. In support of such institutions, Skinner West is helping to nurture the next generation of highly-educated, technologically-capable workers. Skinner West believes in providing students with the most authentic and inspiring science experiences possible, coupled with rigorous instruction in the skills required to conduct scientific investigations. In addition to giving children the skills they need to succeed in the 21st Century, this method of science instruction also fosters a lifelong curiosity about the natural world, and gives children the power to answer their own questions. The Student Spaceflight Experiments Program provides just the type of learning opportunity that Skinner West's students need. This amazing program will give students the chance to actually be scientists, designing real experiments for spaceflight. This is truly a once-in-a-lifetime learning opportunity, with the potential to inspire hundreds of our students to pursue further studies in science, technology, engineering and mathematics.

Partner Institutions

Lead: [Chicago Public Schools](#)
[Motorola Solutions Foundation](#)

SSEP Mission Participation

STS-135

SSEP Community Program Director

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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Avicenna Academy, Crown Point, Indiana

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 101 grade 4 through grade 12 students
SSEP Community-wide Engagement Program: 273 grade K through grade 12 students participating
Number of participating schools: 2

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

Avicenna Academy's school community has high scores in both Language Arts and Mathematics, as measured by Indiana's standardized assessments, and the current priority is creating and fostering an ongoing love for science in the students by establishing a strong, inquiry-based science program. There is a clear connection between the investigation skills that are fine-tuned through scientific exploration and problem-solving ability. The ability to think critically and solve problems is necessary to be competitive in today and tomorrow's job market. The collaborative effort in this project, with Life Learning Cooperative, offers students the chance to collaborate with other budding scientists in a different educational atmosphere. The diversity among the participants is remarkable and will, in that way, mirror much of the work being done by scientists around the world today. It is imperative that today's youth are prepared for success in tomorrow's world. Participation in SSEP allows the school to bring learning out onto the playing field instead of limiting it to a classroom, and that is crucial to effective preparation for students' futures.

Partner Institutions and Individuals

Co-Lead: [Avicenna Academy](#)

Co-Lead: Life Learning Cooperative
[Indiana Space Grant Consortium](#)

Dr. Arshad Malik & Mrs. Malik

Dr. Amjad Bahnasi & Mrs. Bahnasi

Dr. Basil Hajjar & Mrs. Dana Rifai-Hajjar

Dr. M. Hytham Rifai & Mrs. Nuha Rifai

[Anderson University Biology Department](#)

[Hoosier Microbiological Laboratories](#)

[Indiana University Northwest](#)

[The Jackson Laboratory](#)

[Yale University's E. coli bank](#)

SSEP Mission Participation

STS-135

SSEP Community Program Director

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Principal, Avicenna Academy

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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Galva-Holstein, Iowa

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 600 grade 5 through grade 12 students

SSEP Community-wide Engagement Program: 800 grade K through grade 12 students participating

Number of participating schools: 4

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

The participation in the Student Spaceflight Experiments Program will engage communities located in western Iowa in STEM education awareness and career opportunities. The collaboration exemplified by statewide education stakeholders, internationally known companies and entrepreneurs is a testament to the commitment to inspiring our next generation to imagine STEM-related career pathways.

The district has a recognized history of excelling in providing students with college preparation. This tradition continues as the district continues to successfully collaborate and provide new resources that strengthen the STEM learning opportunities for the students. Participation in SSEP will add another level of enhancement to the Virtual Reality Education Pathway consortium resources offered in the district. Students in grades 5 through 12 will have the opportunity to engage in science experiments, create 3D models, and in turn, engage the youngest students in student-led instruction.

Partner Institutions

Lead: [Galva Holstein Community School District](#)

[Ida County Economic Development](#)

John Pappajohn

[Pioneer Hi-Bred International, Inc.](#)

[Rockwell Collins](#)

[Iowa Mathematics & Science Education Partnership](#)

[Iowa Space Grant Consortium](#)

[Iowa State University Extension – Ida County](#)

[Northwest Area Education Agency](#)

SSEP Mission Participation

STS-135

SSEP Community Program Co-Directors

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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Charles County, Maryland

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 1,400 grade 5 through grade 12 students
SSEP Community-wide Engagement Program: 6,000 grade K through grade 12 students participating
Number of participating schools: 20

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

With Charles County's location in the center of a regional technology corridor and the aging of the STEM workforce, Charles County has a goal of attracting and preparing students at all educational levels to pursue STEM coursework; supporting students to pursue postsecondary degrees; providing students and teachers with STEM-related growth and research opportunities and expanding the capacity of the school system to promote STEM education. The following programs have been developed and implemented to meet these goals: trans disciplinary curricula, Gateway and Project Lead The Way classes, lessons co-taught by scientists or engineers, and programs in which robotics and Chesapeake Bay issues introduce the use of technology with science and environmental issues.

In partnership with the Space Foundation, Charles County Public Schools has put into place professional development for teachers to increase their knowledge and application of space and aerospace technologies. This provides them a good foundation to become more comfortable with fundamental space and aerospace concepts allowing them to share their knowledge and enthusiasm for aerospace

engineering with their students. SSEP can support the school system's vision by engaging students in authentic scientific thinking and problem solving as they become scientists in this historic endeavor.

Partner Institutions

Lead: [Charles County Public Schools](#)
[Maryland Space Grant Consortium](#)
[College of Southern Maryland](#)
[Naval Surface Warfare Center, Indian Head Division](#)

SSEP Mission Participation

STS-135

SSEP Community Program Co-Directors

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Scott Hangey
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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Fitchburg, Massachusetts

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 1,400 grade 9 through grade 12 students
SSEP Community-wide Engagement Program: 1,400 grade 9 through grade 12 students participating
Number of participating schools: 1, Montachusett Regional Vocational Technical School

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

The strategic need for the school community in STEM Education is two-fold; it will dramatically increase student interest and prepare and inspire the next generation of scientists for STEM careers, and it will provide new opportunities for community involvement. Participation in this project will empower the students by challenging them to ask authentic questions about the world they live in. Through the STEM Education program, the students have an opportunity to generate questions and integrate knowledge from all of their educational experiences. Using math and science skills to develop and analyze an experiment, students will foster their ability to think critically. This program will also enable students to apply their unique vocational education skills to real-world problems. Beyond engaging and educating students, families, educators and the local community will benefit from this program as well. Through exhibits and programs, and professional development opportunities, members of the Monty Tech community will assist and support teachers in STEM Education. SSEP is assisting Monty Tech in meeting long- and short-term goals by selecting the community for the STS-135 mission.

Partner Institutions

Lead: [Montachusett Regional Vocational Technical School](#)
[The Community Foundation of North Central Massachusetts](#)
[Massachusetts Space Grant Consortium](#)
[MIT](#)
[Massachusetts Workforce Board Association](#)

SSEP Mission Participation

STS-135

SSEP Community Program Director

Paula deDiego
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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Potter and Dix, Nebraska

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 130 grade 5 through grade 12 students

SSEP Community-wide Engagement Program: 200 grade K through grade 12 students participating

Number of participating schools: 2

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

STEM education: The U.S. Department of Labor stated that 15 of the 20 fastest growing occupations require significant mathematics or science preparation. In 2009, these statistics prompted the Potter-Dix school district to evaluate, design and rebuild the science curriculum. The science curriculum is designed to provide students with science, math and engineering/technology in sequences that build upon each other. Physics, taught as the first science course for high school students, parallels the goals of basic algebra; reinforcing skills such as solving equations, interpreting graphs and reasoning proportionately. Engineering components emphasize process and design of solutions. Each successive course builds on the STEM principles. Students will be future scientists, mathematicians and engineers, and the Student Spaceflight Experiments Program will provide Potter-Dix students with the opportunity to increase their critical thinking skills and their science literacy.

Partner Institutions

Lead: [Potter-Dix Public Schools](#)
[The Sherwood Foundation](#)
[NASA Nebraska Space Grant](#)
[Nebraska Natural Resources Conservation Service](#)
[Texas A & M University Department of Soil & Crop Sciences](#)

SSEP Mission Participation

STS-135

SSEP Community Program Co-Directors

Joette Wells
High School Science Instructor, Potter-Dix Public Schools

Kevin Thomas
Superintendent, Potter-Dix Public Schools

Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Lincoln, Nebraska

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 3,200 grade 5 through grade 8 students
SSEP Community-wide Engagement Program: 3,200 grade K through grade 8 students participating
Number of participating schools: 14; also a home-school network

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

As the capital of Nebraska with a population of 255,000, Lincoln has a reputation for quality education and provides students a wide variety of opportunities for authentic learning. The SSEP in Lincoln is open to any student in grades 6 through 12 in the public schools (6 high schools and 11 middle schools), parochial schools and home-school groups. Participating schools have the opportunity to partner with local experts in industry and/or academia. The challenges of meeting the requirements for this authentic scientific effort represent a unique learning opportunity for students and complements the theory and training they get in the classroom.

Partner Institutions

Lead: [UNL Center for Science, Mathematics & Computer Education](#)
[Lincoln Public Schools](#)
[The Sherwood Foundation](#)
[NASA Nebraska Space Grant](#)

SSEP Mission Participation

STS-135

SSEP Community Program Co-Directors

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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Bridgewater-Raritan, New Jersey

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: opportunity provided to 2,955 grade 9 through grade 12 students
SSEP Community-wide Engagement Program: 2,955 grade 9 through grade 12 students participating
Number of participating schools: 1, Bridgewater-Raritan High School

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

The Bridgewater-Raritan School District (BRRSD) has created a unique opportunity to inspire and motivate a community of nearly 3,000 high school students in central New Jersey to pursue fields of study and future careers in science, technology, engineering and mathematics (STEM) by engaging students, teachers, science professionals and the community at large in the Student Spaceflight Experiments Program (SSEP). A community where many of its residents are entrepreneurs, professionals or employed by local corporations in the technology, bio-pharmaceutical and telecommunications industries, our PreK through 12 school system serves approximately over 9,000 students. The district's curriculum has a long tradition of academic excellence designed to prepare students for both college and the workplace. This design allows for varied levels of learning in meeting the needs of individual students while providing a rich and diverse portfolio of academic options that provide challenges aimed at helping students reach their fullest potential. The Science Department at Bridgewater-Raritan High School (BRHS) offers a rich and diverse science core curriculum and a unique portfolio of science electives aimed at providing students with a broad range of knowledge and laboratory skills. Students are encouraged to take the most challenging courses (differentiated by level of rigor) in which they

are most successful. The SSEP offers a truly unique opportunity to capitalize further on the proven academic success of this community by fostering a network of collaboration among students and faculty working together to further motivate and inspire our next generation of leaders who will take on the global challenges of the 21st century.

Partner Institutions

Lead: [Bridgewater-Raritan School District](#)
[AT&T Labs](#)
[Young Science Achievers](#)
[Hawk Pointe Golf Club Foundation](#)
Bridgewater-Raritan Class of 1986
Alumni Foundation/Princeton Area
Community Foundation
[Scitor Corporation](#)

SSEP Mission Participation

STS-135

SSEP Community Program Co-Directors

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Jump to: [a more detailed Community Profile, if available at their Community Blog](#)



Yeshiva Ketana of Long Island, Inwood, New York

Jump to: [their SSEP Community Blog](#)

Program Scope

Experiment Design Competition: Opportunity provided to 150 grade 5 through grade 8 students
SSEP Community-wide Engagement Program: 375 grade K through grade 8 students participating
Number of participating schools: 1

Community Statement on SSEP and Strategic Alignment to Local STEM Education Need

The STEM program provides each student with strong math, science, and computer skills and opportunities to apply those skills to complex problem solving. The goal is for students to become life-long learners, with a thirst for knowledge and the skills to acquire that knowledge. The creative faculty employs Smartboards, hands-on materials, and innovation to help each student maximize his potential. An experiential, inquiry-driven science program, centered on the scientific method, provides each student with weekly laboratory time to view/conduct experiments. Students visit science museums and research facilities where they conduct experiments and research that supplement their classroom and lab findings.

The Student Spaceflight Experiments Program is the natural next step for the STEM program; challenging students in domains they have yet to explore and enabling them to participate in a national mission. This unique project has the potential to ignite the science program while uniting the learning community. While the project itself is open to grades 5 through 8, the entire student body will conduct grade-appropriate scientific projects and research which will engage and involve everyone in preparation for the launch.

This will be a life-changing experience that will serve as the inspiration for many students to enter the STEM fields.

Partner Institutions

Lead: [Elliquence LLC](#)
[Galactic Medical](#)
[Oxygen Ink](#)
[Macro Design Group](#)
[TNT Design Group](#)
[AV Group](#)

SSEP Mission Participation

STS-135

SSEP Community Program Director

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SSEP Community Program Co-Director

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For more information on these experiments, visit:

<http://ssep.ncesse.org/communities/community-directory/community-profiles-and-local-partners-ssep-on-sts-135/>



SHUTTLE REFERENCE DATA

SHUTTLE ABORT MODES

Redundant Set Launch Sequencer (RSL) Aborts

These occur when the onboard shuttle computers detect a problem and command a halt in the launch sequence after taking over from the ground launch sequencer and before solid rocket booster ignition.

Ascent Aborts

Selection of an ascent abort mode may become necessary if there is a failure that affects vehicle performance, such as the failure of a space shuttle main engine or an orbital maneuvering system engine. Other failures requiring early termination of a flight, such as a cabin leak, might also require the selection of an abort mode. There are two basic types of ascent abort modes for space shuttle missions: intact aborts and contingency aborts. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit flight crew survival following more severe failures when an intact abort is not possible. A contingency abort would generally result in a ditch operation.

Intact Aborts

There are four types of intact aborts: Abort To Orbit (ATO), Abort Once Around (AOA), Transoceanic Abort Landing (TAL) and Return To Launch Site (RTLS).

Return to Launch Site

The RTLS abort mode is designed to allow the return of the orbiter, crew and payload to the

launch site, KSC, approximately 25 minutes after liftoff.

The RTLS profile is designed to accommodate the loss of thrust from one space shuttle main engine between liftoff and approximately four minutes 20 seconds, after which not enough main propulsion system propellant remains to return to the launch site. An RTLS can be considered to consist of three stages – a powered stage, during which the space shuttle main engines are still thrusting; an external tank separation phase; and the glide phase, during which the orbiter glides to a landing at the KSC. The powered RTLS phase begins with the crew selection of the RTLS abort, after solid rocket booster separation. The crew selects the abort mode by positioning the abort rotary switch to RTLS and depressing the abort push button. The time at which the RTLS is selected depends on the reason for the abort. For example, a three-engine RTLS is selected at the last moment, about 3 minutes, 34 seconds into the mission; whereas an RTLS chosen due to an engine out at liftoff is selected at the earliest time, about 2 minutes, 20 seconds into the mission (after solid rocket booster separation).

After RTLS is selected, the vehicle continues downrange to dissipate excess main propulsion system propellant. The goal is to leave only enough main propulsion system propellant to be able to turn the vehicle around, fly back toward KSC and achieve the proper main engine cutoff conditions so the vehicle can glide to KSC after external tank separation. During the downrange phase, a pitch-around maneuver is initiated (the time depends in part on the time of a space shuttle main engine



failure) to orient the orbiter/external tank configuration to a heads-up attitude, pointing toward the launch site. At this time, the vehicle is still moving away from the launch site, but the space shuttle main engines are now thrusting to null the downrange velocity. In addition, excess orbital maneuvering system and reaction control system propellants are dumped by the continuous orbital maneuvering system and reaction control system engine thrustings to improve the orbiter weight and center of gravity for the glide phase and landing.

The vehicle will reach the desired main engine cutoff point with less than 2 percent excess propellant remaining in the external tank. At main engine cutoff minus 20 seconds, a pitch down maneuver (called powered pitch-down) takes the mated vehicle to the required external tank separation attitude and pitch rate. After main engine cutoff has been commanded, the external tank separation sequence begins, including a reaction control system maneuver that ensures that the orbiter does not recontact the external tank and that the orbiter has achieved the necessary pitch attitude to begin the glide phase of the RTLS.

After the reaction control system maneuver has been completed, the glide phase of the RTLS begins. From then on, the RTLS is handled similarly to a normal entry.

Transoceanic Abort Landing

The TAL abort mode was developed to improve the options available if a space shuttle main engine fails after the last RTLS opportunity but before the first time that an AOA can be accomplished with only two space shuttle main engines or when a major orbiter system failure, for example, a large cabin

pressure leak or cooling system failure, occurs after the last RTLS opportunity, making it imperative to land as quickly as possible.

In a TAL abort, the vehicle continues on a ballistic trajectory across the Atlantic Ocean to land at a predetermined runway. Landing occurs about 45 minutes after launch. The landing site is selected near the normal ascent ground track of the orbiter to make the most efficient use of space shuttle main engine propellant. The landing site also must have the necessary runway length, weather conditions and U.S. State Department approval. The three landing sites that have been identified for a launch are Zaragoza, Spain; Morón, Spain; and Istres, France.

To select the TAL abort mode, the crew must place the abort rotary switch in the TAL/AOA position and depress the abort push button before main engine cutoff (depressing it after main engine cutoff selects the AOA abort mode). The TAL abort mode begins sending commands to steer the vehicle toward the plane of the landing site. It also rolls the vehicle heads up before main engine cutoff and sends commands to begin an orbital maneuvering system propellant dump (by burning the propellants through the orbital maneuvering system engines and the reaction control system engines). This dump is necessary to increase vehicle performance (by decreasing weight) to place the center of gravity in the proper place for vehicle control and to decrease the vehicle's landing weight. TAL is handled like a normal entry.

Abort to Orbit

An ATO is an abort mode used to boost the orbiter to a safe orbital altitude when performance has been lost and it is impossible



to reach the planned orbital altitude. If a space shuttle main engine fails in a region that results in a main engine cutoff under speed, the MCC will determine that an abort mode is necessary and will inform the crew. The orbital maneuvering system engines would be used to place the orbiter in a circular orbit.

Abort Once Around

The AOA abort mode is used in cases in which vehicle performance has been lost to such an extent that either it is impossible to achieve a viable orbit or not enough orbital maneuvering system propellant is available to accomplish the orbital maneuvering system thrusting maneuver to place the orbiter in space. In addition, an AOA is used in cases in which a major systems problem (cabin leak, loss of cooling) makes it necessary to land quickly. In the AOA abort mode, one orbital maneuvering system thrusting sequence is made to adjust the post-main engine cutoff orbit so a second orbital maneuvering system thrusting sequence will result in the vehicle deorbiting and landing at the AOA landing site (White Sands, N.M.; Edwards Air Force Base, Calif.; or the Kennedy Space Center, Fla). Thus, an AOA results in the orbiter circling the Earth once and landing about 90 minutes after liftoff.

After the deorbit thrusting sequence has been executed, the flight crew flies to a landing at the planned site much as it would for a nominal entry.

Contingency Aborts

Contingency aborts are caused by loss of more than one main engine or failures in other systems. Loss of one main engine while another is stuck at a low thrust setting also may necessitate a contingency abort. Such an abort

would maintain orbiter integrity for in-flight crew escape if a landing cannot be achieved at a suitable landing field.

Contingency aborts due to system failures other than those involving the main engines would normally result in an intact recovery of vehicle and crew. Loss of more than one main engine may, depending on engine failure times, result in a safe runway landing. However, in most three-engine-out cases during ascent, the orbiter would have to be ditched. The inflight crew escape system would be used before ditching the orbiter.

Abort Decisions

There is a definite order of preference for the various abort modes. The type of failure and the time of the failure determine which type of abort is selected. In cases where performance loss is the only factor, the preferred modes are ATO, AOA, TAL and RTLS, in that order. The mode chosen is the highest one that can be completed with the remaining vehicle performance.

In the case of some support system failures, such as cabin leaks or vehicle cooling problems, the preferred mode might be the one that will end the mission most quickly. In these cases, TAL or RTLS might be preferable to AOA or ATO. A contingency abort is never chosen if another abort option exists.

Mission Control Houston is prime for calling these aborts because it has a more precise knowledge of the orbiter's position than the crew can obtain from onboard systems. Before main engine cutoff, Mission Control makes periodic calls to the crew to identify which abort mode is (or is not) available. If ground communications are lost, the flight crew has onboard methods, such as cue cards, dedicated



displays and display information, to determine the abort region. Which abort mode is selected depends on the cause and timing of the failure causing the abort and which mode is safest or improves mission success. If the problem is a space shuttle main engine failure, the flight crew and Mission Control Center select the best option available at the time a main engine fails.

If the problem is a system failure that jeopardizes the vehicle, the fastest abort mode that results in the earliest vehicle landing is chosen. RTLS and TAL are the quickest options (35 minutes), whereas an AOA requires about 90 minutes. Which of these is selected depends on the time of the failure with three good space shuttle main engines.

The flight crew selects the abort mode by positioning an abort mode switch and depressing an abort push button.

SHUTTLE ABORT HISTORY

RSLs Abort History

(STS-41 D) June 26, 1984

The countdown for the second launch attempt for Discovery's maiden flight ended at T minus (T - 4) seconds when the orbiter's computers detected a sluggish valve in main engine No. 3. The main engine was replaced and Discovery was finally launched on Aug. 30, 1984.

(STS-51 F) July 12, 1985

The countdown for Challenger's launch was halted at T - 3 seconds when onboard computers detected a problem with a coolant valve on main engine No. 2. The valve was replaced and Challenger was launched on July 29, 1985.

(STS-55) March 22, 1993

The countdown for Columbia's launch was halted by onboard computers at T - 3 seconds following a problem with purge pressure readings in the oxidizer preburner on main engine No. 2. Columbia's three main engines were replaced on the launch pad, and the flight was rescheduled behind Discovery's launch on STS-56. Columbia finally launched on April 26, 1993.

(STS-51) Aug. 12, 1993

The countdown for Discovery's third launch attempt ended at the T - 3 second mark when onboard computers detected the failure of one of four sensors in main engine No. 2 which monitor the flow of hydrogen fuel to the engine. All of Discovery's main engines were ordered replaced on the launch pad, delaying the shuttle's fourth launch attempt until Sept. 12, 1993.

(STS-68) Aug. 18, 1994

The countdown for Endeavour's first launch attempt ended 1.9 seconds before liftoff when onboard computers detected higher than acceptable readings in one channel of a sensor monitoring the discharge temperature of the high pressure oxidizer turbopump in main engine No. 3. A test firing of the engine at the Stennis Space Center in Mississippi on Sept. 2, 1994, confirmed that a slight drift in a fuel flow meter in the engine caused a slight increase in the turbopump's temperature. The test firing also confirmed a slightly slower start for main engine No. 3 during the pad abort, which could have contributed to the higher temperatures. After Endeavour was brought back to the Vehicle Assembly Building to be outfitted with three replacement engines,



NASA managers set Oct. 2, 1994, as the date for Endeavour's second launch attempt.

Abort to Orbit History

(STS-51 F) July 29, 1985

After an RSLS abort on July 12, 1985, Challenger was launched on July 29, 1985. Five minutes and 45 seconds after launch, a sensor problem resulted in the shutdown of center engine No. 1, resulting in a safe "abort to orbit" and successful completion of the mission.

SPACE SHUTTLE MAIN ENGINES

Developed in the 1970s by NASA's Marshall Space Flight Center, in Huntsville, Ala., the space shuttle main engine is the most advanced liquid-fueled rocket engine ever built. Every space shuttle main engine is tested and proven flight worthy at NASA's Stennis Space Center in south Mississippi, before installation on an orbiter. Its main features include variable thrust, high performance reusability, high redundancy and a fully integrated engine controller.

The shuttle's three main engines are mounted on the orbiter aft fuselage in a triangular pattern. Spaced so that they are movable during launch, the engines are used, in conjunction with the solid rocket boosters, to steer the shuttle vehicle.

Each of these powerful main engines is 14 feet long, weighs about 7,000 pounds and is 7.5 feet in diameter at the end of its nozzle.

The engines operate for about 8.5 minutes during liftoff and ascent, burning more than 500,000 gallons of super-cold liquid hydrogen and liquid oxygen propellants stored in the external tank attached to the underside of the shuttle. The engines shut down just before the

shuttle, traveling at about 17,000 miles per hour, reaches orbit.

The main engine operates at greater temperature extremes than any mechanical system in common use today. The fuel, liquefied hydrogen at -423 degrees Fahrenheit, is the second coldest liquid on Earth. When it and the liquid oxygen are combusted, the temperature in the main combustion chamber is 6,000 degrees Fahrenheit, hotter than the boiling point of iron.

The main engines use a staged combustion cycle so that all propellants entering the engines are used to produce thrust, or power, more efficiently than any previous rocket engine. In a staged combustion cycle, propellants are first burned partially at high pressure and relatively low temperature, and then burned completely at high temperature and pressure in the main combustion chamber. The rapid mixing of the propellants under these conditions is so complete that 99 percent of the fuel is burned.

At normal operating level, each engine generates 490,847 pounds of thrust, measured in a vacuum. Full power is 512,900 pounds of thrust; minimum power is 316,100 pounds of thrust.

The engine can be throttled by varying the output of the preburners, thus varying the speed of the high-pressure turbopumps and, therefore, the flow of the propellant.

At about 26 seconds into ascent, the main engines are throttled down to 316,000 pounds of thrust to keep the dynamic pressure on the vehicle below a specified level, about 580 pounds per square foot, known as max q. Then, the engines are throttled back up to normal operating level at about 60 seconds. This reduces stress on the vehicle. The main



engines are throttled down again at about seven minutes, 40 seconds into the mission to maintain three g's, three times the Earth's gravitational pull, reducing stress on the crew and the vehicle. This acceleration level is about one-third the acceleration experienced on previous crewed space vehicles.

About 10 seconds before Main Engine Cutoff (MECO), the cutoff sequence begins. About three seconds later the main engines are commanded to begin throttling at 10 percent thrust per second until they achieve 65 percent thrust. This is held for about 6.7 seconds, and the engines are shut down.

The engine performance has the highest thrust for its weight of any engine yet developed. In fact, one space shuttle main engine generates sufficient thrust to maintain the flight of two and one-half Boeing 747 airplanes.

The space shuttle main engine also is the first rocket engine to use a built-in electronic digital controller, or computer. The controller accepts commands from the orbiter for engine start, change in throttle, shutdown and monitoring of engine operation.

NASA continues to increase the reliability and safety of shuttle flights through a series of enhancements to the space shuttle main engines. The engines were modified in 1988, 1995, 1998, 2001 and 2007. Modifications include new high-pressure fuel and oxidizer turbopumps that reduce maintenance and operating costs of the engine, a two-duct powerhead that reduces pressure and turbulence in the engine, and a single-coil heat exchanger that lowers the number of post flight inspections required. Another modification incorporates a large-throat main combustion chamber that improves the engine's reliability

by reducing pressure and temperature in the chamber.

The most recent engine enhancement is the Advanced Health Management System (AHMS), which made its first flight in 2007. AHMS is a controller upgrade that provides new monitoring and insight into the health of the two most complex components of the space shuttle main engine – the high pressure fuel turbopump and the high pressure oxidizer turbopump. New advanced digital signal processors monitor engine vibration and have the ability to shut down an engine if vibration exceeds safe limits. AHMS was developed by engineers at Marshall.

After the orbiter lands, the engines are removed and returned to a processing facility at NASA's Kennedy Space Center, Fla., where they are rechecked and readied for the next flight. Some components are returned to the main engine's prime contractor, Pratt & Whitney Rocketdyne, West Palm Beach, Fla., for regular maintenance. The main engines are designed to operate for 7.5 accumulated hours.

SPACE SHUTTLE SOLID ROCKET BOOSTERS (SRB)

The two Solid Rocket Boosters (SRBs) required for a space shuttle launch and first two minutes of powered flight boast the largest solid-propellant motors ever flown. They are the first large rockets designed for reuse and are the only solid rocket motors rated for human flight. The SRBs have the capacity to carry the entire weight of the External fuel Tank (ET), and orbiter, and to transmit the weight load through their structure to the Mobile Launcher Platform (MLP).

The banner features the STS-135 mission logo on the left, which includes a stylized shuttle and the text 'MISSION', 'PROGRESS', 'INTEGRITY', and 'EXPLORATION'. To the right of the logo, the text 'STS-135: The Final Mission' is displayed in a large, bold, white font against a background of a blue and white American flag with a yellow glow on the right side.

STS-135: The Final Mission

The SRBs provide 71.4 percent of the thrust required to lift the space shuttle off the launch pad and during first-stage ascent to an altitude of about 150,000 feet, or 28 miles. At launch, each booster has a sea level thrust of approximately 3.3 million pounds and is ignited after the ignition and verification of the three Space Shuttle Main Engines (SSMEs).

SRB apogee occurs at an altitude of about 230,000 feet, or 43 miles, 75 seconds after separation from the main vehicle. At booster separation, the space shuttle orbiter has reached an altitude of 24 miles and is traveling at a speed in excess of 3,000 miles per hour.

The primary elements of each booster are nose cap, housing the pilot and drogue parachute; frustum, housing the three main parachutes in a cluster; forward skirt, housing the booster flight avionics, altitude sensing, recovery avionics, parachute cameras and range safety destruct system; four motor segments, containing the solid propellant; motor nozzle; and aft skirt, housing the nozzle and thrust vector control systems required for guidance. Each SRB possesses its own redundant auxiliary power units and hydraulic pumps.

SRB impact occurs in the ocean approximately 140 miles downrange. SRB retrieval is provided after each flight by specifically designed and built ships. The frustums, drogue and main parachutes are loaded onto the ships along with the boosters and towed back to NASA's Kennedy Space Center, where they are disassembled and refurbished for reuse. Before retirement, each booster can be used as many as 20 times.

Each booster is just over 149 feet long and 12.17 feet in diameter. Both boosters have a combined weight of 1,303,314 pounds at lift-off.

They are attached to the ET at the SRB aft attach ring by an upper and lower attach strut and a diagonal attach strut. The forward end of each SRB is affixed to the ET by one attach bolt and ET ball fitting on the forward skirt. While positioned on the launch pad, the space shuttle is attached to the MLP by four bolts and explosive nuts equally spaced around each SRB. After ignition of the solid rocket motors, the nuts are severed by small explosives that allow the space shuttle vehicle to perform lift off.

United Space Alliance

United Space Alliance (USA), at Kennedy facilities, is responsible for all SRB operations, except the motor and nozzle portions. In conjunction with maintaining sole responsibility for manufacturing and processing of the nonmotor hardware and vehicle integration, USA provides the service of retrieval, post flight inspection and analysis, disassembly and refurbishment of the hardware. USA also exclusively retains comprehensive responsibility for the orbiter.

The reusable solid rocket motor segments are shipped from ATK Launch Systems in Utah to Kennedy, where they are mated by USA personnel to the other structural components – the forward assembly, aft skirt, frustum and nose cap – in the Vehicle Assembly Building. Work involves the complete disassembly and refurbishment of the major SRB structures – the aft skirts, frustums, forward skirts and all ancillary hardware – required to complete an SRB stack and mate to the ET. Work then proceeds to ET/SRB mate, mate with the orbiter and finally, space shuttle close out operations. After hardware restoration concerning flight configuration is complete, automated checkout and hot fire are performed early in hardware



flow to ensure that the refurbished components satisfy all flight performance requirements.

ATK Launch Systems (ATK)

ATK Launch Systems of Brigham City, Utah, manufactures space shuttle Reusable Solid Rocket Motors (RSRMs), at their Utah facility. Each RSRM – just over 126 feet long and 12 feet in diameter – consists of four rocket motor segments and an aft exit cone assembly is. From ignition to end of burn, each RSRM generates an average thrust of 2.6 million pounds and burns for approximately 123 seconds. Of the motor's total weight of 1.25 million pounds, propellant accounts for 1.1 million pounds. The four motor segments are matched by loading each from the same batches of propellant ingredients to minimize any thrust imbalance. The segmented casing design assures maximum flexibility in fabrication and ease of transportation and handling. Each segment is shipped to KSC on a heavy-duty rail car with a specialty built cover.

SRB Hardware Design Summary

Hold-Down Posts

Each SRB has four hold-down posts that fit into corresponding support posts on the MLP. Hold-down bolts secure the SRB and MLP posts together. Each bolt has a nut at each end, but the top nut is frangible, or breakable. The top nut contains two NASA Standard Detonators (NSDs), that, when ignited at solid rocket motor ignition command, split the upper nut in half.

Splitting the upper nuts allow the hold-down bolts to be released and travel downward because of NSD gas pressure, gravity and the release of tension in the bolt, which is pretensioned before launch. The bolt is stopped by the stud deceleration stand which

contains sand to absorb the shock of the bolt dropping down several feet. The SRB bolt is 28 inches long, 3.5 inches in diameter and weighs approximately 90 pounds. The frangible nut is captured in a blast container on the aft skirt specifically designed to absorb the impact and prevent pieces of the nut from liberating and becoming debris that could damage the space shuttle.

Integrated Electronic Assembly

The aft Integrated Electronic Assembly (IEA), mounted in the ET/SRB attach ring, provides the electrical interface between the SRB systems and the orbiter. The aft IEA receives data, commands, and electrical power from the orbiter and distributes these inputs throughout each SRB. Components located in the forward assemblies of each SRB are powered by the aft IEA through the forward IEA, except for those utilizing the recovery and range safety batteries located in the forward assemblies. The forward IEA communicates with and receives power from the orbiter through the aft IEA, but has no direct electrical connection to the orbiter.

Electrical Power Distribution

Electrical power distribution in each SRB consists of orbiter-supplied main dc bus power to each SRB via SRB buses A, B and C. Orbiter main dc buses A, B and C supply main dc bus power to corresponding SRB buses A, B and C. In addition, orbiter main dc, bus C supplies backup power to SRB buses A and B, and orbiter bus B supplies backup power to SRB bus C. This electrical power distribution arrangement allows all SRB buses to remain powered in the event one orbiter main bus fails.

The nominal dc voltage is 28 V dc, with an upper limit of 32 V dc and a lower limit of 24 V dc.

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STS-135: The Final Mission

Hydraulic Power Units

There are two self-contained, independent Hydraulic Power Units (HPUs) on each SRB. Each HPU consists of an Auxiliary Power Unit (APU); Fuel Supply Module (FSM); hydraulic pump; hydraulic reservoir; and hydraulic fluid manifold assembly. The APUs are fueled by hydrazine and generate mechanical shaft power to a hydraulic pump that produces hydraulic pressure for the SRB hydraulic system. The APU controller electronics are located in the SRB aft integrated electronic assemblies on the aft ET attach rings. The two separate HPUs and two hydraulic systems are located inside the aft skirt of each SRB between the SRB nozzle and skirt. The HPU components are mounted on the aft skirt between the rock and tilt actuators. The two systems operate from T minus 28 seconds until SRB separation from the orbiter and ET. The two independent hydraulic systems are connected to the rock and tilt servoactuators.

The HPUs and their fuel systems are isolated from each other. Each fuel supply module, or tank, contains 22 pounds of hydrazine. The fuel tank is pressurized with gaseous nitrogen at 400 psi to provide the force to expel via positive expulsion the fuel from the tank to the fuel distribution line. A positive fuel supply to the APU throughout its operation is maintained.

The fuel isolation valve is opened at APU startup to allow fuel to flow to the APU fuel pump and control valves and then to the gas generator. The gas generator's catalytic action decomposes the fuel and creates a hot gas. It feeds the hot gas exhaust product to the APU two-stage gas turbine. Fuel flows primarily through the startup bypass line until the APU

speed is such that the fuel pump outlet pressure is greater than the bypass line's, at which point all the fuel is supplied to the fuel pump.

The APU turbine assembly provides mechanical power to the APU gearbox, which drives the APU fuel pump, hydraulic pump and lube oil pump. The APU lube oil pump lubricates the gearbox. The turbine exhaust of each APU flows over the exterior of the gas generator, cooling it and directing it overboard through an exhaust duct.

When the APU speed reaches 100 percent, the APU primary control valve closes and the APU speed is controlled by the APU controller electronics. If the primary control valve logic fails to the open state, the secondary control valve assumes control of the APU at 112 percent speed. Each HPU on an SRB is connected to both servoactuators. One HPU serves as the primary hydraulic source for the servoactuator and the other HPU serves as the secondary hydraulics for the servoactuator. Each servoactuator has a switching valve that allows the secondary hydraulics to power the actuator if the primary hydraulic pressure drops below 2,050 psi. A switch contact on the switching valve will close when the valve is in the secondary position. When the valve is closed, a signal is sent to the APU controller that inhibits the 100 percent APU speed control logic and enables the 112 percent APU speed control logic. The 100 percent APU speed enables one APU/HPU to supply sufficient operating hydraulic pressure to both servoactuators of that SRB.

The APU 100 percent speed corresponds to 72,000 rpm, 110 percent to 79,200 rpm and 112 percent to 80,640 rpm.

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The hydraulic pump speed is 3,600 rpm and supplies hydraulic pressure of 3,050, plus or minus 50 psi. A high-pressure relief valve provides overpressure protection to the hydraulic system and relieves at 3,750 psi.

The APUs/HPUs and hydraulic systems are reusable for 20 missions.

Thrust Vector Control

Each SRB has two hydraulic gimbal servoactuators: one for rock and one for tilt. The servoactuators provide the force and control to gimbal the nozzle for Thrust Vector Control (TVC). The all-axis gimbaling capability is 8 degrees. Each nozzle has a carbon cloth liner that erodes and chars during firing. The nozzle is a convergent-divergent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism.

The space shuttle ascent TVC portion of the flight control system directs the thrust of the three SSMEs and the two SRB nozzles to control shuttle attitude and trajectory during liftoff and ascent. Commands from the guidance system are transmitted to the Ascent TVC, or ATVC, drivers, which transmit signals proportional to the commands to each servoactuator of the main engines and SRBs. Four independent flight control system channels and four ATVC channels control six main engine and four SRB ATVC drivers, with each driver controlling one hydraulic port on each main and SRB servoactuator.

Each SRB servoactuator consists of four independent, two-stage servovalves that receive signals from the drivers. Each servovalve controls one power spool in each actuator, which positions an actuator ram and the nozzle to control the direction of thrust.

The four servovalves in each actuator provide a force-summed majority voting arrangement to position the power spool. With four identical commands to the four servovalves, the actuator force-sum action prevents a single erroneous command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, differential pressure sensing activates a selector valve to isolate and remove the defective servovalve hydraulic pressure. This permits the remaining channels and servovalves to control the actuator ram spool.

Failure monitors are provided for each channel to indicate which channel has been bypassed. An isolation valve on each channel provides the capability of resetting a failed or bypassed channel.

Each actuator ram is equipped with transducers for position feedback to the thrust vector control system. Within each servoactuator ram is a splashdown load relief assembly to cushion the nozzle at water splashdown and prevent damage to the nozzle flexible bearing.

SRB Rate Gyro Assemblies

Each SRB contains two Rate Gyro Assemblies (RGAs) mounted in the forward skirt watertight compartment. Each RGA contains two orthogonally mounted gyroscopes – pitch and yaw axes. In conjunction with the orbiter roll rate gyros, they provide angular rate information that describes the inertial motion of the vehicle cluster to the orbiter computers and the guidance, navigation and control system during first stage ascent to SRB separation. At SRB separation, all guidance control data is handed off from the SRB RGAs to the orbiter RGAs. The RGAs are designed and qualified for 20 missions.



Propellant

The propellant mixture in each SRB motor consists of ammonium perchlorate, an oxidizer, 69.6 percent by weight; aluminum, a fuel, 16 percent by weight; iron oxide, a catalyst, 0.4 percent by weight; polymer, a binder that holds the mixture together, 12.04 percent by weight; and epoxy curing agent, 1.96 percent by weight. The propellant is an 11-point star-shaped perforation in the forward motor segment and a double truncated cone perforation in each of the aft segments and aft closure. This configuration provides high thrust at ignition and then reduces the thrust by about one-third 50 seconds after liftoff to prevent overstressing the vehicle during maximum dynamic pressure.

SRB Ignition

SRB ignition can occur only when a manual lock pin from each SRB safe and arm device has been removed by the ground crew during prelaunch activities. At T minus 5 minutes, the SRB safe and arm device is rotated to the arm position. The solid rocket motor ignition commands are issued when the three SSMEs are at or above 90 percent rated thrust; no SSME fail and/or SRB ignition Pyrotechnic Initiator Controller (PIC) low voltage is indicated; and there are no holds from the Launch Processing System (LPS).

The solid rocket motor ignition commands are sent by the orbiter computers through the Master Events Controllers (MECs) to the NSDs installed in the safe and arm device in each SRB. A PIC is a single-channel capacitor discharge device that controls the firing of each pyrotechnic device. Three signals must be present simultaneously for the PIC to generate the pyro firing output. These signals – arm,

fire 1 and fire 2 – originate in the orbiter general-purpose computers and are transmitted to the MECs. The MECs reformat them to 28 V dc signals for the PICs. The arm signal charges the PIC capacitor to 40 V dc, minimum 20 V dc.

The fire 2 commands cause the redundant NSDs to fire through a thin barrier seal down a flame tunnel. This ignites a pyro booster charge, which is retained in the safe and arm device behind a perforated plate. The booster charge ignites the propellant in the igniter initiator; and combustion products of this propellant ignite the solid rocket motor igniter, which fires down the length of the solid rocket motor igniting the solid rocket motor propellant.

The General Purpose Computer (GPC) launch sequence also controls certain critical main propulsion system valves and monitors the engine-ready indications from the SSMEs. The Main Propulsion System (MPS) start commands are issued by the onboard computers at T minus 6.6 seconds. There is a staggered start – engine three, engine two, engine one – within 0.25 of a second, and the sequence monitors the thrust buildup of each engine. All three SSMEs must reach the required 90 percent thrust within three seconds; otherwise, an orderly shutdown is commanded and safing functions are initiated.

Normal thrust buildup to the required 90 percent thrust level will result in the SSMEs being commanded to the liftoff position at T - 3 seconds as well as the fire 1 command being issued to arm the SRBs. At T - 3 seconds, the vehicle base bending load modes are allowed to initialize.



At T - 0, the two SRBs are ignited by the four orbiter on-board computers; commands are sent to release the SRBs; the two T - 0 umbilicals, one on each side of the spacecraft, are retracted; the onboard master timing unit, event timer and mission event timers are started; the three SSMEs are at 100 percent; and the ground launch sequence is terminated.

SRB Separation

The SRB/ET separation subsystem provides for separation of the SRBs from the orbiter/ET without damage to or recontact of the elements – SRBs, orbiter/ET – during or after separation for nominal modes. SRB separation is initiated when the three solid rocket motor chamber pressure transducers are processed in the redundancy management middle value select and the head end chamber pressure of both SRBs is less than or equal to 50 psi. A backup cue is the time elapsed from booster ignition.

The separation sequence is initiated, commanding the thrust vector control actuators to the null position and putting the main propulsion system into a second-stage configuration 0.8 second from sequence initialization, which ensures the thrust of each SRB is less than 100,000 pounds. Orbiter yaw attitude is held for four seconds and SRB thrust drops to less than 60,000 pounds. The SRBs separate from the ET within 30 milliseconds of the ordnance firing command.

The forward attachment point consists of a ball on the SRB and socket on the ET, held together by one bolt. The bolt contains one NSD pressure cartridge at each end. The forward attachment point also carries the range safety system cross-strap wiring connecting each SRB Range Safety System (RSS), and the ET RSS with each other.

The aft attachment points consist of three separate struts: upper, diagonal, and lower. Each strut contains one bolt with an NSD pressure cartridge at each end. The upper strut also carries the umbilical interface between its SRB and the external tank and on to the orbiter.

Redesigned Booster Separation Motors (RBSM)

Eight Booster Separation Motors (BSMs), are located on each booster – four on the forward section and four on the aft skirt. BSMs provide the force required to push the SRBs away from the orbiter/ET at separation. Each BSM weighs approximately 165 pounds and is 31.1 inches long and 12.8 inches in diameter. Once the SRBs have completed their flight, the BSMs are fired to jettison the SRBs away from the orbiter and external tank, allowing the boosters to parachute to Earth and be reused. The BSMs in each cluster of four are ignited by firing redundant NSD pressure cartridges into redundant confined detonating fuse manifolds. The separation commands issued from the orbiter by the SRB separation sequence initiate the redundant NSD pressure cartridge in each bolt and ignite the BSMs to effect a clean separation.

Redesigned BSMs flew for the first time in both forward and aft locations on STS-125. As a result of vendor viability and manifest support issues, space shuttle BSMs are now being manufactured by ATK. The igniter has been redesigned and other changes include material upgrades driven by obsolescence issues and improvements to process and inspection techniques.

SRB Cameras

Each SRB flies with a complement of four cameras, three mounted for exterior views



during launch, separation and descent; and one mounted internal to the forward dome for main parachute performance assessment during descent.

The ET observation camera is mounted on the SRB forward skirt and provides a wide-angle view of the ET intertank area. The camera is activated at lift off by a G-switch and records for 350 seconds, after which the recorder is switched to a similar camera in the forward skirt dome to view the deployment and performance of the main parachutes to splash down. These cameras share a digital tape recorder located within the data acquisition system.

The ET ring camera is mounted on the ET attach ring and provides a view up the stacked vehicle on the orbiter underside and the bipod strut attach point.

The forward skirt camera is mounted on the external surface of the SRB forward skirt and provides a view aft down the stacked vehicle of the orbiter underside and the wing leading edge Reinforced Carbon-Carbon (RCC) panels.

The ET attach ring camera and forward skirt camera are activated by a global positioning system command at approximately T - 1 minute 56 seconds to begin recording at approximately T - 50 seconds. The camera images are recorded through splash down. These cameras each have a dedicated recorder and are recorded in a digital format. The cameras were designed, qualified, and implemented by USA after Columbia to provide enhanced imagery capabilities to capture potential debris liberation beginning with main engine start and continuing through SRB separation.

The camera videos are available for engineering review approximately 24 hours following the arrival of the boosters at KSC.

Range Safety Systems

The RSS consists of two antenna couplers; command receivers/decoders; a dual distributor; a safe and arm device with two NSDs; two confined detonating fuse manifolds; seven Confined Detonator Fuse (CDF) assemblies; and one linear-shaped charge.

The RSS provides for destruction of a rocket or part of it with on-board explosives by remote command if the rocket is out of control, to limit danger to people on the ground from crashing pieces, explosions, fire, and poisonous substances.

The space shuttle has two RSSs, one in each SRB. Both are capable of receiving two command messages – arm and fire – which are transmitted from the ground station. The RSS is only used when the space shuttle violates a launch trajectory red line.

The antenna couplers provide the proper impedance for radio frequency and ground support equipment commands. The command receivers are tuned to RSS command frequencies and provide the input signal to the distributors when an RSS command is sent. The command decoders use a code plug to prevent any command signal other than the proper command signal from getting into the distributors. The distributors contain the logic to supply valid destruct commands to the RSS pyrotechnics.

The NSDs provide the spark to ignite the CDF that in turn ignites the linear-shaped charge for space shuttle destruction. The safe and arm



device provides mechanical isolation between the NSDs and the CDF before launch and during the SRB separation sequence.

The first message, called arm, allows the onboard logic to enable a destruct and illuminates a light on the flight deck display and control panel at the commander and pilot station. The second message transmitted is the fire command. The SRB distributors in the SRBs are cross-strapped together. Thus, if one SRB received an arm or destruct signal, the signal would also be sent to the other SRB.

Electrical power from the RSS battery in each SRB is routed to RSS A. The recovery battery in each SRB is used to power RSS B as well as the recovery system in the SRB. The SRB RSS is powered down during the separation sequence, and the SRB recovery system is powered up.

Descent and Recovery

After separation and at specified altitudes, the SRB forward avionics system initiates the release of the nose cap, which houses a pilot parachute and drogue parachute; and the frustum, which houses the three main parachutes. Jettison of the nose cap at 15,700 feet deploys a small pilot parachute and begins to slow the SRB decent. At an altitude of 15,200 feet the pilot parachute pulls the drogue parachute from the frustum. The drogue parachute fully inflates in stages, and at 5,500 feet pulls the frustum away from the SRB, which initiates the deployment of the three main parachutes. The parachutes also inflate in stages and further slow the decent of the SRBs to their final velocity at splashdown. The parachutes slow each SRB from 368 mph at first deployment to 52 mph at splashdown, allowing for the recovery and reuse of the boosters.

Two 176-foot recovery ships, Freedom Star and Liberty Star, are on station at the splashdown zone to retrieve the frustums with drogue parachutes attached, the main parachutes and the SRBs. The SRB nose caps and solid rocket motor nozzle extensions are not recovered. The SRBs are dewatered using an enhanced diver operating plug to facilitate tow back. These plugs are inserted into the motor nozzle and air is pumped into the booster, causing it to lay flat in the water to allow it to be easily towed. The boosters are then towed back to the refurbishment facilities. Each booster is removed from the water and components are disassembled and washed with fresh and deionized water to limit saltwater corrosion. The motor segments, igniter and nozzle are shipped back to ATK in Utah for refurbishment. The nonmotor components and structures are disassembled by USA and are refurbished to like-new condition at both KSC and equipment manufacturers across the country.

SPACE SHUTTLE SUPER LIGHT WEIGHT TANK

The Super Lightweight External Tank (SLWT) made its first shuttle flight June 2, 1998, on mission STS-91. The SLWT is 7,500 pounds lighter than the standard external tank. The lighter weight tank allows the shuttle to deliver International Space Station elements (such as the service module) into the proper orbit.

The SLWT is the same size as the previous design. But the liquid hydrogen tank and the liquid oxygen tank are made of aluminum lithium, a lighter, stronger material than the metal alloy used for the shuttle's current tank. The tank's structural design has also been



improved, making it 30 percent stronger and 5 percent less dense.

The SLWT, like the standard tank, is manufactured at NASA's Michoud Assembly Facility, near New Orleans, by Lockheed Martin.

The 154-foot-long external tank is the largest single component of the space shuttle. It stands taller than a 15-story building and has a diameter of about 27 feet. The external tank holds over 530,000 gallons of liquid hydrogen and liquid oxygen in two separate tanks. The hydrogen (fuel) and liquid oxygen (oxidizer) are used as propellants for the shuttle's three main engines.

EXTERNAL TANK

The 154-foot-long external tank is the largest single component of the space shuttle. It stands taller than a 15-story building and has a diameter of about 27 feet. The external tank holds more than 530,000 gallons of liquid hydrogen and liquid oxygen in two separate tanks, the forward liquid oxygen tank and the aft liquid hydrogen tank. An unpressurized intertank unites the two propellant tanks.

Liquid hydrogen (fuel) and liquid oxygen (oxidizer) are used as propellants for the shuttle's three main engines. The external tank weighs 58,500 pounds empty and 1,668,500 pounds when filled with propellants.

The external tank is the "backbone" of the shuttle during launch, providing structural support for attachment with the solid rocket boosters and orbiter. It is the only component of the shuttle that is not reused. Approximately 8.5 minutes after reaching orbit, with its propellant used, the tank is jettisoned and falls

in a preplanned trajectory. Most of the tank disintegrates in the atmosphere, and the remainder falls into the ocean.

The external tank is manufactured at NASA's Michoud Assembly Facility in New Orleans by Lockheed Martin Space Systems.

Foam Facts

The external tank is covered with spray-on foam insulation that insulates the tank before and during launch. More than 90 percent of the tank's foam is applied using an automated system, leaving less than 10 percent to be applied manually.

There are two types of foam on the external tank, known as the Thermal Protection System (TPS). One is low-density, closed-cell foam on the tank acreage and is known as Spray-On-Foam-Insulation, often referred to by its acronym, SOFI. Most of the tank is covered by either an automated or manually applied SOFI. Most areas around protuberances, such as brackets and structural elements, are applied by pouring foam ingredients into part-specific molds. The other, called ablator, is a denser composite material made of silicone resins and cork. An ablator is a material that dissipates heat by eroding. It is used on areas of the external tank subjected to extreme heat, such as the aft dome near the engine exhaust, and remaining protuberances, such as the cable trays. These areas are exposed to extreme aerodynamic heating.

Closed-cell foam used on the tank was developed to keep the propellants that fuel the shuttle's three main engines at optimum temperature. It keeps the shuttle's liquid hydrogen fuel at -423 degrees Fahrenheit and the liquid oxygen tank at near



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-297 degrees Fahrenheit, even as the tank sits under the hot Florida sun. At the same time, the foam prevents a buildup of ice on the outside of the tank.

The foam insulation must be durable enough to endure a 180-day stay at the launch pad, withstand temperatures up to 115 degrees Fahrenheit, humidity as high as 100 percent, and resist sand, salt, fog, rain, solar radiation and even fungus. Then, during launch, the foam must tolerate temperatures as high as 2,200 degrees Fahrenheit generated by aerodynamic friction and radiant heating from the 3,000 degrees Fahrenheit main engine plumes. Finally, when the external tank begins reentry into the Earth's atmosphere about 30 minutes after launch, the foam maintains the tank's structural temperatures and allows it to safely disintegrate over a remote ocean location.

Though the foam insulation on the majority of the tank is only 1-inch thick, it adds 4,823 pounds to the tank's weight. In the areas of the tank subjected to the highest heating, insulation is somewhat thicker, between 1.5 to 3 inches thick. Though the foam's density varies with the type, an average density is about 2.4 pounds per cubic foot.

Application of the foam, whether automated by computer or hand-sprayed, is designed to meet NASA's requirements for finish, thickness, roughness, density, strength and adhesion. As in most assembly production situations, the foam is applied in specially designed, environmentally controlled spray cells and applied in several phases, often over a period of several weeks. Before spraying, the foam's raw

material and mechanical properties are tested to ensure they meet NASA specifications. Multiple visual inspections of all foam surfaces are performed after the spraying is complete.

Most of the foam is applied at NASA's Michoud Assembly Facility in New Orleans when the tank is manufactured, including most of the "closeout" areas, or final areas applied. These closeouts are done either by hand pouring or manual spraying. Additional closeouts are completed once the tank reaches NASA's Kennedy Space Center, Fla.

The SLWT made its first shuttle flight in June 1998 on mission STS-91. The SLWT is 7,500 pounds lighter than previously flown tanks. The SLWT is the same size as the previous design, but the liquid hydrogen tank and the liquid oxygen tank are made of aluminum lithium, a lighter, stronger material than the metal alloy used previously.

Beginning with the first Return to Flight mission, STS-114 in June 2005, several improvements were made to improve safety and flight reliability.

Forward Bipod

The external tank's forward shuttle attach fitting, called the bipod, was redesigned to eliminate the large insulating foam ramps as a source of debris. Each external tank has two bipod fittings that connect the tank to the orbiter through the shuttle's two forward attachment struts. Four rod heaters were placed below each forward bipod, replacing the large insulated foam Protuberance Airload (PAL) ramps.



Liquid Hydrogen Tank & Liquid Oxygen Intertank Flange Closeouts

The liquid hydrogen tank flange located at the bottom of the intertank and the liquid oxygen tank flange located at the top of the intertank provide joining mechanisms with the intertank. After each of these three component tanks, liquid oxygen, intertank and liquid hydrogen, are joined mechanically, the flanges at both ends are insulated with foam. An enhanced closeout, or finishing, procedure was added to improve foam application to the stringer, or intertank ribbing, and to the upper and lower area of both the liquid hydrogen and liquid oxygen intertank flanges.

Liquid Oxygen Feedline Bellows

The liquid oxygen feedline bellows were reshaped to include a “drip lip” that allows condensate moisture to run off and prevent freezing. A strip heater was added to the forward bellow to further reduce the potential of high density ice or frost formation. Joints on the liquid oxygen feedline assembly allow the feedline to move during installation and during liquid hydrogen tank fill. Because it must flex, it cannot be insulated with foam like the remainder of the tank.

Other tank improvements include:

Liquid Oxygen & Liquid Hydrogen Protuberance Airload (PAL) Ramps

External tank ET-119, which flew on the second Return to Flight mission, STS-121, in July 2006, was the first tank to fly without PAL ramps along portions of the liquid oxygen and liquid hydrogen tanks. These PAL ramps were extensively studied and determined to not be necessary for their original purpose, which was

to protect cable trays from aeroelastic instability during ascent. Extensive tests were conducted to verify the shuttle could fly safely without these particular PAL ramps. Extensions were added to the ice frost ramps for the pressline and cable tray brackets, where these PAL ramps were removed to make the geometry of the ramps consistent with other locations on the tank and thereby provide consistent aerodynamic flow. Nine extensions were added, six on the liquid hydrogen tank and three on the liquid oxygen tank.

Engine Cutoff Sensor Modification

Beginning with STS-122, ET-125, which launched on Feb. 7, 2008, the Engine Cutoff (ECO) sensor system feed-through connector on the liquid hydrogen tank was modified by soldering the connector’s pins and sockets to address false readings in the system. All subsequent tanks after ET-125 have the same modification.

Liquid Hydrogen Tank Ice Frost Ramps

ET-128, which flew on the STS-124 shuttle mission, May 31, 2008, was the first tank to fly with redesigned liquid hydrogen tank ice frost ramps. Design changes were incorporated at all 17 ice frost ramp locations on the liquid hydrogen tank, stations 1151 through 2057, to reduce foam loss. Although the redesigned ramps appear identical to the previous design, several changes were made. PDL* and NCFI foam have been replaced with BX* manual spray foam in the ramp’s base cutout to reduce debonding and cracking; Pressline and cable tray bracket feet corners have been rounded to reduce stresses; shear pin holes have been sealed to reduce leak paths; isolators were primed to promote adhesion; isolator corners were rounded to help reduce thermal



protection system foam stresses; BX manual spray was applied in bracket pockets to reduce geometric voids.

*BX is a type of foam used on the tank's "closeout," or final finished areas; it is applied manually or hand-sprayed. PDL is an acronym for Product Development Laboratory, the first supplier of the foam during the early days of the external tank's development. PDL is applied by pouring foam ingredients into a mold. NCFI foam is used on the aft dome, or bottom, of the liquid hydrogen tank.

Liquid Oxygen Feedline Brackets

ET-128 also was the first tank to fly with redesigned liquid oxygen feedline brackets. Titanium brackets, much less thermally conductive than aluminum, replaced aluminum brackets at four locations, XT 1129, XT 1377, XT 1624 and XT 1871. This change minimizes ice formation in under-insulated areas, and reduces the amount of foam required to cover the brackets and the propensity for ice development. Zero-gap/slip plane Teflon material was added to the upper outboard monoball attachment to eliminate ice adhesion. Additional foam has been added to the liquid oxygen feedline to further minimize ice formation along the length of the feedline.



LAUNCH & LANDING

LAUNCH

As with all previous space shuttle launches, Atlantis has several options to abort its ascent, if needed, after engine failures or other systems problems. Shuttle launch abort philosophy is intended to facilitate safe recovery of the flight crew and intact recovery of the orbiter and its payload.

Abort modes include the following:

ABORT TO ORBIT

This mode is used if there is a partial loss of main engine thrust late enough to permit reaching a minimal 105 by 85 nautical mile orbit with the Orbital Maneuvering System engines. The engines boost the shuttle to a safe orbital altitude when it is impossible to reach the planned orbital altitude.

TRANSOCEANIC ABORT LANDING

The loss of one or more main engines midway through powered flight would force a landing at either Zaragoza, Spain; Morón, Spain; or Istres, France. For the launch to proceed, weather conditions must be acceptable at one of these Transoceanic Abort Landing (TAL) sites.

RETURN TO LAUNCH SITE

If one or more engines shut down early and there is not enough energy to reach Zaragoza or another TAL site, the shuttle would pitch around back toward the Kennedy Space Center (KSC) until within gliding distance of the shuttle landing facility. For the launch to proceed, weather conditions must be forecast to be acceptable for a possible landing at KSC about 20 minutes after liftoff.

ABORT ONCE AROUND

An abort once around is selected if the vehicle cannot achieve a viable orbit or will not have enough propellant to perform a deorbit burn, but has enough energy to circle the Earth once and land about 90 minutes after liftoff. The KSC shuttle landing facility is the primary landing site for an AOA, and White Sands Space Harbor, N.M., is the backup site.

LANDING

The primary landing site for Atlantis on STS-135 is Kennedy's Shuttle Landing Facility. Alternate landing sites that could be used if needed because of weather conditions or systems failures are at Edwards Air Force Base, Calif., and White Sands Space Harbor, N.M.



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ACRONYMS & ABBREVIATIONS

A/G	Alignment Guides
A/L	Airlock
AAA	Avionics Air Assembly
ABC	Audio Bus Controller
ACBM	Active Common Berthing Mechanism
ACDU	Airlock Control and Display Unit
ACO	Assembly Checkout Officer
ACRFG	Assembly Contingency Radio Frequency Group
ACS	Atmosphere Control and Supply
ACTRA	Assembly/Contingency Transmitter/Receiver Assembly
ACU	Arm Control Unit
ADS	Audio Distribution System
AE	Approach Ellipsoid
AEP	Airlock Electronics Package
AFRL	Air Force Research Lab
AHMS	Advanced Health Management System
AI	Approach Initiation
AIS	Automatic Identification System
AJIS	Alpha Joint Interface Structure
AM	Atmosphere Monitoring
AMOS	Air Force Maui Optical and Supercomputing Site
AMS	Alpha Magnetic Spectrometer
AOA	Abort Once Around
AOH	Assembly Operations Handbook
APAS	Androgynous Peripheral Attachment
APCU	Assembly Power Converter Unit
APE	Antenna Pointing Electronics Audio Pointing Equipment
APFR	Articulating Portable Foot Restraint
APM	Antenna Pointing Mechanism
APS	Automated Payload Switch
APU	Auxiliary Power Unit
APV	Automated Procedure Viewer
AR	Atmosphere Revitalization
ARCU	American-to-Russian Converter Unit
ARFTA	Advanced Recycle Filter Tank Assembly
ARS	Atmosphere Revitalization System
ASW	Application Software



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ATA	Ammonia Tank Assembly
ATCS	Active Thermal Control System
ATO	Abort To Orbit
ATU	Audio Terminal Unit
BAD	Broadcast Ancillary Data
BC	Bus Controller
BCDU	Battery Charge/Discharge Unit
	Berthing Mechanism Control and Display Unit
BEP	Berthing Mechanism Electronics Package
BGA	Beta Gimbal Assembly
BIC	Bus Interface Controller
BIT	Built-In Test
BM	Berthing Mechanism
BOS	BIC Operations Software
BSM	Booster Separation Motors
BSS	Basic Software
BSTS	Basic Standard Support Software
C&C	Command and Control
C&DH	Command and Data Handling
C&T	Communication and Tracking
C&W	Caution and Warning
C/L	Crew Lock
C/O	Checkout
CAM	Collision Avoidance Maneuver
CAPE	Canister for All Payload Ejections
CAPPS	Checkout, Assembly and Payload Processing Services
CAS	Common Attach System
CB	Control Bus
CBCS	Centerline Berthing Camera System
CBM	Common Berthing Mechanism
CCA	Circuit Card Assembly
CCAA	Common Cabin Air Assembly
CCHA	Crew Communication Headset Assembly
CCP	Camera Control Panel
CCT	Communication Configuration Table
CCTV	Closed-Circuit Television
CDF	Confined Detonator Fuse
CDR	Space Shuttle Commander
CDRA	Carbon Dioxide Removal Assembly
CEIT	Crew Equipment Interface Test



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CETA	Crew Equipment Translation Aid
CHeCS	Crew Health Care System
CHX	Cabin Heat Exchanger
CISC	Complicated Instruction Set Computer
CLA	Camera Light Assembly
CLPA	Camera Light Pan Tilt Assembly
CMG	Control Moment Gyro
COLT	Contingency Operations Large Adapter Assembly Tool
COTS	Commercial Off the Shelf
CPA	Control Panel Assembly
CPB	Camera Power Box
CR	Change Request
CRT	Cathode-Ray Tube
CSA	Canadian Space Agency
CSA-CP	Compound Specific Analyzer
CTC	Cargo Transport Container
CVIU	Common Video Interface Unit
CVT	Current Value Table
CZ	Communication Zone
DB	Data Book
DC	Docking Compartment
DCSU	Direct Current Switching Unit
DDCU	DC-to-DC Converter Unit
DEM	Demodulator
DFL	Decommutation Format Load
DIU	Data Interface Unit
DMS	Data Management System
DMS-R	Data Management System-Russian
DoD	Department of Defense
DPG	Differential Pressure Gauge
DPU	Baseband Data Processing Unit
DRTS	Japanese Data Relay Satellite
DYF	Display Frame
E/L	Equipment Lock
E-ORU	EVA Essential ORU
EATCS	External Active Thermal Control System
EBCS	External Berthing Camera System
ECAL	Electromagnetic Calorimeter
ECC	Error Correction Code
ECLSS	Environmental Control and Life Support System



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ECO	Engine Cutoff
ECS	Environmental Control System
ECU	Electronic Control Unit
EDSU	External Data Storage Unit
EDU	EEU Driver Unit
EE	End Effector
EETCS	Early External Thermal Control System
EEU	Experiment Exchange Unit
EF	Exposed Facility
EFBM	Exposed Facility Berthing Mechanism
EFHX	Exposed Facility Heat Exchanger
EFU	Exposed Facility Unit
EGIL	Electrical, General Instrumentation, and Lighting
EIU	Ethernet Interface Unit
ELC	ExPRESS Logistics Carrier
ELM-ES	Japanese Experiment Logistics Module – Exposed Section
ELM-PS	Japanese Experiment Logistics Module – Pressurized Section
ELPS	Emergency Lighting Power Supply
EMGF	Electric Mechanical Grapple Fixture
EMI	Electro-Magnetic Imaging
EMU	Extravehicular Mobility Unit
EOTP	Enhanced Orbital Replacement Unit Temporary Platform
EP	Exposed Pallet
EPS	Electrical Power System
ES	Exposed Section
ESA	European Space Agency
ESC	JEF System Controller
ESP	External Stowage Platform
ESW	Extended Support Software
ET	External Tank
ETCS	External Thermal Control System
ETI	Elapsed Time Indicator
ETRS	EVA Temporary Rail Stop
ETVCG	External Television Camera Group
EV	Extravehicular
EVA	Extravehicular Activity
EWC	External Wireless Communication
EXP-D	Experiment-D
ExPRESS	Expedite the Processing of Experiments to the Space Station
EXT	External



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FA	Fluid Accumulator
FAS	Flight Application Software
FCT	Flight Control Team
FD	Flight Day
FDDI	Fiber Distributed Data Interface
FDIR	Fault Detection, Isolation, and Recovery
FDS	Fire Detection System
FE	Flight Engineer
FET-SW	Field Effect Transistor Switch
FGB	Functional Cargo Block
FOB	Forward Osmosis Bag
FOR	Frame of Reference
FPMU	Floating Potential Measurement Unit
FPP	Fluid Pump Package
FR	Flight Rule
FRAM	Flight Releasable Attachment Mechanism
FRD	Flight Requirements Document
FRGF	Flight Releasable Grapple Fixture
FRM	Functional Redundancy Mode
FSE	Flight Support Equipment
FSEGF	Flight Support Equipment Grapple Fixture
FSM	Fuel Supply Module
FSW	Flight Software
GAS	Get-Away Special
GATOR	Grappling Adaptor to On-orbit Railing
GCA	Ground Control Assist
GLA	General Lighting Assemblies
	General Luminaire Assembly
GLONASS	Global Navigational Satellite System
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
GPS	Global Positioning System
GPSR	Global Positioning System Receiver
GSSDF	Goddard Satellite Servicing Demonstration Facility
GUI	Graphical User Interface
H&S	Health and Status
HCE	Heater Control Equipment
HCTL	Heater Controller
HD	High Definition
HEPA	High Efficiency Particulate Acquisition



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HGA	High Gain Antenna
HPA	High Power Amplifier
HPGT	High Pressure Gas Tank
HPP	Hard Point Plates
HPU	Hydraulic Power Unit
HRDR	High Rate Data Recorder
HREL	Hold/Release Electronics
HRFM	High Rate Frame Multiplexer
HRM	Hold Release Mechanism
HRMS	High Rate Multiplexer and Switcher
HTV	H-II Transfer Vehicle
HTVCC	HTV Control Center
HTV Prox	HTV Proximity
HX	Heat Exchanger
I/F	Interface
IAA	Intravehicular Antenna Assembly
IAC	Internal Audio Controller
IBM	International Business Machines
ICB	Inner Capture Box
ICC	Integrated Cargo Carrier
ICS	Interorbit Communication System
ICS-EF	Interorbit Communication System – Exposed Facility
IDRD	Increment Definition and Requirements Document
IEA	Integrated Electronic Assembly
IELK	Individual Equipment Liner Kit
IFHX	Interface Heat Exchanger
IMCS	Integrated Mission Control System
IMCU	Image Compressor Unit
IMV	Intermodule Ventilation
INCO	Instrumentation and Communication Officer
IP	International Partner
IP-PCDU	ICS-PM Power Control and Distribution Unit
IP-PDB	Payload Power Distribution Box
ISLE	In-Suit Light Exercise
ISP	International Standard Payload
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSSH	International Space Station Systems Handbook
ITCS	Internal Thermal Control System
ITS	Integrated Truss Segment
IV	Intravehicular



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IVA	Intravehicular Activity
IVSU	Internal Video Switch Unit
JAXA	Japan Aerospace Exploration Agency
JCP	JEM Control Processor
JEF	JEM Exposed Facility
JEM	Japanese Experiment Module
JEMAL	JEM Airlock
JEM-EF	Japanese Experiment Module Exposed Facility
JEM-PM	Japanese Experiment Module – Pressurized Module
JEMRMS	Japanese Experiment Module Remote Manipulator System
JEUS	Joint Expedited Undocking and Separation
JFCT	Japanese Flight Control Team
JLE	Japanese Experiment Logistics Module – Exposed Section
JLP	Japanese Experiment Logistics Module – Pressurized Section
JLP-EDU	JLP-EFU Driver Unit
JLP-EFU	JLP Exposed Facility Unit
JPM	Japanese Pressurized Module
JPM WS	JEM Pressurized Module Workstation
JSC	Johnson Space Center
JTVE	JEM Television Equipment
Kbp	Kilobit per second
KOS	Keep Out Sphere
KSC	Kennedy Space Center
LB	Local Bus
LCA	LAB Cradle Assembly
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEE	Latching End Effector
LGA	Low Gain Antenna
LMC	Lightweight Multi-Purpose Experiment Support Structure Carrier
LPS	Launch Processing System
LSW	Light Switch
LTA	Launch-to-Activation
LTAB	Launch-to-Activation Box
LTL	Low Temperature Loop
MA	Main Arm
MAUI	Main Analysis of Upper-Atmospheric Injections
Mb	Megabit
Mbps	Megabit per second



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MBS	Mobile Base System
MBSU	Main Bus Switching Unit
MCA	Major Constituent Analyzer
MCC	Mission Control Center
MCC-H	Mission Control Center – Houston
MCC-M	Mission Control Center – Moscow
MCDS	Multifunction Cathode-Ray Tube Display System
MCS	Mission Control System
MDA	MacDonald, Dettwiler and Associates Ltd.
MDM	Multiplexer/Demultiplexer
MDP	Management Data Processor
MEC	Master Events Controller
MECO	Main Engine Cutoff
MEDS	Multi-functional Electronic Display System
MELFI	Minus Eighty-Degree Laboratory Freezer for ISS
MGB	Middle Grapple Box
MHTEX	Massive Heat Transfer Experiment
MIP	Mission Integration Plan
MISSE	Materials International Space Station Experiment
MKAM	Minimum Keep Alive Monitor
MLE	Middeck Locker Equivalent
MLI	Multi-layer Insulation
MLM	Multipurpose Laboratory Module
MMOD	Micrometeoroid/Orbital Debris
MOD	Modulator
MON	Television Monitor
MPC	Main Processing Controller
MPES	Multipurpose Experiment Support Structure
MPEV	Manual Pressure Equalization Valve
MPL	Manipulator Retention Latch
MPLM	Multipurpose Logistics Module
MPM	Manipulator Positioning Mechanism
MPS	Main Propulsion System
MPV	Manual Procedure Viewer
MRM	Mini-Research Module
MSD	Mass Storage Device
MSFC	Marshall Space Flight Center
MSP	Maintenance Switch Panel
MSS	Mobile Servicing System
MT	Mobile Tracker
	Mobile Transporter



MTL	Moderate Temperature Loop
MUX	Data Multiplexer
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NCS	Node Control Software
NET	No Earlier Than
NLT	No Less Than
n. mi.	nautical mile
NPRV	Negative Pressure Relief Valve
NSD	NASA Standard Detonator
NSV	Network Service
NTA	Nitrogen Tank Assembly
NTSC	National Television Standard Committee
OAK	ORU Adapter Kit
OBSS	Orbiter Boom Sensor System
OCA	Orbital Communications Adapter
OCAD	Operational Control Agreement Document
OCAS	Operator Commanded Automatic Sequence
OCRA	Oxygen Recharge Compressor Assembly
ODF	Operations Data File
ODS	Orbiter Docking System
OI	Orbiter Interface
OIU	Orbiter Interface Unit
OMDP	Orbiter Maintenance Down Period
OMM	Orbiter Major Modification
OMS	Orbital Maneuvering System
OODT	Onboard Operation Data Table
ORCA	Oxygen Recharge Compressor Assembly
ORU	Orbital Replacement Unit
OS	Operating System
OSA	Orbiter-based Station Avionics
OSE	Orbital Support Equipment
OTCM	ORU and Tool Changeout Mechanism
OTP	ORU and Tool Platform
P/L	Payload
PAL	Planning and Authorization Letter
	Protuberance Airload
PAM	Payload Attach Mechanism
PAO	Public Affairs Office



STS-135: The Final Mission

PAS	Payload Adapter System
PBA	Portable Breathing Apparatus
PCA	Pressure Control Assembly
PCBM	Passive Common Berthing Mechanism
PCN	Page Change Notice
PCS	Portable Computer System
PCU	Power Control Unit
	Plasma Contactor Unit
PCVP	Pump and Control Valve Package
PDA	Payload Disconnect Assembly
PDB	Power Distribution Box
PDGF	Power and Data Grapple Fixture
PDH	Payload Data Handling
PDL	Produce Development Laboratory
PDRS	Payload Deployment Retrieval System
PDU	Power Distribution Unit
PEC	Passive Experiment Container
	Payload Experiment Carrier
PEHG	Payload Ethernet Hub Gateway
PFAP	PFRAM Adapter Plate Assembly
PFE	Portable Fire Extinguisher
PFRAM	Passive Flight Releasable Attachment Mechanism
PGSC	Payload General Support Computer
PIB	Power Interface Box
PIC	Pyrotechnic Initiator Controller
PIU	Payload Interface Unit
PLB	Payload Bay
PLBD	Payload Bay Door
PLC	Pressurized Logistics Carrier
PLT	Payload Laptop Terminal
	Space Shuttle Pilot
PM	Pressurized Module
	Pump Module
PMA	Pressurized Mating Adapter
PMCU	Power Management Control Unit
PMM	Pressurized Multipurpose Module
PMU	Pressurized Mating Adapter
POA	Payload ORU Accommodation
POR	Point of Resolution
PPRV	Positive Pressure Relief Valve
PRCS	Primary Reaction Control System



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PREX	Procedure Executor
PRLA	Payload Retention Latch Assembly
PROX	Proximity Communications Center
psia	Pounds per Square Inch Absolute
PSP	Payload Signal Processor
PSRR	Pressurized Section Resupply Rack
PTCS	Passive Thermal Control System
PTR	Port Thermal Radiator
PTU	Pan/Tilt Unit
PVCU	Photovoltaic Controller Unit
PVM	Photovoltaic Module
PVR	Photovoltaic Radiator
PVTCS	Photovoltaic Module Thermal Control System Photovoltaic Thermal Control System
QD	Quick Disconnect
R-ORU	Robotics Compatible Orbital Replacement Unit
R&MA	Restraint and Mobility Aid
R2	Robonaut 2
RACU	Russian-to-American Converter Unit
RAM	Read Access Memory
RBVM	Radiator Beam Valve Module
RCC	Range Control Center Reinforced Carbon-Carbon
RCT	Rack Configuration Table
RF	Radio Frequency
RFG	Radio Frequency Group
RFTA	Recycle Filter Tank Assembly
RGA	Rate Gyro Assemblies
RHC	Rotational Hand Controller
RICH	Ring Imaging Cherenkov
RIGEX	Rigidizable Inflatable Get-Away Special Experiment
RIP	Remote Interface Panel
RLF	Robotic Language File
RLT	Robotic Laptop Terminal
RMS	Remote Manipulator System
ROEU	Remotely Operated Electrical Umbilical
ROM	Read Only Memory
ROS	Russian Orbital Segment
RPC	Remote Power Controller
RPCM	Remote Power Controller Module



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RPDA	Remote Power Distribution Assembly
RPM	Roll Pitch Maneuver
RRM	Robotic Refueling Mission
RS	Russian Segment
RSLS	Redundant Set Launch Sequencer
RSP	Return Stowage Platform
RSR	Resupply Stowage Rack
RSS	Range Safety System
RT	Remote Terminal
RTAS	Rocketdyne Truss Attachment System
RTLS	Return To Launch Site
RVFS	Rendezvous Flight Software
RWS	Robotics Workstation
SAFER	Simplified Aid for EVA Rescue
SAM	SFA Airlock Attachment Mechanism
SAPA	Small Adapter Plate Assembly
SARJ	Solar Alpha Rotary Joint
SASA	S-Band Antenna Sub-Assembly
SCU	Sync and Control Unit
SD	Smoke Detector
SDS	Sample Distribution System
SEDA	Space Environment Data Acquisition equipment
SEDA-AP	Space Environment Data Acquisition equipment – Attached Payload
SELS	SpaceOps Electronic Library System
SEU	Single Event Upset
SFA	Small Fine Arm
SFAE	SFA Electronics
SI	Smoke Indicator
SLM	Structural Latch Mechanism
SLP-D	Spacelab Pallet – D
SLP-D1	Spacelab Pallet – Deployable
SLP-D2	Spacelab Pallet – D2
SLT	Station Laptop Terminal System Laptop Terminal
SLWT	Super Lightweight External Tank
SM	Service Module
SMDP	Service Module Debris Panel
SOC	System Operation Control
SODF	Space Operations Data File
SOFI	Spray-On-Foam Insulation
SPA	Small Payload Attachment



SPB	Survival Power Distribution Box
SPDA	Secondary Power Distribution Assembly
SPDM	Special Purpose Dexterous Manipulator
SPEC	Specialist
SRAM	Static RAM
SRB	Solid Rocket Booster
SRMS	Shuttle Remote Manipulator System
SSAS	Segment-to-Segment Attach System
SSC	Station Support Computer
SSCB	Space Station Control Board
SSCO	Satellite Servicing Capabilities Office
SSE	Small Fine Arm Storage Equipment
SSIPC	Space Station Integration and Promotion Center
SSME	Space Shuttle Main Engine
SSOR	Space-to-Space Orbiter Radio
SSP	Standard Switch Panel
SSPTS	Station-to-Shuttle Power Transfer System
SSRMS	Space Station Remote Manipulator System
STC	Small Fire Arm Transportation Container
STORRM	Sensor Test for Orion Relative Navigation Risk Mitigation
STP-H3	Space Test Program—Houston 3
STR	Starboard Thermal Radiator
STS	Space Transfer System
STVC	SFA Television Camera
SVS	Space Vision System
TA	Thruster Assist
TAC	TCS Assembly Controller
TAC-M	TCS Assembly Controller – M
TAL	Transoceanic Abort Landing
TCA	Thermal Control System Assembly
TCB	Total Capture Box
TCCS	Trace Contaminant Control System
TCCV	Temperature Control and Check Valve
TCS	Thermal Control System
TCV	Temperature Control Valve
TDK	Transportation Device Kit
TDRS	Tracking Data and Relay Satellite
THA	Tool Holder Assembly
THC	Temperature and Humidity Control
	Translational Hand Controller
THCU	Temperature and Humidity Control Unit



STS-135: The Final Mission

TIU	Thermal Interface Unit
TKSC	Tsukuba Space Center (Japan)
TLM	Telemetry
TMA	Russian vehicle designation
TMR	Triple Modular Redundancy
ToF	Time-of-Flight
TPL	Transfer Priority List
TPS	Thermal Protection System
TRD	Transition Radiation Detector
TRRJ	Thermal Radiator Rotary Joint
TUS	Trailing Umbilical System
TVC	Television Camera Thrust Vector Control
UCCAS	Unpressurized Cargo Carrier Attach System
UCM	Umbilical Connect Mechanism
UCM-E	UCM – Exposed Section Half
UCM-P	UCM – Payload Half
UHF	Ultrahigh Frequency
UIL	User Interface Language
ULC	Unpressurized Logistics Carrier
UMA	Umbilical Mating Adapter
UOP	Utility Outlet Panel
UPA	Urine Processing Assembly
UPC	Up Converter
USA	United Space Alliance
US LAB	United States Laboratory
USOS	United States On-Orbit Segment
UTA	Utility Transfer Assembly
VAJ	Vacuum Access Jumper
VBSP	Video Baseband Signal Processor
VCU	Video Control Unit
VDS	Video Distribution System
VLU	Video Light Unit
VNS	Vision Navigation Sensor
VRA	Vent Relief Assembly
VRCS	Vernier Reaction Control System
VRCV	Vent Relief Control Valve
VRIV	Vent Relief Isolation Valve
VSU	Video Switcher Unit
VSW	Video Switcher



WAICO	Waiving and Coiling
WCL	Water Cooling Loop
WETA	Wireless Video System External Transceiver Assembly
WIF	Work Interface
WPA	Water Processing Assembly
WRM	Water Recovery and Management
WRS	Water Recovery System
WS	Water Separator
	Work Site
	Work Station
WVA	Water Vent Assembly
ZSR	Zero-g Stowage Rack



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MEDIA ASSISTANCE

NASA TELEVISION AND INTERNET

The digital NASA Television system provides higher quality images and better use of satellite bandwidth, meaning multiple channels from multiple NASA program sources at the same time.

Digital NASA TV has the following four digital channels:

1. NASA Public Channel (“Free to Air”), featuring documentaries, archival programming, and coverage of NASA missions and events.
2. NASA Education Channel (“Free to Air/Addressable”), dedicated to providing educational programming to schools, educational institutions and museums.
3. NASA Media Channel (“Addressable”), for broadcast news organizations.
4. NASA Mission Channel (Internal Only), provides high-definition imagery from science and human spaceflight missions and special events.

Digital NASA TV channels may not always have programming on every channel simultaneously.

NASA Television Now in High Definition

NASA TV now has a full-time High Definition (HD) Channel available at no cost to cable and satellite service providers. Live coverage of

space shuttle missions; on-orbit video of Earth captured by astronauts aboard the International Space Station; and rocket launches of advanced scientific spacecraft are among the programming offered on NASA HD. Also available are imagery from NASA’s vast array of space satellites, as well as media briefings, presentations by expert lecturers, astronaut interviews and other special events, all in the improved detail and clarity of HD.

Getting NASA TV via satellite (AMC3 Transponder 15C)

In continental North America, Alaska and Hawaii, NASA Television’s Public, Education, Media and HD channels are MPEG-2 digital C-band signals carried by QPSK/DVB-S modulation on satellite AMC-3, transponder 15C, at 87 degrees west longitude. Downlink frequency is 4000 MHz, horizontal polarization, with a data rate of 38.86 Mhz, symbol rate of 28.1115 Ms/s, and 3/4 FEC. A Digital Video Broadcast (DVB) compliant Integrated Receiver Decoder (IRD) is needed for reception.

Effective Sept. 1, 2010, NASA TV changed the primary audio configuration for each of its four channels to AC-3, making each channel’s secondary audio MPEG 1 Layer II.

For NASA TV downlink information, schedules and links to streaming video, visit <http://www.nasa.gov/ntv>



Television Schedule

A schedule of key mission events and media briefings during the mission will be detailed in a NASA TV schedule posted at the link above. The schedule will be updated as necessary and will also be available at

http://www.nasa.gov/multimedia/nasatv/mission_schedule.html

Status Reports

Status reports and timely updates on launch countdown, mission progress, and landing operations will be posted at: <http://www.nasa.gov/shuttle>

Internet Information

Information on NASA and its programs is available through the NASA Home Page and the NASA Public Affairs Home Page:

<http://www.nasa.gov>

or

<http://www.nasa.gov/newsinfo/index.html>

Information on the International Space Station is available at: <http://www.nasa.gov/station>

The NASA Human Space Flight Web contains an up-to-date archive of mission imagery, video and audio at: <http://spaceflight.nasa.gov>

Resources for educators can be found at: <http://education.nasa.gov>



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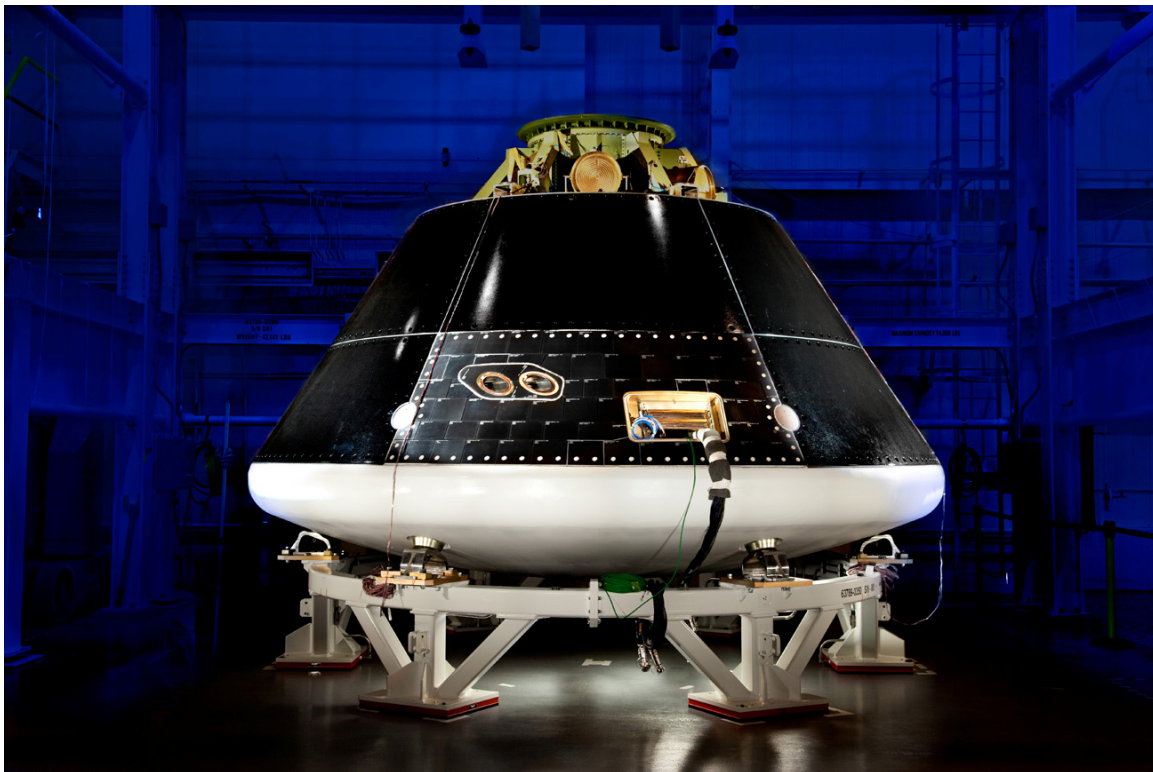
STS-135: The Final Mission

THE FUTURE

ORION MULTI-PURPOSE CREW VEHICLE

As the flagship of our nation's next-generation space fleet, the Orion Multi-Purpose Crew Vehicle (MPCV) will push the envelope of human spaceflight far beyond low Earth orbit (LEO). It will serve as the exploration vehicle that will carry NASA's astronauts to space, provide emergency abort capability, sustain the crew during the space travel and provide safe re-entry from deep space return velocities.

Orion MPCV will serve as the primary crew vehicle for missions beyond LEO and will be capable of conducting regular in-space operations such as rendezvous, docking and extravehicular activity. It will work in conjunction with payloads delivered by NASA's Space Launch System (SLS) for deep space missions and will have the capability to be a backup system for International Space Station cargo and crew delivery in the unlikely event that is needed.



The Orion Multi-Purpose Crew Vehicle Ground Test Article (GTA) is shown at the Lockheed Martin Vertical Test Facility in Colorado. The GTA's heat shield and thermal protection backshell were completed in preparation for environmental testing. The GTA will undergo a series of rigorous tests to confirm Orion MPCV's ability to safely fly astronauts through all the harsh environments of deep space exploration missions.



NASA personnel around the country are continuing to make progress on Orion MPCV's development and have already passed rigorous human rating reviews and other critical milestones required for safe, successful human spaceflight. With a proven launch abort system and its inherent design to provide the highest level of safety for the crew during long-duration missions, the Orion MPCV is poised to take on increasingly challenging missions that will take human space exploration beyond LEO and out into the cosmos.

Drawing from more than 50 years of spaceflight research and development, Orion MPCV is designed to meet the evolving needs of our nation's space program for decades to come. It may resemble its Apollo-era predecessors, but its technology and capability are light-years apart. Orion MPCV features dozens of

technology advancements and innovations that have been incorporated into the spacecraft's subsystem and component design, including life support, propulsion, thermal protection and avionics systems that will enable integration of new technical innovations in the future. Orion MPCV's crew module is larger than Apollo's and designed to accommodate four astronauts on long-duration, deep-space missions. The service module is the powerhouse that fuels and propels the spacecraft as well as the storehouse for the life-sustaining air and water astronauts need during their space travels. The service module's structure will also provide places to mount scientific experiments and cargo.

The adaptability of Orion MPCV and its flexible design will allow it to carry astronauts on a variety of expeditions beyond LEO – ushering in a new era of space exploration.



NASA ORION MULTI-PURPOSE CREW VEHICLE PROGRAM MAJOR ACCOMPLISHMENTS

July 2008	NASA and the United States Navy complete water egress and survival tests with an Orion MPCV mock-up.
October 2008	Orion MPCV's Ultraflex solar arrays are successfully tested.
October 2009	Main parachutes are tested over Yuma, Arizona.
February 2010	Fabrication of Orion MPCV's heat shield structure – the largest in the world – is completed.
April 2010	Installation of the Orion MPCV navigation (STORRM) reflective elements on the ISS docking target.
May 2010	Orion MPCV's launch abort system is successfully tested at White Sands Missile Range.
June 2010	Orion MPCV's S-band antennas are tested at the Johnson Space Center.
August 2010	Completion of the first test of the Crew Module lifting/lowering structure in the Operations and Checkout Facility at Kennedy Space Center. The first Proof Pressure Test of Crew Module Ground Test Article is completed.
October 2010	First integration of flight software on Orion MPCV flight computer hardware is completed.
September 2010	Orion MPCV begins structural pressure tests at the Michoud Assembly Facility.
January 2011	The Hydro Impact Basin is completed at the Langley Research Center.
February 2011	The first Orion MPCV ground test article is shipped from the Michoud Assembly Facility.
May 2011	Orion MPCV's Vision Navigation Sensor (STORRM) tested on board Endeavour during STS-134.



NASA COMMERCIAL CREW PROGRAM

NASA awarded approximately \$270 million to four commercial companies April 18, 2011, to continue development of commercial rockets and spacecraft capable of safely flying astronauts into orbit and to the International Space Station. The award was the second phase of the agency's Commercial Crew Development effort, known as CCDev2.

The goal of the program is to have a human-capable certified spacecraft flying by the middle of the decade. NASA's goal is for development costs to be cheaper because the launchers and spacecraft can split the price between commercial and government uses. For the second round of agreements, the proposals selected and the value of the award made to each were:

Blue Origin: \$22 million. The company is working on a space vehicle design development for their biconic "New Shepard" spacecraft, designed to take off and land vertically.

Sierra Nevada Corp.: \$80 million. Sierra Nevada is designing a lifting body called "Dream Chaser."

Space Exploration Technologies (SpaceX): \$75 million. SpaceX plans to use the award to develop an escape system for a crewed version of its Dragon capsule, an uncrewed version of which has already flown.

The Boeing Company: \$92.3 million. The Boeing Company will continue development of the CST-100 crew capsule, including maturation of the design and integration of the capsule with a launch vehicle.

The selection was based on how far the awards would move the companies toward their goals

and the business plans of each project. NASA's Commercial Crew Program manager is Ed Mango, located at the Kennedy Space Center, Fla. NASA's goal is for a new, commercially developed spacecraft to take over the work of carrying astronauts into LEO, saving development and operational costs by partnering with commercial industry. As the companies continue their development plans under the agreement guidelines, the next step will be for NASA is to refine the strategy for the next round of development.

Quick Look – NASA Commercial Crew Development Program (CCDev)

The Commercial Crew Development Program is designed to stimulate efforts within the private sector to develop and demonstrate human spaceflight capabilities. NASA provides funds that help support delivery of a station docking interface engineering test unit, a set of human rating requirements for commercial crew vehicles, and the collection of industry input regarding the best way to enable the technologies for commercial crew access to the International Space Station. This development work must show, within the timeframe of the agreement, significant progress on long lead capabilities, technologies and commercial crew risk mitigation tasks to accelerate the development of their commercial crew space transportation concept.

NASA's preference in developing commercial crew capability is to support a logical and deliberate development of capabilities that build on prior demonstrated success. The first step is for companies to demonstrate the ability to deliver unpressurized and pressurized cargo to the International Space Station. The next would be to return pressurized cargo to Earth.



The final step would be to deliver crew to the International Space Station, which would require development of a launch abort system.

NASA is evaluating the need to demonstrate the capability to perform the crew rescue and return function for the station, positioning a commercial partner to then provide a U.S. “lifeboat” capability for station crew.

CCDev Awards

CCDev Round 1

NASA’s Commercial Crew and Cargo Program applied \$90 million of American Recovery and Reinvestment Act (ARRA) funds to the CCDev Program. On Feb. 2, 2010, the agency awarded five grants totaling \$50 million to:

- Blue Origin of Kent, Wash. – \$3.7 million
- The Boeing Company of Houston – \$18 million
- Paragon Space Development Corporation of Tucson, Ariz. – \$1.4 million
- Sierra Nevada Corporation of Louisville, Colo. – \$20 million
- United Launch Alliance of Centennial, Colo. – \$6.7 million

CCDev Round 2

NASA announced its second round of Commercial Crew Development awards in April 2011. The five companies receiving CCDev2 funds are:

- Blue Origin, Kent, Wash., \$22 million
- Sierra Nevada Corp., Louisville, Colo., \$80 million
- Space Exploration Technologies (SpaceX), Hawthorne, Calif., \$75 million
- The Boeing Company, Houston, \$92.3 million

NASA’s preference in developing commercial crew capability is to support a logical and deliberate development of capabilities that build on prior demonstrated success. The first step is for companies to demonstrate the ability to deliver unpressurized and pressurized cargo to the International Space Station. The next would be to return pressurized cargo to Earth. The final step would be to deliver crew to the International Space Station, which would require development of a launch abort system.

NASA is evaluating the need to demonstrate the capability to perform the crew rescue and return function for the station, positioning a commercial partner to then provide a U.S. “lifeboat” capability for station crew.



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