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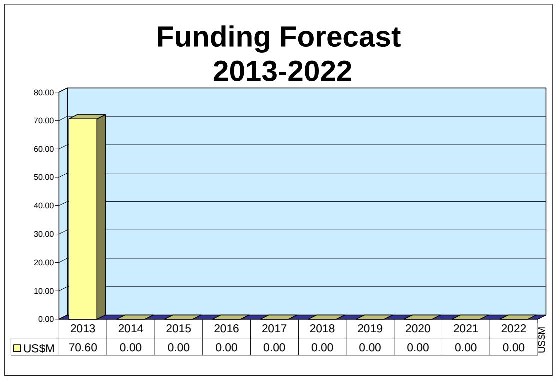
Space Shuttle

Outlook

- Space shuttle Atlantis ended its mission on July 19, 2011, marking the completion of NASA's Space Shuttle program
- NASA is pursuing a two-pronged strategy to move beyond the Space Shuttle: designing an in-house capsule for deep space exploration and paying companies to taxi astronauts to low-Earth orbit
- With funding planned to end after 2013, this report will be archived in 2014



Orientation

Description. The Space Shuttle was a reusable launch vehicle.

Sponsor. NASA's Office of Manned Space Flight, Washington, DC, is responsible for overall program management of the Space Shuttle. Additional agencies and their responsibilities include the Lyndon B. Johnson Space Flight Center, Houston, Texas (orbiter development and shuttle integration); Marshall Space Flight Center, Huntsville, Alabama (booster development and orbiter main engine, and tank development); Kennedy Space Center, Cocoa Beach, Florida (launch and recovery facilities); Langley Research Center, Hampton, Virginia (shuttle thermal protection system and structural integrity); and Glenn Research Center, Cleveland, Ohio (materials development support).

Status. Retired. Surviving shuttles will be sent to museums around the country.

Total Produced. Six: five operational orbiters – Atlantis, Columbia, Challenger, Discovery, and Endeavour – and the Enterprise flight-test vehicle.

Application. Heavy-lift reusable launch vehicle.

Price Range. Endeavour, the newest orbiter, cost approximately $1.8 billion.

Contractors

Prime

United Space Alliance LLC	http://www.unitedspacealliance.com, 1150 Gemini St, Houston, TX 77058 United States, Tel: + 1 (281) 212-6000, Prime
Boeing	http://www.boeing.com, 100 North Riverside, Chicago, IL 60606 United States, Tel: + 1 (312) 544-2000, Fax: + 1 (312) 544-2082, Historical Prime

Subcontractor

Curtiss-Wright Corp	http://www.curtisswright.com, 10 Waterview Blvd, 2nd Fl, Parsippany, NJ 07054

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	United States, Tel: + 1 (973) 541-3700, Fax: + 1 (973) 541-3699 (Payload Bay Door Actuator System)
Eaton Electrical	http://www.eaton.com/electrical, 1000 Cherrington Pkwy, Coraopolis, PA 15108 United States, Tel: + 1 (412) 893-3300 (Microwave Scan Beam Landing Navigation System)

IBM Corp	http://www.ibm.com, New Orchard Rd, Armonk, NY 10504 United States, Tel: + 1 (914) 499-1900, Fax: + 1 (914) 765-7382 (OOS/TUG Orbital Oper & Mission Support Study)
Lockheed Martin Corp	http://www.lockheedmartin.com, 6801 Rockledge Dr, Bethesda, MD 20817 United States, Tel: + 1 (301) 897-6000, Fax: + 1 (301) 897-6704 (Ejection Seats; OV-101 Drogue & Personnel Chute)
Lockheed Martin Space Systems Co, Division HQ	http://www.lockheedmartin.com/us/ssc/ssc.html, 12257 S Wadsworth Blvd, Littleton, CO 80125-8500 United States, Tel: + 1 (303) 977-3000 (Ablative Heat Shield Design; Dynamic Load; Opt TT; Plume Impingement Study; SRB Structural Analysis Program Refinement; Electro-Magnetic Environment Experiment Definition)
Pratt & Whitney Rocketdyne, West Palm Beach Operations	http://www.pratt-whitney.com, PO Box 109600, West Palm Beach, FL 33410-9600 United States, Tel: + 1 (561) 796-2000, Fax: + 1 (561) 796-7285 (SRB Refurbishment & Assembly Facility)
Teledyne Technologies Inc	http://www.teledynetechnologies.com, 1049 Camino Dos Rios, Thousand Oaks, CA 91360 United States, Tel: + 1 (805) 373-4545, Fax: + 1 (805) 373-4775 (Cable & Wire for Power System; Pyrotechnic Initiator Assembly for Crew Escape System)
UTC Aerospace Systems	http://utcaerospacesystems.com, Four Coliseum Centre, 2730 W Tyvola Rd, Charlotte, NC 28217-4578 United States, Tel: + 1 (704) 423-7000, Fax: + 1 (704) 423-7002 (Main Landing Gear Brakes; Nose Landing Gear Up-Lock Release for Thruster Assembly)

Technical Data

	Metric	U.S.
Dimensions		
Orbiter		
Wingspan	23.8 m	78 ft
Length	37.2 m	122 ft
Height	17.3 m	56.6 ft
SRM length	45.5 m	149.1 ft
SRM diameter	3.8 m	12.5 ft
External tank length	47 m	154.2 ft
External tank diameter	8.4 m	27.5 ft
Weight		
Complete System	2,040,000 kg	4,497,384 lb
Orbiter (empty)	69,000 kg	152,117 lb
Orbiter (gross mass)	94,000 kg	207,232 lb
External tank (empty)	29,000 kg	63,933 lb
External tank (gross mass)	750,000 kg	1,653,450 lb
SRM (empty, each)	88,000 kg	194,005 lb
SRM (gross mass, each)	590,000 kg	1,300,714 lb
Performance		
Orbiter Thrust (each, vac)	2,090 kN	470,000 lb
SRM Thrust (each)	11,788.3 kN	2,650,000 lb
Payload to 104 km, 28° inclination	24,404 kg	53,800 lb

Propulsion. The shuttle was powered by three liquid hydrogen/oxygen-powered Space Shuttle main engines (SSME). The orbiter also was equipped with two orbital maneuvering system engines and several reaction control system engines (38 primary and six vernier). For launch, the Space Shuttle employed two reusable solid rocket motors (SRMs). An external liquid hydrogen/oxygen fuel tank was the Space Shuttle's sole expendable part.

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Space Shuttle Atlantis in the Vehicle Assembly Building

Source: NASA

Variants/Upgrades

Propulsion Upgrades. The most complex components of the SSME were the high-pressure turbopumps. In reviewing the most critical items on the SSME that could result in a catastrophic failure, 14 of the top 25 are associated with the turbopumps.

In 1985, NASA solicited industry interest in second sourcing the SSME turbopump, with Rocketdyne to remain the SSME prime contractor. Aerojet and Pratt & Whitney completed SSME component improvement studies later in the year. P&W was selected for the Alternate Turbopump Development program in August 1986.

P&W's contract called for parallel development of both the high-pressure oxidizer turbopump and the high-pressure fuel turbopump to correct the shortcomings of the existing high-pressure turbopumps. This objective was achieved by using design, analytical, and manufacturing technology not available during development of the original components; applying lessons learned from the original SSME development program; eliminating failure modes from the design; implementing a build-to-print fabrication and assembly process; and adding full inspection capability by design.

The turbopumps used precision castings, reducing the total number of welds in the pumps from 769 to seven. Turbine blades, bearings, and rotor stiffness are all improved through the use of new materials and manufacturing techniques.

The SSME powerhead is the structural backbone of the engine, connecting the two pre-burners powering the high-pressure turbopumps to the main propellant injector. The powerhead is the attach point for the high-pressure turbopumps and the main combustion chamber, and is the duct for routing turbine discharge gas back to the main injector.

The use of the Phase II+ Powerhead resulted in improved hot gas flow-path characteristics from the high-pressure fuel turbine to the main injector LOx posts. Static and dynamic flow characteristics are improved throughout the hot gas flow path. The Phase II+ Powerhead also reduced the number of welds, which hastens production and improves reliability.

The heat exchanger, mounted in the oxidizer side of the powerhead, used the hot hydrogen-rich turbine discharge gases to convert liquid oxygen in a thin-walled coil to gaseous oxygen for pressurization of the external oxygen tank. In the older heat exchanger coil, seven welds are exposed to the hot gas environment. A small leak in one of these welds would result in catastrophic failure. The newer single-coil heat exchanger eliminated all seven critical welds and tripled the wall thickness of the tube.

The main objective of development of the large throat main combustion chamber (LTMCC) was to lower chamber pressure, which resulted in lower pressures and temperatures throughout the engine system, thereby increasing the overall shuttle system flight safety and reliability. The wider throat area accommodated additional cooling channels, reducing hot gas wall thickness and increasing chamber life.

The LTMCC design also incorporated investment cast manifolds into the fabrication technique to reduce the number of critical welds and improve the producibility of the chamber. The powerhead, heat exchanger, and LTMCC were all performed under contract with Rocketdyne.

The block change concept for incorporating changes into the main engine was introduced in FY94. The Phase II+ Powerhead, the single-coil heat exchanger, and the new high-pressure oxidizer turbopump comprised Block I. This change was introduced and flown for the first time in 1995.

The new turbopumps, originally expected to cost $230 million to develop, cost nearly $500 million. Production of enough pumps to power the Space Shuttle fleet added $370 million to the final price tag. The new pumps saved about $1.5 million per launch through lower maintenance costs.

First P&W Turbopump Flight. The first flight of the new oxidizer turbopump, part of NASA's Block I engine upgrade, took place in one of three engines on Discovery in 1995. The center engine with the new pump performed flawlessly, leading to use of the new pump on two of three engines aboard Columbia later in the year. A Block IIA engine, which included a larger throat to the main combustion chamber, first flew on STS-89 in 1998.

The Block II main engine flew for the first time in 2001 on Atlantis. The shuttle used two Block IIA engines to complete its full complement of three engines. The Block II engine included a new high-pressure turbopump developed by Pratt & Whitney. The design eliminated welds by using a casting process for the housing and included a heavy integral shaft/disk with robust bearings, which made the pump stronger and increased the number of flights between major overhauls.

A major overhaul, the Block III engine, was planned to fly in 2005 but was canceled by NASA after the Columbia accident. NASA cited technological, cost, and schedule uncertainties for the cancellation. Block III was to include further improvements to the combustion chamber and a simplified nozzle design.

New Nozzle Design. In May 2001, Thiokol successfully performed a 123.2-second test firing of a shuttle solid rocket motor. The test qualified a new insulation design for the motor's nozzle case joint. The new design was introduced in 2004.

External Tanks. In FY95, both a Preliminary Design Review and a Critical Design Review were completed for the Super Lightweight External Tank, leading to the release of drawings to the manufacturing process at the Michoud Assembly Facility.

Lockheed Martin Space Systems - Michoud Operations developed the new fuel tank as part of a program to lighten the overall Space Shuttle by some 3,400 kilograms. The lighter orbiters were needed to carry parts of the International Space Station (ISS) into orbit.

The new Space Shuttle external tank was used for the first time on the orbiter Discovery in 1998 on a mission to the Mir space station. The new tank cost $43 million, about $8 million more than the tank it replaced.

Additional Improvements. Additional improvements slated for the Space Shuttle orbiters included the following:

- Adding the Space Shuttle Main Engine Advanced Health Management System – a monitoring and detection system that would provide real-time and post-flight engine information.
- Modifying the shuttle's main propulsion system propellant valves from pneumatic to electro-mechanical actuation.
- Replacing the alkaline fuel cell technology with a proton exchange membrane fuel cell.

Post-Columbia Improvements. After it was determined that a piece of foam insulation was the most likely cause of STS-107's disintegration, a redesign of the shuttle external tank was drawn up. The redesign was expected to include the elimination of insulating foam in the bipod area and the installation of a heating element to prevent ice buildup.

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First Five-Segment Motor Tested. In October 2003, ATK conducted a static test firing of a five-segment motor to validate the safety margins of the four-segment motor then used by the shuttle. The test was also designed to demonstrate the ability of the five-segment motor to produce thrust levels in excess of 3.6 million pounds. This would increase the shuttle payload capacity by 23,000 pounds. The test was considered highly successful. The new motor measured 12 feet in diameter and was 153.5 feet long, which was, 27.5 feet longer than the four-segment motor.

Remote Manipulator System. The RMS, built by Spar Aerospace of Canada, was designed for payload deployment and retrieval and is sometimes called the "Canadarm." In the wake of the Columbia accident, an extension to double the length of the arm to 100 feet was ordered. This extension was used to view the entire underside of the shuttle for thermal protection system inspection and repair.

Program Review

Background

Early Development. Space Shuttle development began in 1969 with a Presidential Space Task Force recommendation that the United States develop new systems of technology for space operations. This would be done through a program directed initially toward development of a new space transportation capability. In 1970, NASA initiated extensive engineering design and cost studies of a space shuttle. These studies covered a wide variety of concepts, ranging from a fully reusable manned booster and orbiter to dual strap-on solid-propellant rocket motors and an expendable liquid propellant tank.

In 1972, NASA announced it would proceed with development of a reusable, low-cost space shuttle system. Two months later, NASA said the shuttle would use two solid-propellant rocket motors, a decision based on information that showed the solid rocket system offered lower development costs and lower technical risks.

Planned Orbiter Fleet Size Reduced

When the shuttle's Space Transportation System was approved, plans called for five operational orbiters and one engineering model. Three vehicles were to be located at Kennedy SFC and two at Vandenberg AFB. A flight-like engineering model was to be maintained as a testbed. Because of the high costs of the shuttle program, NASA had to limit itself to a four-orbiter Space Shuttle fleet that it believed could satisfy known and postulated mission requirements through 1987 or 1988.

Beyond that time, orbiter attrition or downtime was expected to require an additional orbiter. Each orbiter was expected to have a lifespan of 25 years or 100 flights. The airframe was expected to remain relatively unchanged over its lifetime, with improvements occurring in avionics, engines, and communications links.

COMSAT Estimates of Launch Costs. COMSAT Communications Division reported that when the Space Shuttle was proposed in the 1970s, the plan called for the six orbiters to be relaunched 36 times per year, which would reduce the cost of low-Earth orbital launches from the 1970 standard of about $1,500 per kilogram to the 1970 NASA shuttle price of $135 per kilogram.

By 1974, NASA had raised the shuttle cost to $339 per kilogram. Between 1974 and the end of the program, the cost of a shuttle launch rose past $1,000 per kilogram, to about $3,000 per kilogram.

Solid Rocket Boosters. The Space Shuttle solid rocket booster motor contract for delivery of 12 flight test units and test hardware was awarded to Thiokol's Wasatch Division in 1975. At the time, NASA estimated the cost of a new solid rocket booster to be $25 million. The cost of recovering and refurbishing a single booster was estimated at $7 million.

Orbiter Contract. In 1979, NASA signed a $1.9 billion cost-plus-award-fee contract with Rockwell International's Space Systems Group, Shuttle Orbiter Division, Downey, California, for the manufacture of two orbiters, Discovery OV-103 and Atlantis OV-104; conversion of a ground test orbiter, Challenger OV-099; and modification of the first flight orbiter, Columbia OV-102.

First Flight. The first successful space flight of the shuttle Columbia took place in 1981. Liftoff weight was 2,021,746 kilograms. The flight made 36 orbits of the Earth at an inclination of 40° and an altitude of 270 kilometers. The payload was the Development Flight Instrumentation and Aerodynamic Coefficient Identification Package.

Challenger Replacement Approved in 1986

The Reagan administration, in August 1986, gave NASA the authority to construct a replacement for

Challenger, which was lost in January 1986 when a faulty solid rocket motor ignited the hydrogen in the external fuel tank. The White House instructed the agency that future shuttle missions would be confined to the launch of military and non-commercial payloads. The $1.3 billion prime contract for the replacement shuttle was awarded to Rockwell in August 1987. NASA's Johnson Space Center, Houston, Texas, managed the construction program.

Endeavour was officially rolled out in April 1992 at Rockwell's Palmdale facility. The orbiter was then transferred to the Kennedy Space Center for installation of its engines.

United Space Alliance. In 1995, NASA decided to consolidate the large number of Space Shuttle program contracts under a single prime contractor. Prior to this decision, the majority of the operations, processing, and training work was conducted by Rockwell, under NASA's space operations contract for flight support, and Lockheed Martin, under the shuttle processing contract for ground operations. The two companies agreed to create a Limited Liability Corporation and formed United Space Alliance. In November of that year, Daniel Goldin, then NASA Administrator, decided to pursue a sole-source agreement with United Space Alliance. In early 1996, the company assumed management responsibility for Rockwell's flight operations contract in Texas and Lockheed Martin's shuttle processing contract in Florida, establishing the company as the prime contractor for NASA's Space Shuttle program.

The Space Flight Operations Contract (SFOC) was signed at the Johnson Space Center in September 1996. United Space Alliance's six-year, $7 billion contract went into effect on October 1, 1996. The contract had a base period of performance of six years, with two two-year options.

United Space Alliance Contract Extension and New Award

In August 2004, NASA exercised its contract option with United Space Alliance to extend management of the space flight operations contract, which supported the Space Shuttle program. This two-year option, valued at $3.6 billion, extended the contract period of performance with United Space Alliance through September 30, 2006.

In October 2006, NASA awarded a contract valued at $1.1 billion for the first six months of the contract, which resulted in a four-year contract through September 30, 2010, to cover Space Shuttle operations. The Space Shuttles were retired in 2011, after the International Space Station was completed.

Contractors. Space Shuttle contractors included the following:

Contractor	Component
Aerojet	APU, gas generator/thrusters
Aerospace Corporation	Technical services
Ares	Quality and safety support for upgrades
ATK (Alliant Techsystems)	Booster separation motors and reusable solid rocket motors
Ball Aerospace & Technologies	Star tracker, power supply
Barrios Technology	Engineering support
Bastion Technologies	Reproduction and documentation
Boeing Company Reusable Space Systems	Orbiter engineering, provisioning, and logistics
Cincinnati Electronics	Electronics, cable assemblies
David Clark	Helmets, flight suit repair, refurbishment
DP Associates	Software development
GB Tech	Logistics and warehouse support, flight software support
General Dynamics Decision Systems	Software engineering services
Goodrich Wheel & Brake	Wheel and brake systems
Hamilton Sundstrand	Environmental control, life support, APU
Honeywell International	Multiplexer-demultiplexers, multifunction electronic displays
Kearfott Guidance & Navigation	Gyros, display/transformers/cover flywheel/cable assembly
L-3 Communications	Integrated electronic assembly repairs, upgrades
Launch Coast Services	Clean room environmental services
Lockheed Martin	Cockpit avionics
Lockheed Martin Missiles and Fire Control	Reinforced carbon-carbon subassembly/panel assembly
Lockheed Martin Space Operations	Pyrotechnic initiator control engineering and spares
Moog Inc	Servoactuator/services/closure stop, power stool
MRI Technologies	Flight software support
Pacific Scientific Energetic Materials	Reefing lines, separation bolts, frangible nuts
Pratt & Whitney Chemical Systems Division	Forward booster separation motors
Rockwell Collins	Navigation instrumentation

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Contractor	Component
SAIC	Software engineering
Space Gateway Support	Engineering and Kennedy Space Center support
Spar Aerospace	Remote Manipulator System (RMS)
Titan Systems	Software engineering
Troutman Technical Services	Technical documentation, cleaning services in mission critical areas
Universal Propulsion Company	Thrusters, confined detonating fuses, window severance assemblies, emergency egress systems
UTC International Fuel Cells	Fuel cell repairs and spares
Wiltech of Florida	Component cleaning

Columbia Accident. The space shuttle Columbia and its seven astronauts were lost on February 1, 2003, when the vehicle broke up over north-central Texas during its re-entry from orbit.

Communications were lost with Columbia and its crew at around 8:00 a.m. CST, while the shuttle was traveling about 18 times the speed of sound at an altitude of 207,000 feet. Columbia was 16 minutes away from landing at the Kennedy Space Center when flight controllers at Mission Control lost contact with the vehicle. Columbia was returning from a 16-day scientific research mission, its 28th flight, which launched on January 16.

Aboard Columbia were Cmdr. Rick Husband, completing his second flight; pilot William McCool, wrapping up his first mission; mission specialists Dave Brown, also completing his first mission, and Kalpana Chawla, on her second flight; Laurel Clark, a first-time space traveler; payload commander Mike Anderson, ending his second flight; and payload specialist Ilan Ramon of the Israel Space Agency, on his first flight.

Prior to the loss of communications with Columbia, the shuttle's return to Earth appeared perfectly normal. After assessing some wispy fog near the shuttle's three mile-long landing strip at KSC before dawn, Entry Flight Director LeRoy Cain gave approval for the firing of the shuttle's braking rockets to begin its descent from orbit.

Husband and McCool began the deorbit burn to allow Columbia to slip out of orbit at 7:15 a.m. CST. There was no indication of anything abnormal with Columbia's re-entry until the last communications between Mission Control and the crew.

The space agency immediately convened an investigative board, called the Columbia Accident Investigation Board, which consisted of the following members:

- Chairman of the Board, Adm. Hal Gehman, United States Navy
- Rear Adm. Stephen Turcotte, commander, Naval Safety Center
- Maj. Gen. John Barry, director, Plans and Programs, Headquarters Air Force Materiel Command
- Maj. Gen. Kenneth W. Hess, commander, HQ USAF Chief of Safety
- Dr. James N. Hallock, chief, Aviation Safety Division, Department of Transportation
- Steven B. Wallace, director of Accident Investigation, Federal Aviation Administration
- Brig. Gen. Duane Deal, commander, 21st Space Wing, USAF
- Scott Hubbard, director, NASA Ames Research Center
- Roger E. Tetrault, retired chairman of McDermott International
- Dr. Sheila Widnall, professor of Aeronautics and Astronautics and Engineering Systems, MIT
- Dr. Douglas D. Osheroff, professor of Physics and Applied Physics, Stanford University
- Dr. Sally Ride, professor of Space Science, University of California at San Diego
- Dr. John Logsdon, director of the Space Policy Institute, George Washington University

CAIB Findings and Recommendations. Film footage taken at the time of the Columbia liftoff confirmed that a lightweight chunk of foam insulation ripped off the shuttle's external fuel tank and hit the wing at a high rate of speed. Engineers determined at the time that it represented no threat to the spacecraft. The CAIB sought to determine what the outcome would be if such a piece of foam struck the shuttle and conducted the test that has come to be known as the "smoking gun." During the test, chunks of foam insulation were fired at a mockup of the Columbia wing. One piece of insulation produced a 16-inch hole in the shuttle wing's leading edge. This hole would have allowed boiling hot gases to enter the wing, resulting in temperatures that would have exceeded 3,000°F. These extreme temperatures would certainly melt the inside of the wing and result in a critical and fatal destabilization of the shuttle.

In response to these results and the completion of the CAIB, the following recommendations were made to NASA concerning what must be done before the shuttle returned to flight:

- Initiation of an aggressive program to eliminate all external tank thermal protection from shedding, with emphasis on the area where the bipod struts attach to the tank.
- Provision of an increase in the shuttle's ability to withstand minor debris damage.
- Implementation of a comprehensive inspection plan to determine the structural integrity of all carbon-carbon components.
- Development of a capability to inspect the shuttle on-orbit and carry out emergency repairs to the thermal protection system.
- Upgrade of the imaging system to provide a minimum of three useful views from liftoff to at least SRB separation.
- Provision of the ability to downlink high-resolution images of the shuttle prior to re-entry.
- Development of new technology to inspect all orbiter wiring, including inaccessible areas.
- Test and qualification of new flight hardware bolt catchers for the massive bolts that connect the SRBs to the external tank.
- Enactment of a requirement that at least two employees attend final closeout inspections.
- Change of the micrometeoroid and orbital debris safety criteria from guidelines to requirements.
- Adoption of a shuttle flight schedule that was consistent with available resources and deadlines to avoid incurring additional risk.
- Establishment of an independent technical engineering authority that would be responsible for all waivers to requirements and the analysis of hazards.

STS-115 a Success

The space shuttle Atlantis successfully lifted off September 9, 2006, from the Kennedy Space Center in Florida at 11:15 a.m. EDT (1515 GMT) after a trouble-free countdown. Atlantis reached orbit eight minutes later. The launch had been delayed nearly two weeks by a variety of factors, including a tropical depression, a problem with one of the shuttle's three fuel cells, and a sensor glitch on the shuttle's external tank. The space shuttle Atlantis docked with the International Space Station early September 11 as the STS-115 crew prepared to begin its station assembly tasks. Atlantis docked with the station's Destiny module at 6:48 a.m. EDT (1048 GMT), a little less than two days after the shuttle's launch from Florida. STS-115 returned to Earth safely on September 21, 2006.

STS-121 Launched Despite Crack

The space shuttle Discovery lifted off July 4, 2006, on the first shuttle mission in nearly a year. Discovery started the STS-121 mission with a liftoff at 2:37 p.m. EDT (1837 GMT) from the Kennedy Space Center in Florida. The launch took place on the third attempt to put the shuttle in orbit; earlier attempts were scrubbed because of bad weather. NASA proceeded with the launch after investigating a crack in external tank foam discovered early on July 3, concluding that the crack and the small piece of foam that fell off did not pose a safety risk to the shuttle.

The space shuttle Discovery landed safely at the Kennedy Space Center in Florida on July 17, despite some weather that forced a last-minute change in landing plans. Discovery landed on runway 15 at KSC's Shuttle Landing Facility at 9:14 a.m. EDT (1314 GMT), ending a nearly 13-day mission to the International Space Station.

STS-116 Launched

The space shuttle Discovery launched December 9, 2006, on a mission to the ISS. Discovery lifted off from Launch Complex 39B at the Kennedy Space Center at 8:47 p.m. EST (0147 GMT December 10) and reached orbit eight minutes later. NASA pressed ahead with launch preparations after falling behind on fueling the shuttle's external tank and despite forecasts of poor weather. However, winds died down and skies remained clear, allowing the launch to proceed. The space shuttle Discovery overcame poor weather forecasts on its return and successfully landed in Florida the afternoon of December 22. Discovery landed at the Kennedy Space Center at 5:32 p.m. EST (2232 GMT) on the second of two landing opportunities at the spaceport. The landing brought to a successful conclusion the 13-day STS-116 mission to the space station, the third and final shuttle mission of 2006.

STS-117 Launched

The space shuttle Atlantis launched June 8, 2007, on a mission to the ISS. Atlantis lifted off from Launch Complex 39A at the Kennedy Space Center at 7:38 p.m. EDT (2338 GMT), reaching orbit about eight minutes later. On June 10, the space shuttle Atlantis docked with

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the ISS as astronauts prepared to attach a new truss segment to the orbiting outpost. Atlantis landed safely on June 22 at Edwards Air Force Base in California after weather prevented attempts to land in Florida. Atlantis landed at Edwards at 3:49 p.m. EDT (1949 GMT) on the first of three possible landing windows there. The landing ended the nearly 14-day STS-117 mission, which featured the addition of a new truss segment and solar panel unit to the ISS. The shuttle also returned with ISS astronaut Sunita Williams, who had spent six months on the ISS; she was replaced by Clay Anderson, who flew to the ISS on the shuttle.

STS-118 a Success

The space shuttle Endeavour launched August 8, 2007, on a mission to the ISS. Endeavour lifted off from pad 39A at the Kennedy Space Center on time at 6:36 p.m. EDT (2236 GMT) after a smooth countdown, and entered orbit eight minutes later. The main purpose of the STS-118 mission was to install a new truss segment at the ISS and deliver additional equipment to the facility, including a new gyro that is used to control the station's attitude. STS-118 notably included former teacher Barbara Morgan, the runner-up in 1986 to Christa McAuliffe in the Teacher in Space program; Ms. McAuliffe perished with the rest of the Challenger crew when the spacecraft exploded shortly after launch in January 1986. The August 2007 mission was the first for Endeavour since the late 2002 STS-113 ISS assembly mission and astronaut exchange, which was the final successful shuttle flight before the ill-fated STS-107 Columbia, which disintegrated on February 1, 2003, during re-entry into Earth's atmosphere, killing all seven crewmembers; Endeavour underwent an overhaul while the other two orbiters, Discovery and Atlantis, returned to flight.

In 2008, NASA conducted four Space Shuttle missions, all in support of the International Space Station. Atlantis was launched as part of STS-122 on February 7. The mission delivered and installed the European Space Agency's Columbus laboratory. Endeavour's STS-123 mission launched on March 11 to deliver the Japanese Experiment Logistics Module, Pressurized Section, called the JLP. JLP will contain critical avionics and be used to store materials for experiments. Combined with other elements, it will make up Kibo, the International Space Station's Japanese complex.

The space shuttle Discovery's STS-124 mission launched on May 31 carrying the main section of the Japanese module for the ISS. The module will be the largest single laboratory on the station.

The final mission of 2008 took place on November 15 with Endeavour's STS-126 mission to fix power generation equipment at the station and bring equipment to recycle urine and condensation into pure drinking water. This allows the station to operate with minimal water deliveries.

In 2009, five more Space Shuttle missions were conducted. Discovery's STS-119 mission was launched on March 15 to deliver the final set of solar arrays to the ISS. On May 11, Discovery's STS-125 mission was launched to repair and upgrade the Hubble Space Telescope. On July 15, the space shuttle Endeavour's STS-127 mission carried supplies to the ISS, and the crew spent 16 days working on the station. On August 28, space shuttle Discovery's STS-128 mission brought tools to the crew on board the ISS to conduct experiments. On November 16, Atlantis' STS-129 mission was launched carrying nearly 30,000 pounds of replacement parts for the space station.

In 2010, the Space Shuttle launched three times. Endeavour launched on February 25 under STS-130. The Space Shuttle carried the final components of the U.S. section of the ISS. On April 23, Discovery's STS-131 mission was launched to the space station carrying supplies such as sleeping quarters for the crew, an ammonia tank, gyroscope, and experiments. Atlantis' STS-132 launched on May 14 to the space station carrying a Russian module and spare parts for station operation.

All flights were originally expected to be completed by the end of FY10; however, delays pushed two of the launches into FY11. NASA has continued funding shuttle operations into FY12 and FY13 to cover closing costs that were stretched by these delays. In addition, contracts, such as those with ATK, have been extended to allow for the delay in operations.

The shuttle Discovery blasted off on February 24, 2011, for the STS-133 mission, carrying the Permanent Multipurpose Module (PMM) to the ISS. On May 16, STS-134 began with the lift off of space shuttle Endeavour, which. delivered the Alpha Magnetic Spectrometer-2 (AMS-2) and supplies to the ISS. The final shuttle mission, STS-135, began on July 8 with the launch of Atlantis. The shuttle delivered 8,000 pounds of supplies to the ISS to help sustain station operations after the cessation of the shuttle program.

Funding

NASA's shuttle funding for FY12 is located under Mission Directorate: Space Operations, Theme: Space Shuttle.

U.S. FUNDING

	FY09 AMT	FY10 AMT	FY11 AMT	FY12 AMT	FY13 AMT	FY14 AMT	FY15 AMT
Space Shuttle	2,979.5	3,101.4	1,592.9	556.2	70.6	-	-

All $ are in millions.

Timetable

Month	Year	Major Development
Jul	1972	Columbia contract award
Jul	1972	Challenger contract award
Jan	1979	Atlantis contract award
Jan	1979	Discovery contract award
Mar	1979	Columbia rollout from Palmdale
Apr	1981	Columbia flight 1 (duration 2 days)
Jun	1982	Challenger rollout from Palmdale
Apr	1983	Challenger flight 1 (duration 5 days)
Oct	1983	Discovery rollout from Palmdale
Aug	1984	Discovery flight 1 (duration 7 days)
Mar	1985	Atlantis rollout from Palmdale
Oct	1985	Atlantis flight 1 (duration 4 days)
Jan	1986	Loss of Challenger
Jul	1987	Endeavour contract award
Sep	1988	Discovery flight 7 (duration 4 days); shuttle missions resume
Apr	1991	Endeavour rollout from Palmdale
May	1992	Endeavour flight 1 (duration 8 days)
Dec	1998	Endeavour flight 13 (duration 11 days); first ISS flight
Oct	2000	Discovery flight 28 (duration 12 days); 100th Space Shuttle flight
Mar	2002	Columbia flight 27 (duration 10 days)
Apr	2002	Atlantis flight 25 (duration 10 days)
Jun	2002	Endeavour flight 18 (duration 13 days)
Oct	2002	Atlantis flight 26 (duration 10 days)
Nov	2002	Endeavour flight 19 (duration 10 days)
Jan	2003	STS-107, Columbia flight 28 (duration 16 days); orbiter lost during re-entry
Jul	2005	STS-114, Discovery flight 31 (duration 13 days)
Jul	2005	Shuttle fleet grounded again following foam loss on STS-114
Jul	2006	STS-121, Discovery flight 32 (duration 13 days)
Sep	2006	STS-115, Atlantis flight 27 (duration 12 days)
Dec	2006	STS-116, Discovery flight 33 (duration 13 days)
Jun	2007	STS-117, Atlantis flight 28 (duration 11 days)
Aug	2007	STS-118, Endeavour flight 20 (duration 11 days)
Oct	2007	STS-120, Discovery flight 34 (duration 15 days)
Feb	2008	STS-122, Atlantis flight 29 (duration 11 days)
Mar	2008	STS-123, Endeavour flight 21 (duration 15 days)
May	2008	STS-124, Discovery flight 35 (duration 13 days)
Nov	2008	STS-126, Endeavour flight 22 (duration 15 days)
Feb	2009	STS-125, Atlantis flight 30, Hubble Space Telescope servicing mission
Nov	2009	STS-129, Atlantis flight 31 (duration 11 days)
Feb	2010	STS-130, Endeavour flight 23 (duration 13 days)
Apr	2010	STS-131, Discovery flight 36 (duration 15 days)
May	2010	STS-132, Atlantis flight 32 (duration 12 days)
Feb	2011	STS-133, Discovery flight 37 (duration 13 days)

Space Shuttle

Month	**Year**	**Major Development**
May	2011	STS-134, Endeavour flight 24 (duration 16 days)
Jul	2011	STS-135, Atlantis flight 33 (duration 13 days)

Forecast Rationale

Space Shuttle Atlantis ended its mission on July 19, 2011, marking the completion of NASA's Space Shuttle program. Surviving shuttles have been moved to museums around the country.

Some members of Congress proposed adding flights to the manifest in response to the five-year gap between the shuttle's retirement and the planned introduction of replacement spacecraft. John Shannon, the NASA Space Shuttle program manager, said that technically and mechanically the shuttles could continue to fly; however, NASA would require $200 million per month to keep the shuttle program active. That money was not available, and NASA will move forward with terminating the program.

The primary goal of the final shuttle missions was to complete the International Space Station, leaving the station as self-sufficient as possible after the shuttle missions ended. The missions delivered important components to the station, such as the Permanent Multipurpose Module and the Alpha Magnetic Spectrometer-2. In addition, shuttle flights delivered large amounts of spare parts and supplies to the station, allowing the station crew to stock up and reducing the number of deliveries required until the U.S. introduces its next generation of space transport vehicles. In the meantime, the ISS will rely on Russian, Japanese, and ESA spacecraft for its replenishment.

NASA is now headed in a different direction as it moves beyond its venerable Space Shuttle fleet, pursuing a two-pronged strategy based on compromises between President Barack Obama and Congress. First, NASA will develop an in-house heavy-lift launch vehicle (the Space Launch System) and a crew capsule (the Multipurpose Crew Vehicle). Second, the agency will fund development of commercial crew launch vehicles, which will allow astronauts to travel into space on commercially owned and operated space vessels.

NASA will fund the Space Shuttle program through fiscal year 2013. Funding will primarily be used to close out the program. Funding will also be used to cover the pension obligations of United Space Alliance, the prime contractor for the Space Shuttle program.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR O&M FUNDING (in millions $)												
Designation or Program		**High Confidence**				**Good Confidence**			**Speculative**			
	Thru 2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
United Space Alliance LLC												
Space Shuttle <> United States												
	19,691.20	70.60	.00	.00	.00	.00	.00	.00	.00	.00	.00	70.60
Total	19,691.20	70.60	.00	.00	.00	.00	.00	.00	.00	.00	.00	70.60