SPACE FLIGHT

The First 30 Years

NASA

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NASA
National Aeronautics and
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Contents

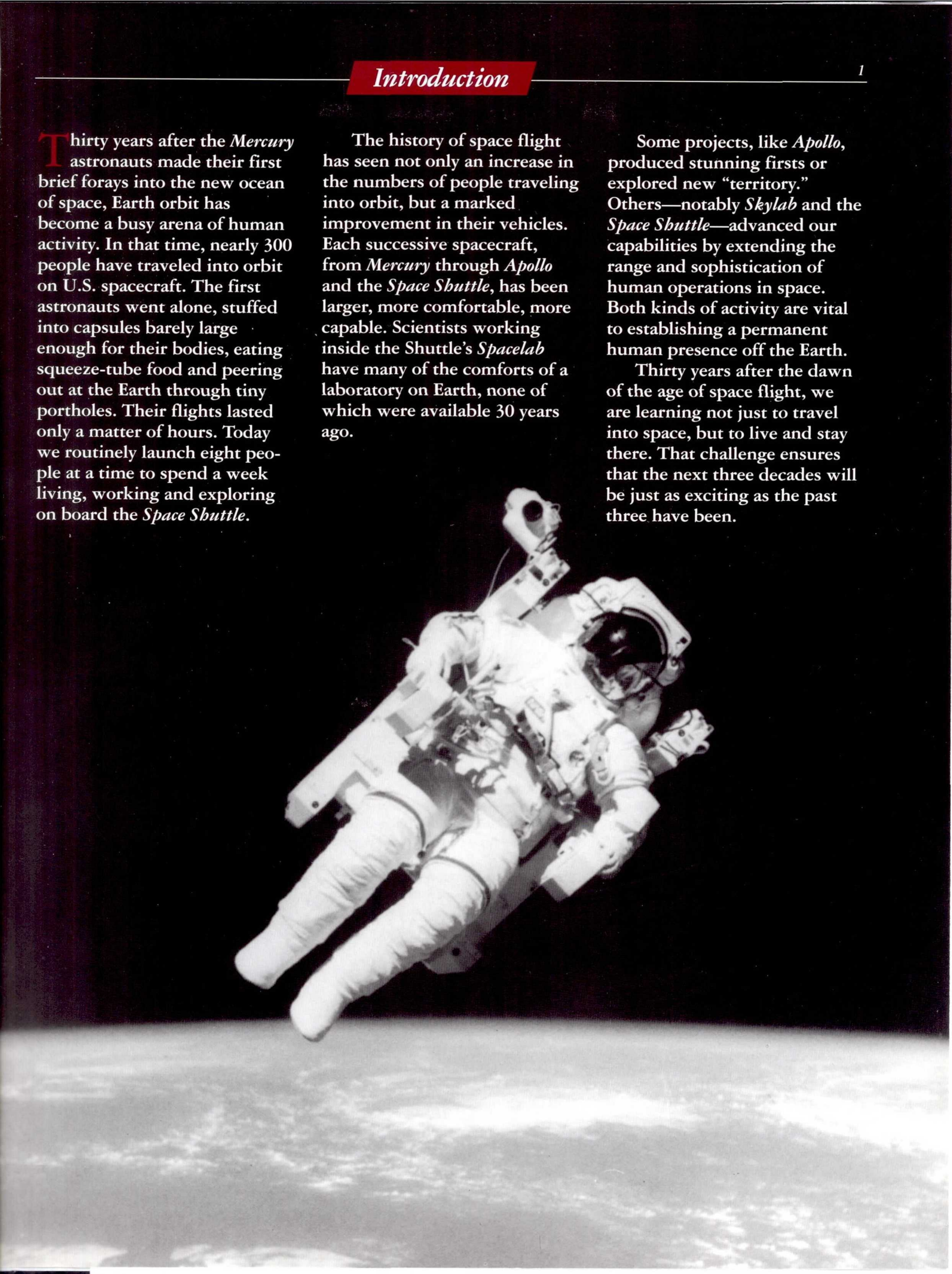
Introduction

Thirty years after the *Mercury* astronauts made their first brief forays into the new ocean of space, Earth orbit has become a busy arena of human activity. In that time, nearly 300 people have traveled into orbit on U.S. spacecraft. The first astronauts went alone, stuffed into capsules barely large enough for their bodies, eating squeeze-tube food and peering out at the Earth through tiny portholes. Their flights lasted only a matter of hours. Today we routinely launch eight people at a time to spend a week living, working and exploring on board the *Space Shuttle*.

The history of space flight has seen not only an increase in the numbers of people traveling into orbit, but a marked improvement in their vehicles. Each successive spacecraft, from *Mercury* through *Apollo* and the *Space Shuttle*, has been larger, more comfortable, more capable. Scientists working inside the Shuttle's *Spacelab* have many of the comforts of a laboratory on Earth, none of which were available 30 years ago.

Some projects, like *Apollo*, produced stunning firsts or explored new "territory." Others—notably *Skylab* and the *Space Shuttle*—advanced our capabilities by extending the range and sophistication of human operations in space. Both kinds of activity are vital to establishing a permanent human presence off the Earth.

Thirty years after the dawn of the age of space flight, we are learning not just to travel into space, but to live and stay there. That challenge ensures that the next three decades will be just as exciting as the past three have been.



Project Mercury came into being on October 7, 1958, only a year and three days after the Soviet Union's *Sputnik 1* satellite opened the Space Age. The goal of sending people into orbit and back had been discussed for many years before that, but with the initiation of the *Mercury* project, theory became engineering reality.

Mercury engineers had to devise a vehicle that would protect a human being from the temperature extremes, vacuum and newly discovered radiation of space. Added to these demands was the need to keep an astronaut cool during the burning, high-speed reentry through the atmosphere. The vehicle that best fit these requirements was a wingless "capsule" designed for a ballistic reentry, with an ablative heat shield that burned off as *Mercury* returned to Earth.

Mercury capsules rode into space on two different kinds of booster. The first suborbital flights were launched on *Redstone* rockets designed by Wernher von Braun's team in Huntsville, Alabama. For orbital flights, *Mercury* was placed on top of an *Atlas-D*, a modified ballistic missile whose steel skin was so thin (to save weight) it would have collapsed like a bag if not pressurized from within.

The first Americans to venture into space were drawn from a group of 110 military pilots chosen for their flight test experience and because they met certain physical requirements. Seven of those 110 became astronauts in April 1959. Six of the seven flew *Mercury* missions (Deke Slayton was removed from flight status due to a heart condition). Beginning with Alan Shepard's *Freedom 7* flight, the astronauts named their own spacecraft, and all added 7 to the name to acknowledge the teamwork of their fellow astronauts.

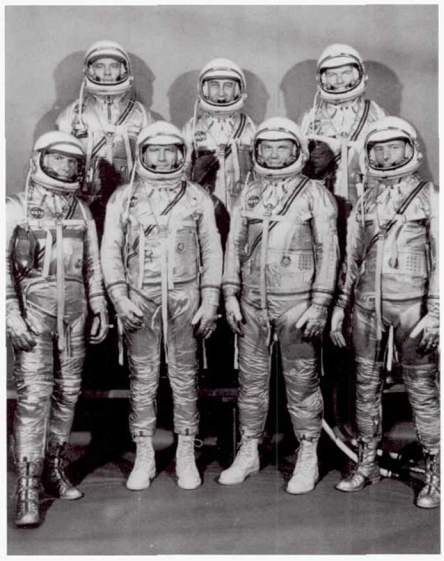
With only 12.133 cubic meters of volume, the *Mercury* capsule was barely big enough to include its pilot. Inside were 120 controls, 55 electrical switches, 30 fuses and 35 mechanical levers. Before Shepard's flight, surrogate "passengers" tested the integrity of the spacecraft design: two rhesus monkeys, Ham the chimpanzee, and an electronic "crewman simulator" mannequin that could breathe in and out to test the cabin environment. Finally, in May 1961, Shepard became the first American in space. Nine months later, John Glenn became the first American to orbit the Earth.

The six *Mercury* flights (which totalled two days and six hours in space), taught the pioneers of space flight several important lessons. They learned not only that humans could function in space, but that they were critical to a mission's success. Ground engineers learned the difficulty of launch preparations, and found that a worldwide communications network was essential for manned space flight.

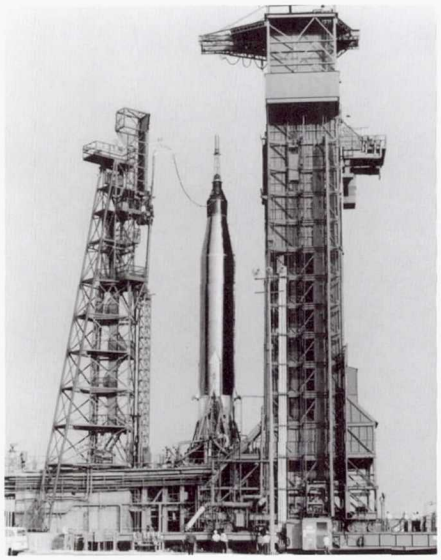
By the time of the last *Mercury* flight in May 1963, the focus of the U.S. space program had already shifted. President John F. Kennedy had announced the goal of reaching the Moon only three weeks after Shepard's relatively simple 15-minute suborbital flight, and by 1963, only 500 of the 2,500 people working at NASA's Manned Spacecraft Center were still working on *Mercury*—the remainder were already busy on *Gemini* and *Apollo*.

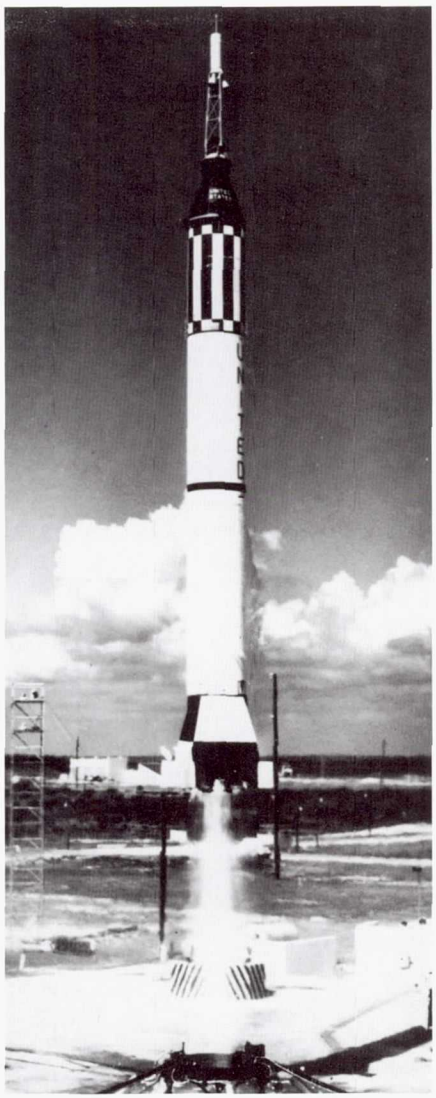
But *Mercury* had taken the critical first step, and had given reassuring answers to a number of fundamental questions: Could humans survive in space? Could a spacecraft be designed to launch them into orbit? Could they return safely to Earth?

At the moment John Glenn's *Friendship 7* capsule was placed into its orbital trajectory, fulfilling the primary goal of *Project Mercury*, one member of the launch team on the ground made a notation in his log: "We are through the gates."



The Mercury Seven: (Top) Shepard, Grissom, Cooper (Bottom) Schirra, Slayton, Glenn, and Carpenter.





Top left: Mercury Atlas 9 on the pad.

Top right: Liftoff of *Mercury Redstone 3*.

Left: Shepard waits to be sealed inside *Freedom 7*.

Project Mercury

Dates: 1961-1963

Vehicles: *Redstone* and *Atlas* launchers
Mercury spacecraft

Number of People Flown: 6

Highlights: First American in space
First American in orbit

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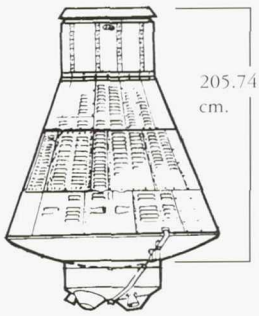
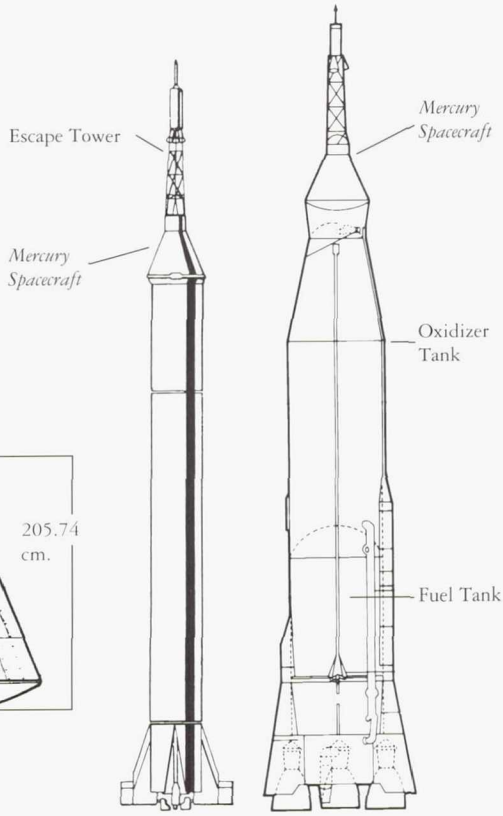


Mercury Spacecraft



Redstone *Atlas*

1962

- February 20: *Mercury Atlas 6* (*Friendship 7*) First U.S. manned orbital flight
- May 24: *Mercury Atlas 7* (*Aurora 7*)
- September: Nine astronauts chosen for *Gemini* program (Group 2)
- October 3: *Mercury Atlas 8* (*Sigma 7*)

Mercury Redstone 3 (Freedom 7)

May 5, 1961
Crew: Alan B. Shepard, Jr.

Alan Shepard's suborbital flight lasted only 15 minutes, but it proved that an astronaut could survive and work comfortably in space, and demonstrated to the 45 million Americans watching on TV that the United States was now in the space flight business. *Freedom 7* was a ballistic "cannon shot"—Shepard reached no higher than 187.45 kilometers, and traveled only 486.022 kilometers down range from Cape Canaveral. During his short time in space he maneuvered his spacecraft using hand controllers that pitched, yawed and rolled the tiny *Mercury* capsule with small thrusters. He found the ride smoother than expected and reported no discomfort during five minutes of weightlessness. Although this first *Mercury* capsule lacked a window, Shepard was able to look down at the Atlantic coastline through a periscope. His view, though, was in black and white—the astronaut had inadvertently left a gray filter in place while waiting on the pad for liftoff.

Mercury Redstone 4 (Liberty Bell 7)

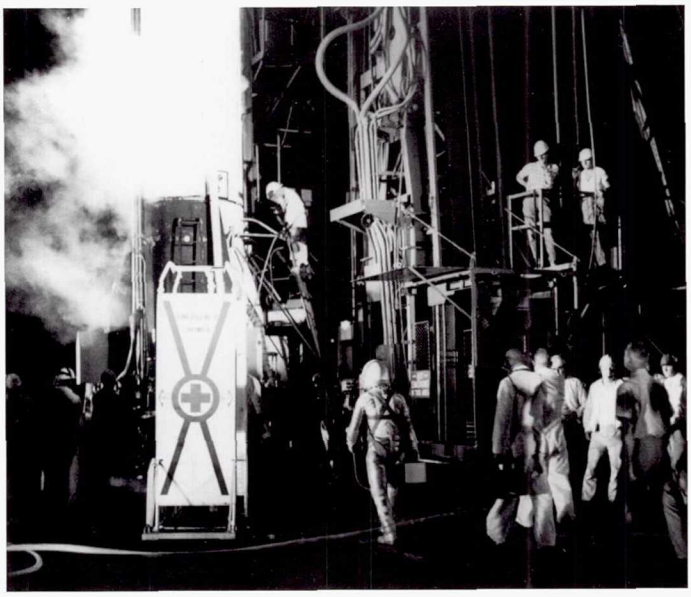
July 21, 1961
Crew: Virgil I. "Gus" Grissom

Grissom's suborbital mission was essentially a repeat of Shepard's, again using the *Redstone* launcher instead of the more powerful *Atlas*. Grissom's *Mercury* capsule had a few minor improvements, including new, easier-to-use hand controllers, a window, and an explosive side hatch, which the astronauts had requested for easier escape in case of an emergency. Since Shepard's flight had been overly busy, Grissom's duties were deliberately reduced, and he spent more time observing the Earth. The only significant failure came at the end of the 15-minute flight, after *Liberty Bell 7* had parachuted into the Atlantic Ocean near the Bahamas. While Grissom waited inside the floating capsule to be picked up by helicopter rescue teams, the side hatch opened, filling the tiny spacecraft with seawater. *Liberty Bell* sank, but a wet Grissom was safely recovered, and the *Mercury* program was able to move on to orbital flights.

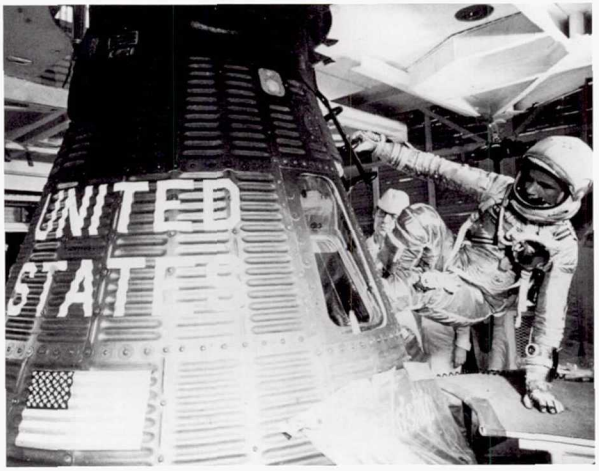
Mercury Atlas 6 (Friendship 7)

February 20, 1962
Crew: John H. Glenn, Jr.

John Glenn's orbital flight—an American first—lasted four hours, 55 minutes, during which he circled the Earth three times, observing everything from a dust storm in Africa to Australian cities from an altitude of 260.71 kilometers. Glenn was the first American to see a sunrise and sunset from space, and was the first photographer in orbit, having taken along a 35-millimeter Minolta purchased from a Cocoa Beach, Florida drugstore. The most nervous moments of the flight came before and during reentry, when a signal received on the ground (erroneously, as it turned out) indicated that the capsule's heat shield had come loose. At one point, Glenn thought his shield was burning up and breaking away. He ran out of fuel trying to stop the capsule's bucking motion as it descended through the atmosphere, but splashed down safely, 64.37 kilometers short of his target (preflight calculations of the spacecraft's weight had not considered the loss of on-board "consumables"). Glenn returned to Earth a national hero, having achieved *Project Mercury's* primary goal.



Mercury Redstone 4: Grissom walks to the launch pad.

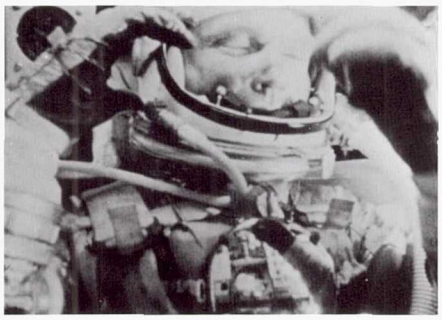


Mercury Atlas 6: Glenn boards *Friendship 7*.

Mercury Atlas 7 (Aurora 7)

May 24, 1962
Crew: M. Scott Carpenter

The focus of Carpenter's five-hour *Aurora 7* mission was on science. The full flight plan included the first study of liquids in weightlessness, Earth photography and an unsuccessful attempt to observe a flare fired from the ground. At dawn of the third and final orbit, Carpenter inadvertently bumped his hand against the inside wall of the cabin and solved a mystery from the previous flight. The resulting bright shower of particles outside the capsule—what Glenn had called "fireflies"—turned out to be ice particles shaken loose from the capsule's exterior. Like Glenn, Carpenter circled the Earth three times. Partly because he had been distracted watching the fireflies and partly because of his busy schedule, he overshot his planned reentry mark, and splashed down 402.34 kilometers, off target.



Mercury Atlas 6: Glenn in flight.

Mercury Atlas 8 (Sigma 7)

October 3, 1962
Crew: Walter M. Schirra, Jr.

Schirra's was the first of two longer-duration *Mercury* missions. After Carpenter's flawed reentry, the emphasis returned to engineering rather than science (Schirra even named his spacecraft "*Sigma*" for the engineering symbol meaning "summation"). The six-orbit mission lasted nine hours and 13 minutes, much of which Schirra spent in what he called "chimp configuration," a free drift that tested the *Mercury's* autopilot system. Schirra also tried "steering" by the stars (he found this difficult), took photographs with a Hasselblad camera, exercised with a bungee-cord device, saw lighting in the atmosphere, broadcast the first live message from an American spacecraft to radio and TV listeners below, and made the first splashdown in the Pacific. This was the highest flight of the *Mercury* program, with an apogee of 283.24 kilometers, but Schirra later claimed to be unimpressed with space scenery as compared to the view from high-flying aircraft. "Same old deal, nothing new," he told debriefers after the flight.

Mercury Atlas 9 (Faith 7)

May 15-16, 1963
Crew: L. Gordon Cooper, Jr.

If Schirra's mission was an endurance test, the final *Mercury* flight was a marathon. Cooper circled the Earth 22 1/2 times, and released the first satellite from a spacecraft—a 152.4-millimeter sphere with a beacon for testing the astronaut's ability to track objects visually in space. Although a balloon for measuring atmospheric drag failed to deploy properly, Cooper finally completed another *Mercury* experiment when he was able to spot a powerful, 44,000-watt xenon lamp shining up from the ground. (He also claimed to be able to see individual houses from orbit, even smoke from chimneys in the Tibetan highlands.) During his 34 hours in space, Cooper slept, spoke a prayer into his tape recorder and took the best photographs of the *Mercury* program, including pictures of the Earth's limb and infrared weather photographs. His mission was deemed a great success—so successful, in fact, that it allowed *Mercury* officials to cancel a planned seventh flight and move on to the two-man *Gemini* program.

Mercury Redstone 3: Recovering *Freedom 7* from the Caribbean.

Gemini

Gemini was not pure pioneering like *Mercury*, nor did it have the excitement of *Apollo*. But its success was critical to Kennedy's goal of reaching the Moon "by decade's end."

The program was announced to the public on January 3, 1962, after *Apollo* already was well underway. *Gemini's* primary purpose was to demonstrate space rendezvous and docking—techniques that would be used during *Apollo*, when the lunar lander would separate from the command module in orbit around the Moon, then meet up with it again after the astronauts left the lunar surface. *Gemini* also sought to extend astronauts' stays in space to two weeks, longer than even the *Apollo* missions would require.

It was during the *Gemini* program that space flight became routine. Ten manned missions left the launch pads of Cape Canaveral in less than 20 months, and the Manned Space Flight Center outside Houston (later Johnson Space Center) took over the role of Mission Control. Ground operations became smooth and efficient, due in part to fleetingly short launch windows—the *Gemini XI* "window" opened for only 2 seconds—dictated by the need to rendezvous with targets already in orbit. Meanwhile, sixteen new astronauts chalked up experience in space.

The *Gemini* spacecraft was an improvement on *Mercury* (it was originally called *Mercury Mark II*) in both size and capability. *Gemini* weighed more than 3,628.72 kilograms—twice the weight of *Mercury*—but ironically seemed more cramped, having only 50 percent more cabin space for twice as many people. Ejection seats replaced *Mercury's* escape rocket, and more storage space was added for the longer *Gemini* flights. The long duration missions also required fuel cells instead of batteries for generating electrical power.

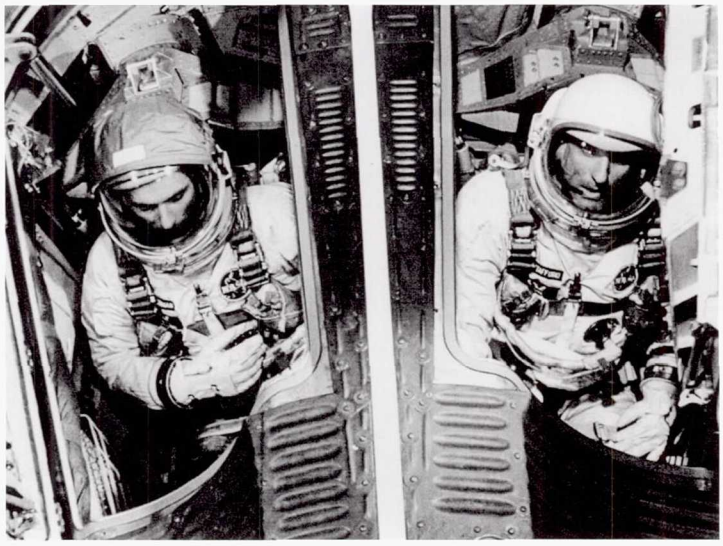
Unlike *Mercury*, which had only been able to change its orientation in space, *Gemini* needed real maneuvering capability to rendezvous with another spacecraft. *Gemini* would have to move forward, backward and sideways in its orbital path, even change orbits. The complexity of rendezvous demanded two people on board, and more piloting than had been possible with *Mercury*. It also required the first on-board computers to calculate complicated rendezvous maneuvers.

Gemini rode into orbit on a *Titan 2* launch vehicle. The target for rendezvous operations was an unmanned *Agena* upper stage, which was launched ahead of the *Gemini*. After meeting up in orbit, the nose of the *Gemini* capsule then fit into a docking collar on the *Agena*.

To avoid long delays between flights, *Gemini* spacecraft were made more serviceable, with subsystems that could be removed and replaced easily. An adapter module fitted to the rear of the capsule (and jettisoned before reentry) carried on-board oxygen, fuel and other consumable supplies.

Gemini gave U.S. astronauts their first real experience with living and working in space. They had to learn to sleep and keep house on long flights in crowded quarters, both of which were difficult. *Gemini* astronauts also made the first forays outside their spacecraft, which required a new spacesuit design. Space walks proved more difficult than expected—following Ed White's successful solo on *Gemini IV*, it wasn't until the final *Gemini* flight that another extravehicular activity went as smoothly as planned.

By *Gemini's* end, an important new capability—orbital rendezvous and docking—had become routine, and space doctors had gained confidence that humans could live, work and stay healthy in space for days or even weeks at a time. *Gemini* also completed a long list of on-board science experiments, including studies of the space environment and Earth photography. Above all, the program added nearly 1,000 hours of valuable space-flight experience in the years between *Mercury* and *Apollo*, which by 1966 was nearing flight readiness. Five days before the launch of the last *Gemini*, Lunar Orbiter 2 had been sent to the Moon, already scouting out *Apollo* landing sites.



The *Gemini* spacecraft had room for two astronauts: Cernan (l) and Stafford prepare for *Gemini IX*.

1965

- March 23: ***Gemini III* (*Molly Brown*)**, First manned *Gemini* flight
- June 3-7: ***Gemini IV***, First U.S. space-walk
- June: First six scientist-astronauts chosen (Group 4)
- August 21-29: ***Gemini V***
- December 4-18: ***Gemini VII***
- December 15-16: ***Gemini VI***

The *Titan 2* booster lifted *Gemini* into orbit (*left*). During the *Gemini* missions, Mission Control (*above*) shifted to Houston.

Project Gemini

Dates: 1965-1966

Vehicles: *Titan 2* launcher
Gemini spacecraft

Number of People Flown: 20

Highlights: First orbital rendezvous and docking
First U.S. space-walk

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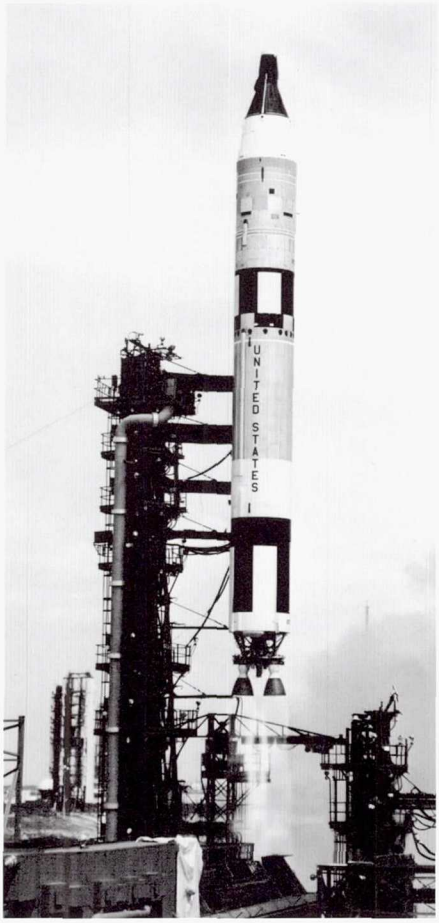
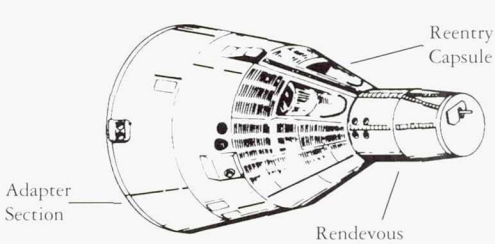
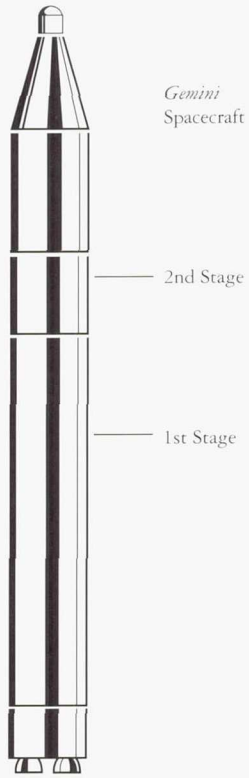




Gemini Spacecraft



Titan 2

1966

■ March 16: *Gemini VIII* First docking in orbit

■ June 3-6: *Gemini IX*

■ July 18-21: *Gemini X*

■ September 12-15: *Gemini XI*

November 11-15: *Gemini XII*, last *Gemini* flight ■

April: 19 pilot-astronauts chosen (Group 5)

Gemini 3

March 23, 1965
Crew: Virgil I. "Gus" Grissom and John W. Young

In a playful reference to the Broadway hit *The Unsinkable Molly Brown*, Grissom nicknamed the *Gemini 3* spacecraft "Molly Brown," hoping that it would not duplicate his experience with *Liberty Bell 7*. (It was the last *Gemini* to be named by an astronaut. All subsequent flights in the program were designated by a Roman numeral). The mission's primary goal was to test the new, maneuverable *Gemini* spacecraft. In space, the crew fired thrusters to change the shape of their orbit, shift their orbital plane slightly, and drop to a lower altitude. The spacecraft was supposed to have enough lift for a precision landing, but reality did not match wind tunnel predictions: *Gemini 3* splashed down some 80.47 kilometers short of its intended target. The capsule was designed to land on its side, suspended at two points from a parachute. But during the descent, when the astronauts threw a switch to shift "Molly Brown" to its landing position, they were thrown forward with such force that Grissom's faceplate cracked. Still, the first test of the two-seat spacecraft—and of *Gemini* ground operations—had been a success.

Gemini IV

June 3-7, 1965
Crew: James A. McDivitt and Edward H. White II

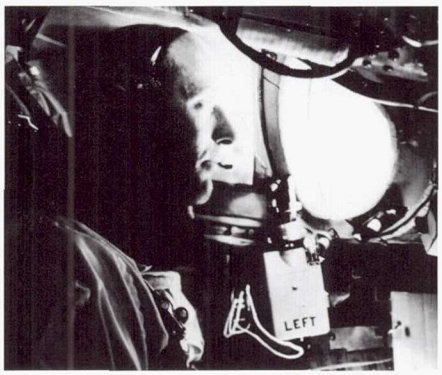
The plan for this four-day, 62-orbit mission was for *Gemini* to fly in formation with the spent second stage of its *Titan 2* booster in orbit. On this first attempt, however, space-flight engineers learned something about the complication of orbital rendezvous. Thrusting toward their target, the astronauts only moved farther away. They finally gave up after using nearly half their fuel. (On later rendezvous missions, a spacecraft chasing another in orbit would first drop to a lower, faster orbit before rising again.) The mission's highlight was White's 22-minute space-walk, the first ever for an American. Tied to a tether and using a handheld "zip gun" to maneuver himself, White swam through space while McDivitt took photographs. *Gemini IV* set a record for flight duration, and eased fears about the medical consequences of longer missions. It also was the first use of the new Mission Control Center outside Houston, which because of the long duration, had to conduct the first three-shift operations.

Gemini V

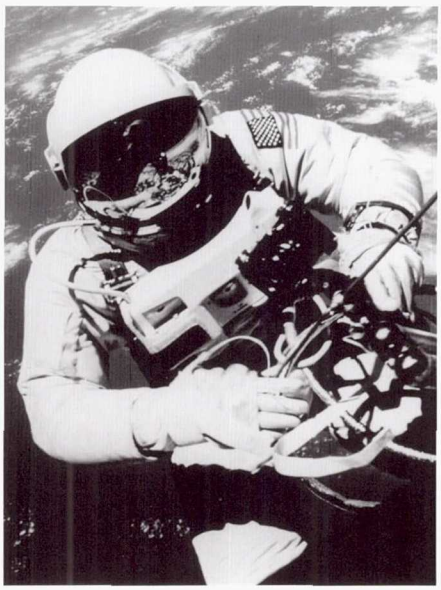
August 21-29, 1965
Crew: L. Gordon Cooper, Jr. and Charles "Pete" Conrad, Jr.

Gemini V doubled the space-flight record to eight days, thanks to new fuel cells that generated enough electricity to power longer missions. Cooper and Conrad were to have made a practice rendezvous with a "pod" deployed from the spacecraft, but problems with the electricity supply forced a switch to a simpler "phantom rendezvous," whereby the *Gemini* maneuvered to a predetermined position in space. *Mercury* Veteran Gordon Cooper was the first person to travel into space twice. He and Conrad took high-resolution photographs for the Defense Department, but problems with the fuel cells and maneuvering system forced the cancellation of several other experiments. The astronauts found themselves marking time in orbit, and Conrad later lamented that he had not brought along a book. On-board medical tests, however, continued to show the feasibility of longer flights.

Gemini VII: Lovell (left) and Borman



Gemini IX: Stafford in flight.



Gemini IV: White Steps out.

Gemini VII

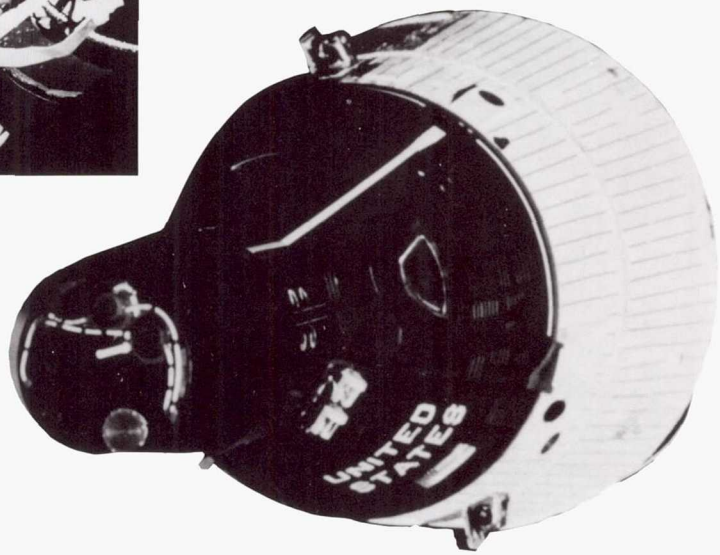
December 4-18, 1965
Crew: Frank Borman and James A. Lovell, Jr.

This 14-day mission required NASA to solve problems of long-duration space flight, not the least of which was stowage (the crew had practiced stuffing waste paper behind their seats before the flight). Timing their workday to match that of ground crews, both men worked and slept at the same time. *Gemini VII* flew the most experiments—20—of any *Gemini* mission, including studies of nutrition in space. The astronauts also evaluated a new, lightweight spacesuit, which proved uncomfortable if worn for a long time in *Gemini's* hot, cramped quarters. The high point of the mission was the rendezvous with *Gemini VI*. But the three days that followed were something of an endurance test, and both astronauts, heeding Pete Conrad's *Gemini V* advice, brought books along. *Gemini VII* was the longest space flight in U.S. history, until the *Skylab* missions of the 1970s.

Gemini VI

December 15-16, 1965
Crew: Walter M. Schirra, Jr. and Thomas P. Stafford

A rendezvous and docking with an unmanned *Agena* target was this mission's original objective, but when Mission Control lost contact with the *Agena* during an October launch attempt, an alternate mission was substituted: a meeting in space of two *Gemini* spacecraft. Eight days after the launch of Borman and Lovell's *Gemini VII*, Schirra and Stafford tried to join them, but their *Titan 2* launcher shut down on the pad (the cool-headed Schirra did not eject, even though the countdown clock had started ticking—he felt no motion, and trusted his senses). Three days later, *Gemini VI* made it into orbit. Using guidance from the computer as well as his own piloting, Schirra rendezvoused with the companion spacecraft in orbit on the afternoon of December 15. Once in formation, the two *Gemini* capsules flew around each other, coming within 0.3048 meters of each other but never touching. The two spacecraft stayed in close proximity for five hours. One of *Gemini's* primary goals—orbital rendezvous—had been achieved.



Gemini VIII

March 16, 1966

Crew: Neil A. Armstrong and David R. Scott

A second major objective of the *Gemini* program was completed less than six hours after launch, when Neil Armstrong brought *Gemini VIII* within 0.9144 meters of the pre-launched *Agena* target, then slowly docked—the first orbital docking ever. What followed, however, were some of the most hair-raising few minutes in space-program history. The *Gemini* capsule, still docked to the *Agena*, began rolling continuously. Never having faced this in simulation, the crew undocked from the *Agena*, but the problem was a stuck thruster on the *Gemini*, which now tumbled even faster, at the dizzying rate of one revolution per second. The only way to stop the motion was to use the capsule's reentry control thrusters, which meant that Armstrong and Scott had to cut short their mission and make an emergency return to Earth 10 hours after launch. They were still nauseated after splashdown, as well as disappointed: Scott had missed out on a planned space-walk.

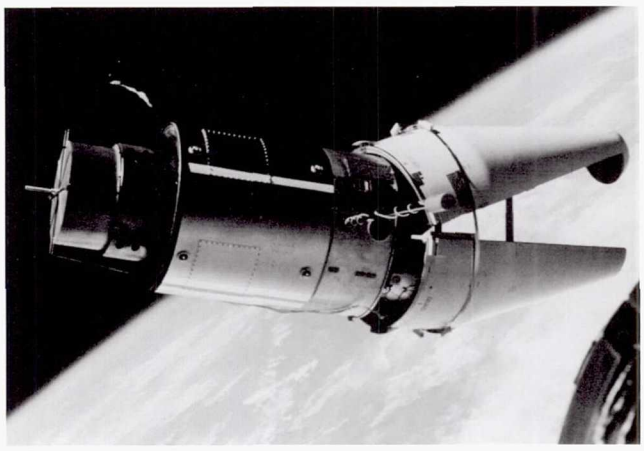
Gemini IX

June 3-6, 1966

Crew: Thomas P. Stafford and Eugene A. Cernan

Stafford and Cernan became the first backup crew to fly in space after the first crew of Elliott See and Charles Bassett died in a plane crash four months before the flight. The highlight of the mission was to have been a docking with a shortened *Agena* called the Augmented Target Docking Adapter. The docking was canceled, though, after Stafford and Cernan rendezvoused with the target to find its protective shroud still attached, which made it look, in Stafford's words, like an "angry alligator." Cernan also was to have tested an Astronaut Maneuvering Unit (AMU)—a jet-powered backpack stowed outside in *Gemini's* adapter module, to which the space-walking astronaut was to have strapped himself. But Cernan's space-walk was troubled from the start. His visor fogged, he sweated and struggled with his tasks, and he had problems moving in microgravity. Everything took longer than expected, and Cernan had to go inside before getting a chance to fly the AMU. The device was not finally tested in space until *Skylab*, seven years later.

Gemini III: Young (left) and Grissom ready themselves for launch.



Gemini IX: The "angry alligator."

Gemini X

July 18-21, 1966
Crew: John W. Young and Michael Collins

Gemini X established that radiation at high altitude was not a problem. After docking with their *Agena* booster in low orbit, Young and Collins used it to climb another 482.8032 kilometers to meet with the dead, drifting *Agena* left over from the aborted *Gemini VIII* flight—thus executing the program's first double rendezvous. With no electricity on board the second *Agena*, the rendezvous was accomplished with eyes only—no radar. After the rendezvous, Collins space-walked over to the dormant *Agena* at the end of a 15.24 meter tether, making Collins the first person to meet another spacecraft in orbit. He retrieved a cosmic dust-collecting panel from the side of the *Agena*, but returned no pictures of his close encounter—in the complicated business of keeping his tether clear of the *Gemini* and *Agena*, Collins' Hasselblad camera worked itself free and drifted off into orbit.

Gemini XI

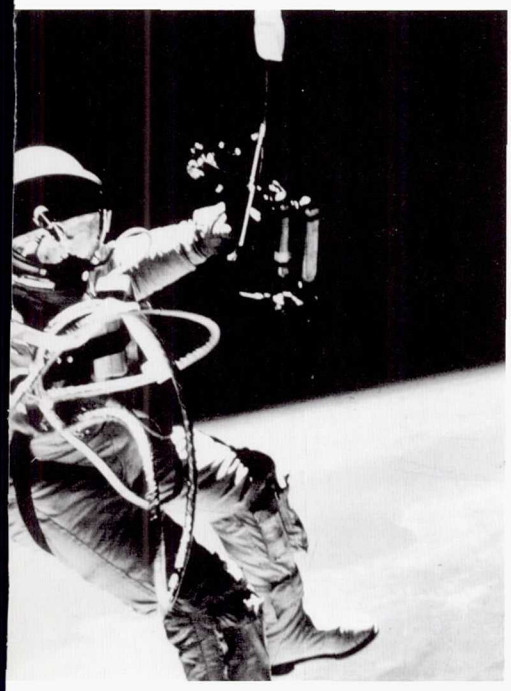
September 12-15, 1966
Crew: Charles "Pete" Conrad, Jr. and Richard F. Gordon, Jr.

With *Apollo* looming on the horizon, *Gemini* project managers wanted to accomplish a rendezvous immediately after reaching orbit, just as it would have to be done around the Moon. Only 85 minutes after launch, Conrad and Gordon matched orbits with their *Agena* target stage and docked several times. Conrad had originally hoped for a *Gemini* flight around the Moon, but had to settle for the highest Earth orbit—1367.94 kilometers—ever reached by an American manned spacecraft. Gordon's first space-walk once again proved more difficult than ground simulations, and had to be cut short when he became overtired. A second, two-hour "stand-up" space-walk went more smoothly: Gordon even fell asleep while floating halfway out the hatch. An experiment to link the *Agena* and *Gemini* vehicles with a 15.24 meter tether (which Gordon had attached during his space-walk) and rotate the joined pair was troublesome—Conrad had problems keeping the tether taut—but was able to generate a modicum of "artificial gravity." The mission ended with the first totally automatic, computer-controlled reentry, which brought *Gemini XI* down only 4.506 kilometers from its recovery ship.

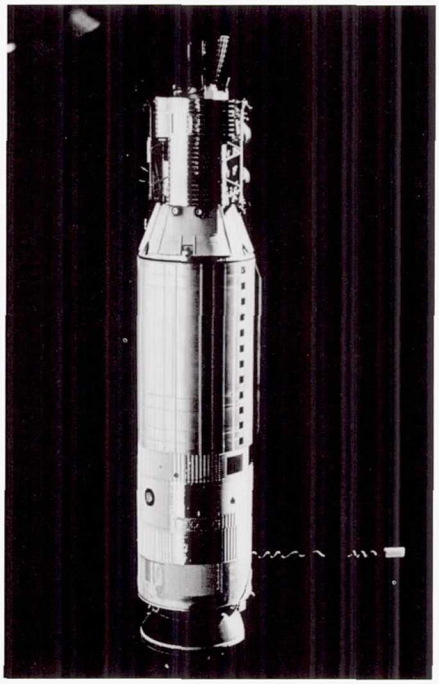
Gemini XII

November 11-15, 1966
Crew: James A. Lovell, Jr. and Edwin E. "Buzz" Aldrin, Jr.

By the time of the last *Gemini* flight, the program still had not demonstrated that an astronaut could work easily and efficiently outside the spacecraft. In preparation for *Gemini XII*; new, improved restraints were added to the outside of the capsule, and a new technique—underwater training—was introduced, which would become a staple of all future space-walk simulation. Aldrin's two-hour, 20-minute tethered space-walk, during which he photographed star fields, retrieved a micrometeorite collector and did other chores, at last demonstrated the feasibility of extravehicular activity. Two more stand-up EVAs also went smoothly, as did the by-now routine rendezvous and docking with an *Agena*, which was done "manually" using the on-board computer and charts when a rendezvous radar failed. The climb to a higher orbit, however, was canceled because of a problem with the *Agena* booster.



Gemini IV: The first U.S. Space-walk.



Gemini VII: *Agena* target in orbit.

Apollo

The *Apollo* program had been underway since July 1960, when NASA announced a follow-on to *Mercury* that would fly astronauts around the Moon. But with President John F. Kennedy's speech of May 25, 1961, declaring the goal of landing an astronaut on the surface of the Moon and returning to Earth by decade's end, *Apollo* shifted its focus. That goal was achieved with five months to spare, when, on July 20, 1969, Neil Armstrong and Edwin "Buzz" Aldrin touched down in the Sea of Tranquility.

Apollo was one of the great triumphs of modern technology. Six expeditions landed on the Moon, and one—*Apollo 13*—was forced to return without landing. Before that, there had been two manned checkouts of *Apollo* hardware in Earth orbit and two lunar orbit missions.

The *Apollo* lunar module, or LM, was the first true spacecraft—designed to fly only in a vacuum, with no aerodynamic qualities whatsoever. Launched attached to the *Apollo* command/service module, it separated in lunar orbit and descended to the Moon with two astronauts inside. At the end of their stay on the surface, the lunar module's ascent stage fired its own rocket to rejoin the command/service module in lunar orbit.

The teardrop-shaped *Apollo* command module, the living quarters for the three-man crews, had a different shape from the conical-nosed *Gemini* and *Mercury*. The attached cylindrical service module contained supplies as well as the Service Propulsion System engine that placed the vehicle in and out of lunar orbit.

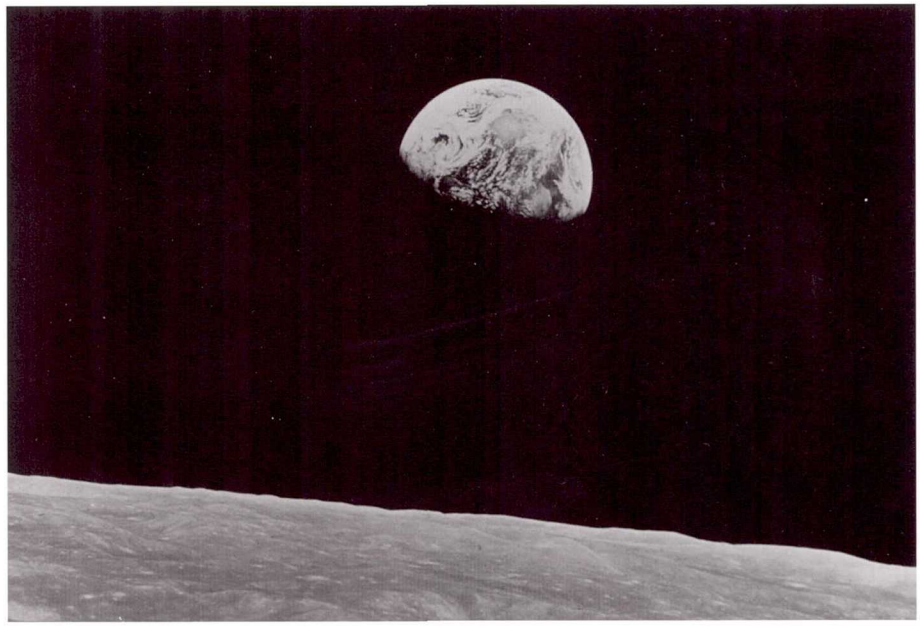
Boosting the *Apollo* vehicles to the Moon was the job of the giant *Saturn* V—the first launch vehicle large enough that it had to be assembled away from the launch pad and transported there. A fueled *Saturn V* weighed more than six million pounds at liftoff, and stood 110.64 meters high with the *Apollo* vehicles on top. The vehicle had three stages: the S-1C, S-II, and S-IVB, the last of which burned to send *Apollo* out of Earth orbit and on its way to the Moon.

The *Apollo* program greatly increased the pace and complexity of ground operations, both before launch and during the missions, when ground controllers had to track two spacecraft at the same time. The lunar missions also required extensive training. *Apollo* astronauts logged some 84,000 hours—nearly 10 man-years—practicing for their flights: everything from simulations of lunar gravity, to geology field trips, to flying the lunar lander training vehicle.

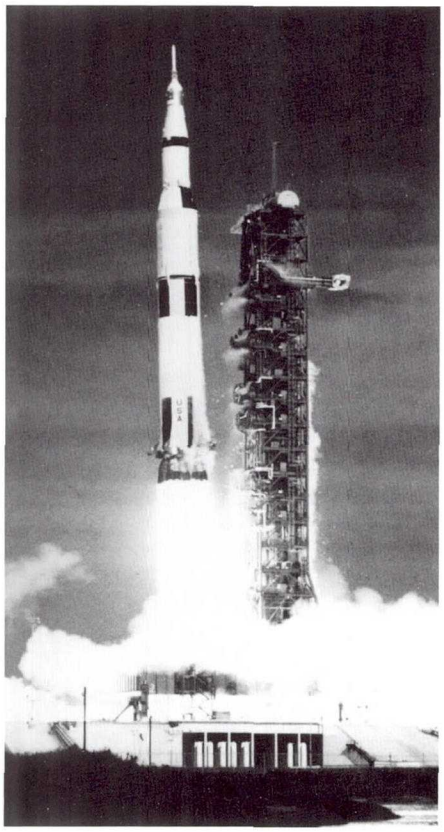
On January 27, 1967, just as the program was nearing readiness for its first manned flight, tragedy struck. A fire inside an *Apollo* command module took the lives of astronauts Virgil "Gus" Grissom, Edward White and Roger Chaffee, who were training inside it at the time. The fire resulted in delays and modifications to the spacecraft, but by October 1968, *Apollo 7* was ready to carry three astronauts into Earth orbit, where they checked out the command/service module (both had been tested in an unmanned mode during the November 1967 *Apollo 4* mission, which also was the first flight of the *Saturn V*). By December 1968, *Apollo 8* was ready to try for lunar orbit (on the *Saturn V's* third outing), and seven months later *Apollo 11* made the first lunar landing.

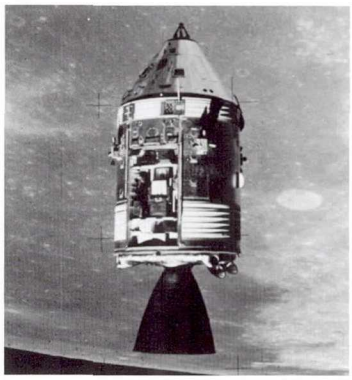
By the time the *Apollo* program ended in 1972, astronauts had extended the range and scope of their lunar explorations. The final three missions were far more sophisticated than the first three, in large part because the astronauts carried a lunar rover that allowed them to roam miles from their base. *Apollo 11's* Armstrong and Aldrin spent only two-and-a-half hours walking on the surface. On *Apollo 17* the Moon walks totaled 22 hours, and the astronauts spent three days "camped out" in the Moon's Taurus-Littrow valley.

After six lunar landings the *Apollo* program came to a conclusion (*Apollo 18, 19* and *20* missions had been canceled in 1970 because of budget limitations), and with it ended the first wave of human exploration of the Moon.



Earthrise from *Apollo 8*.





Tools of *Apollo*: The *Saturn V* (*left*); command/service module (*above*); and lunar rover (*below*).

Project Apollo

Dates: 1967-1972

Vehicles: *Saturn IB* and *Saturn V* launch vehicles

Apollo command/service module

Lunar module

Number of People Flown: 33

Highlights: First humans to leave Earth orbit

First human landing on the Moon

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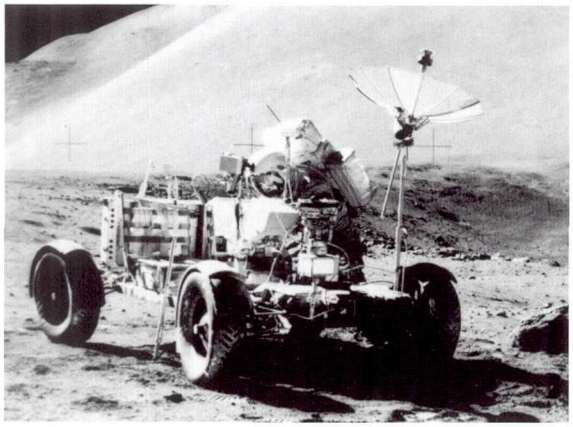
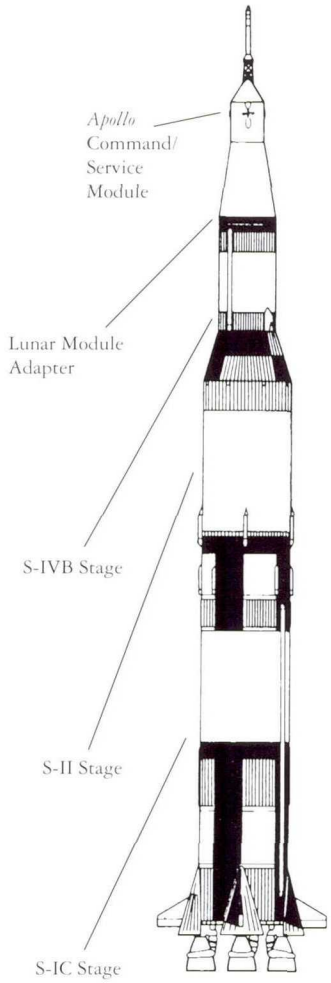
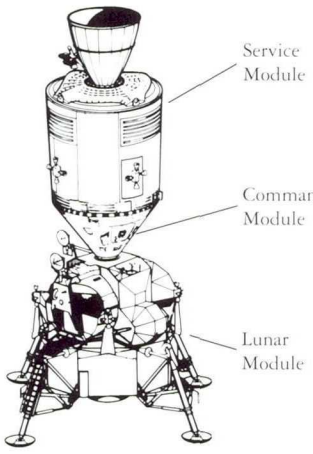




Apollo Saturn V



Apollo Spacecraft

Apollo 7

October 11-22, 1968
Crew: Walter M. Schirra, Jr., Donn F. Eisele, Walter Cunningham

Apollo 7 was a confidence-builder. After the January 1967 *Apollo* launch pad fire, the *Apollo* command module had been extensively redesigned. Schirra, the only astronaut to fly *Mercury, Gemini* and *Apollo* missions, commanded this Earth-orbital shakedown of the command and service modules. With no lunar lander, *Apollo 7* was able to use the *Saturn IB* booster rather than the giant *Saturn V*. The *Apollo* hardware and all mission operations worked without any significant problems, and the Service Propulsion System (SPS)—the all-important engine that would place *Apollo* in and out of lunar orbit—made eight nearly perfect firings. Even though *Apollo's* larger cabin was more comfortable than *Gemini's*, eleven days in orbit took its toll on the astronauts. The food was bad, and all three developed colds. But their mission proved the spaceworthiness of the basic *Apollo* vehicle.

Apollo 8

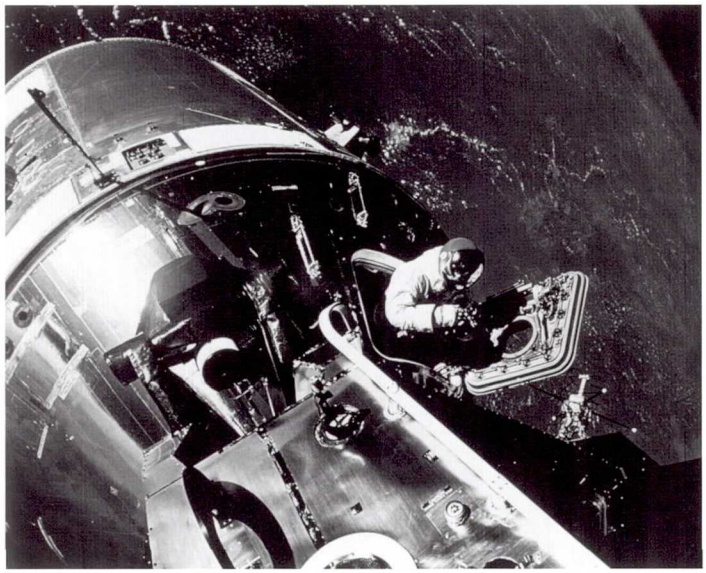
December 21-27, 1968
Crew: Frank Borman, James A. Lovell, Jr., William A. Anders

The *Apollo 8* astronauts were the first human beings to venture beyond low Earth orbit and visit another world. What was originally to have been an Earth-orbit checkout of the lunar lander became instead a race with the Soviets to become the first nation to orbit the Moon. The *Apollo 8* crew rode inside the command module, with no lunar lander attached. They were the first astronauts to be launched by the *Saturn V*, which had flown only twice before. The booster worked perfectly, as did the SPS engines that had been checked out on *Apollo 7*. *Apollo 8* entered lunar orbit on the morning of December 24, 1968. For the next 20 hours the astronauts circled the Moon, which appeared out their windows as a gray, battered wasteland. They took photographs, scouted future landing sites, and on Christmas Eve read from the Book of Genesis to TV viewers back on Earth. They also photographed the first Earthrise as seen from the Moon. *Apollo 8* proved the ability to navigate to and from the Moon, and gave a tremendous boost to the entire *Apollo* program.

Apollo 9

March 3-13, 1969
Crew: James A. McDivitt, David R. Scott, Russell L. Schweickart

Apollo 9 was the first space test of the third critical piece of *Apollo* hardware—the lunar module. For ten days, the astronauts put all three *Apollo* vehicles through their paces in Earth orbit, undocking and then redocking the lunar lander with the command module, just as they would in lunar orbit. For this and all subsequent *Apollo* flights, the crews were allowed to name their own spacecraft. The gangly lunar module was "Spider," the command module "Gumdrop." Schweickart and Scott performed a spacewalk, and Schweickart checked out the new *Apollo* spacesuit, the first to have its own life support system rather than being dependent on an umbilical connection to the spacecraft. *Apollo 9* gave proof that the *Apollo* machines were up to the task of orbital rendezvous and docking.



Apollo 9: Scott leaves the command/service module in Earth orbit.

Apollo 11: First on the moon.

Apollo 10

May 18-26, 1969
Crew: Thomas P. Stafford, John W. Young, Eugene A. Cernan

This dress rehearsal for a Moon landing brought Stafford and Cernan's lunar module—nicknamed "Snoopy"—to within nine miles of the lunar surface. Except for that final stretch, the mission went exactly as a landing would have, both in space and on the ground, where *Apollo's* extensive tracking and control network was put through a dry run. Shortly after leaving low Earth orbit, the LM and the command/service module separated, then redocked, top to top. Upon reaching lunar orbit, they separated again. While Young orbited the Moon alone in his command module "Charlie Brown," Stafford and Cernan checked out the LM's radar and ascent engine, rode out a momentary gyration in the lunar lander's motion (due to a faulty switch setting), and surveyed the *Apollo 11* landing site in the Sea of Tranquility. This test article of the lunar module was not equipped to land, however. *Apollo 10* also added another first—broadcasting live color TV from space.

Apollo 11

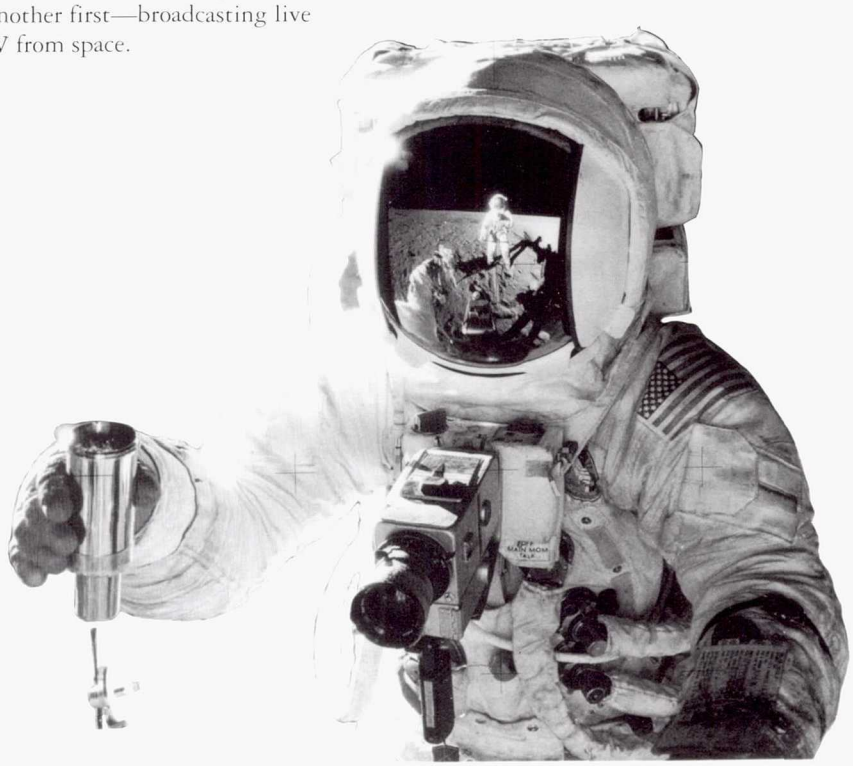
July 16-24, 1969
Crew: Neil A. Armstrong, Michael Collins, Edwin E. "Buzz" Aldrin, Jr.

Half of *Apollo's* primary goal—a safe return—was achieved at 4:17 p.m. Eastern Daylight Time on July 20, when Armstrong piloted "Eagle" to a touchdown on the Moon, with less than 30 seconds' worth of fuel left in the lunar module. Six hours later, Armstrong took his famous "one giant leap for mankind." Aldrin joined him, and the two spent two-and-a-half hours drilling core samples, photographing what they saw and collecting rocks. After more than 21 hours on the lunar surface, they returned to Collins on board "Columbia," bringing 20.87 kilograms of lunar samples with them. The two Moon-walkers had left behind scientific instruments, an American flag and other mementos, including a plaque bearing the inscription: "Here Men From Planet Earth First Set Foot Upon the Moon. July 1969 A.D. We Came in Peace For All Mankind."

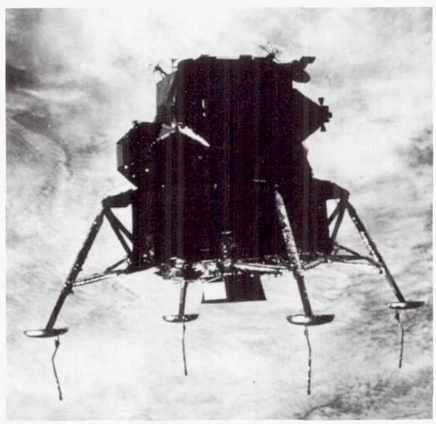
Apollo 12

November 14-24, 1969
Crew: Charles "Pete" Conrad, Jr., Richard F. Gordon, Jr., Alan L. Bean

The second lunar landing was an exercise in precision targeting. The descent was automatic, with only a few manual corrections by Conrad. The landing, in the Ocean of Storms, brought the lunar module "Intrepid" within walking distance—182.88 meters—of a robot spacecraft that had touched down there two-and-a-half years earlier. Conrad and Bean brought pieces of the *Surveyor 3* back to Earth for analysis, and took two Moon-walks lasting just under four hours each. They collected rocks and set up experiments that measured the Moon's seismicity, solar wind flux and magnetic field. Meanwhile Gordon, on board the "Yankee Clipper" in lunar orbit, took multispectral photographs of the surface. The crew stayed an extra day in lunar orbit taking photographs. When "Intrepid's" ascent stage was dropped onto the Moon after Conrad and Bean rejoined Gordon in orbit, the seismometers the astronauts had left on the lunar surface registered the vibrations for more than an hour.



Apollo 12: Sampling the lunar soil.

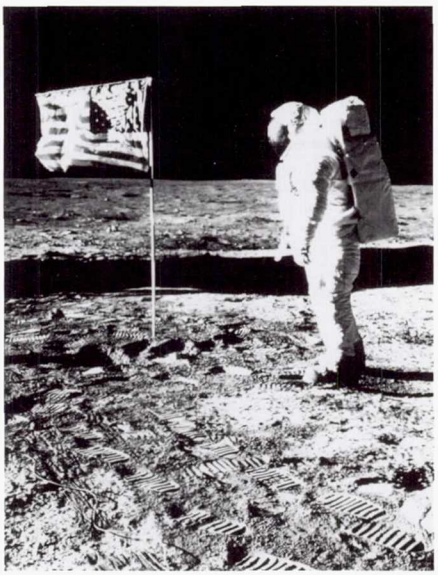


Apollo 9: Checking out the lunar module in Earth orbit.

Apollo 13

April 11-17, 1970
Crew: James A. Lovell, Jr., Fred W. Haise, Jr., John L. Swigert, Jr.

The crew's understated radio message to Mission Control was "Okay, Houston, we've had a problem here." Within 321,860 kilometers of Earth, an oxygen tank in the service module exploded. The only solution was for the crew to abort their planned landing, swing around the Moon and return on a trajectory back to Earth. Since their command module "Odyssey" was almost completely dead, however, the three astronauts had to use the lunar module "Aquarius" as a crowded lifeboat for the return home. The four-day return trip was cold, uncomfortable and tense. But *Apollo 13* proved the program's ability to weather a major crisis and bring the crew back home safely.



Apollo 11: Aldrin plants the flag.

Apollo 14

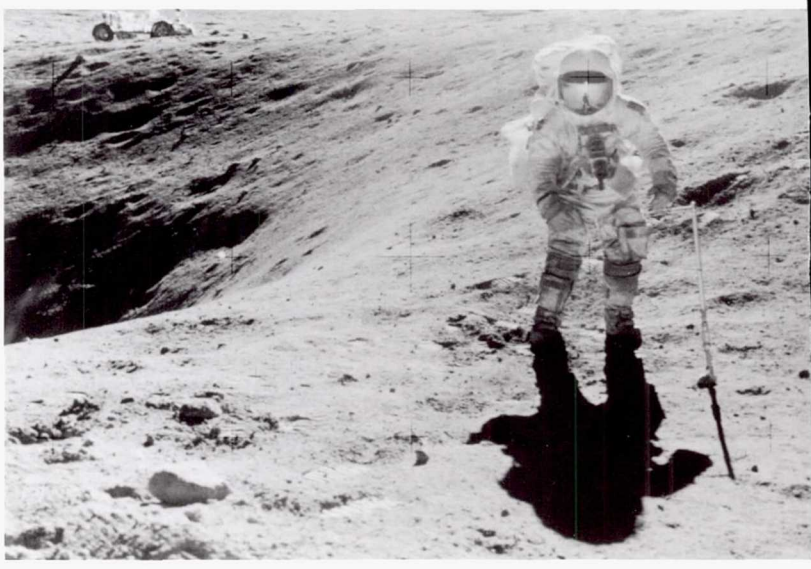
January 31-February 9, 1971
Crew: Alan B. Shepard, Jr., Stuart A. Roosa, Edgar D. Mitchell

After landing in the Fra Mauro region—the original destination for *Apollo 13*—Shepard and Mitchell took two Moon-walks, adding new seismic studies to the by-now familiar *Apollo* experiment package, and using a "lunar rickshaw" pull-cart to carry their equipment. A planned rock-collecting trip to the 1,000-foot-wide Cone Crater was dropped, however, when the astronauts had trouble finding their way around the lunar surface. Although later estimates showed that they had made it to within 30.48 meters of the crater's rim, the explorers had become disoriented in the alien landscape. Roosa, meanwhile, took pictures from on board command module "Kitty Hawk" in lunar orbit. On the way back to Earth, the crew conducted the first U.S. materials processing experiments in space. The *Apollo 14* astronauts were the last lunar explorers to be quarantined on their return from the Moon.

Apollo 15

July 26-August 7, 1971
Crew: David R. Scott, James B. Irwin, Alfred M. Worden

The first of the longer, expedition-style lunar landing missions was also the first to include the lunar rover, a car-like vehicle that extended the astronauts' range. The lunar module *Falcon* touched down near the sinuous channel known as Hadley Rille. Scott and Irwin rode more than 27.36 kilometers in their rover, and had a free hand in their geological field studies compared to earlier lunar astronauts. They brought back one of the prize trophies of the *Apollo* program—a sample of ancient lunar crust nicknamed the "Genesis Rock." *Apollo 15* also launched a small subsatellite for measuring particles and fields in the lunar vicinity. On the way back to Earth, Worden, who had flown solo on board *Endeavour* while his crewmates walked on the surface, conducted the first space-walk between Earth and the Moon to retrieve film from the side of the spacecraft.

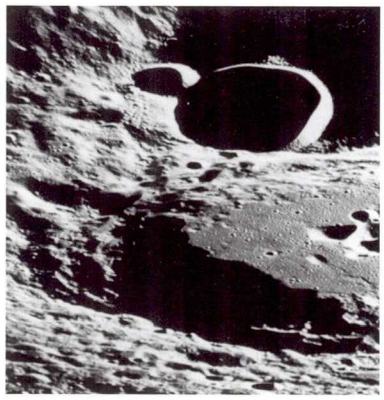


Apollo 16: Duke exploring the Plum Crater.

Apollo 16

April 16-27, 1972
Crew: John W. Young, Thomas K. Mattingly II, Charles M.Duke ,Jr.

A malfunction in the main propulsion system of the lunar module "Orion" nearly caused their Moon landing to be scrubbed, but Young and Duke ultimately spent three days exploring the Descartes highland region, while Mattingly circled overhead in "Casper." What was thought to have been a region of volcanism turned out not to be, based on the astronauts' discoveries. Their collection of returned specimens included a 11.34 kilograms chunk that was the largest single rock returned by the *Apollo* astronauts. The *Apollo 16* astronauts also conducted performance tests with the lunar rover, at one time getting up to a top speed of 17.70 kilometers per hour.

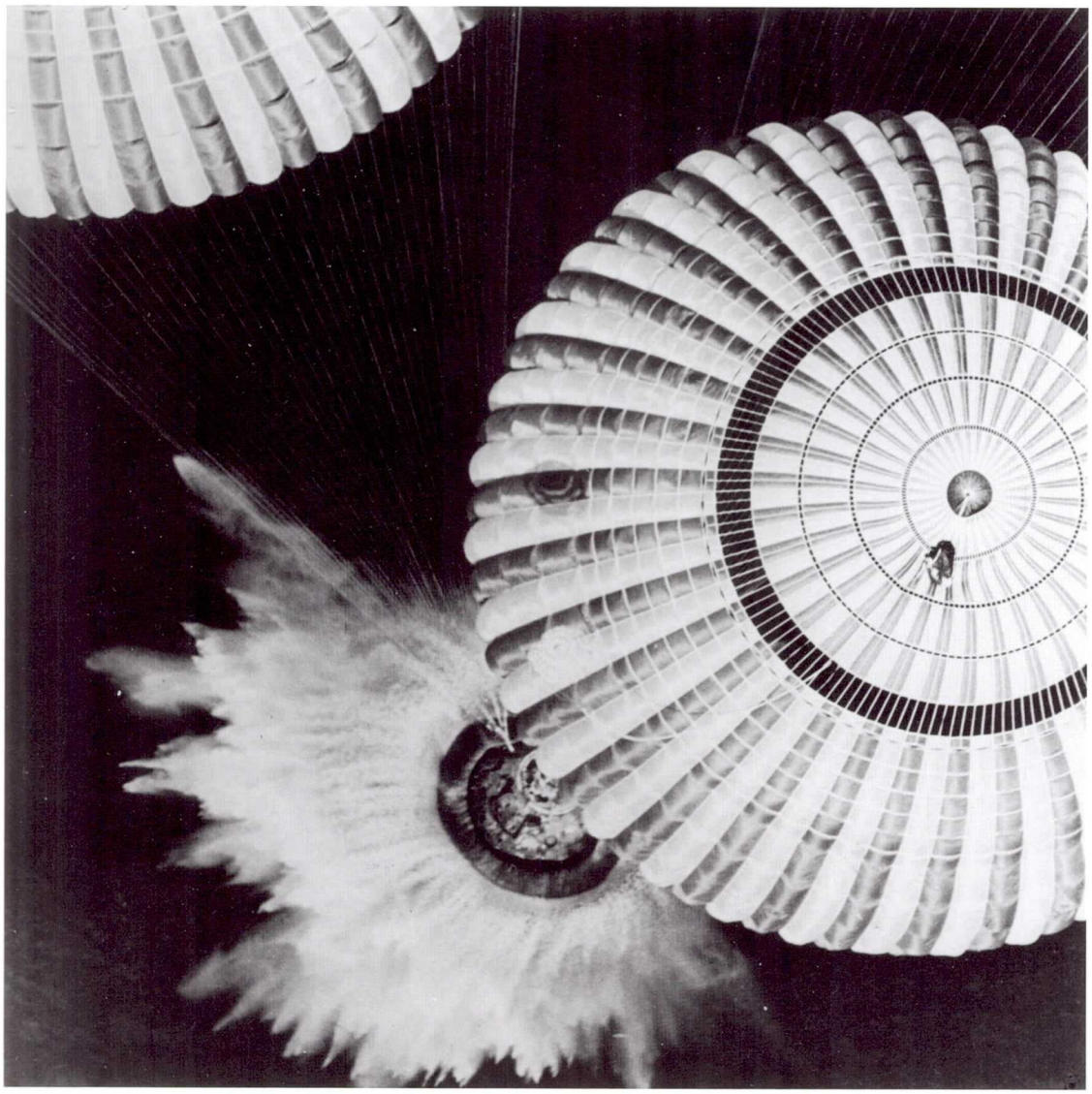


Apollo 11: Craters on the lunar far side.

Apollo 17

December 7-19, 1972
Crew: Eugene A. Cernan, Ronald E. Evans, Harrison H. "Jack" Schmitt

The last man to set foot on the Moon was also the first scientist—astronaut/geologist Harrison Schmitt. While Evans circled in "America," Schmitt and Cernan collected a record 108.86 kilograms of rocks during three Moon-walks. The crew roamed for 33.80 kilometers through the Taurus-Littrow valley in their rover, discovered orange-colored soil, and left behind a plaque attached to their lander *Challenger*, which read: "Here Man completed his first exploration of the Moon, December 1972 A.D. May the spirit of peace in which we came be reflected in the lives of all mankind." The *Apollo* lunar program had ended.



Apollo 17: Splashdown in the Pacific.

NASA had studied concepts for space stations, including an inflatable donut-shaped station, since the earliest days of the space program. But it wasn't until the Saturn rocket came into existence in the mid-1960s that the *Skylab* program was born. Initially called the *Apollo* Applications Program, *Skylab* was designed to use left-over *Apollo* lunar hardware to achieve extended stays by astronauts in Earth orbit.

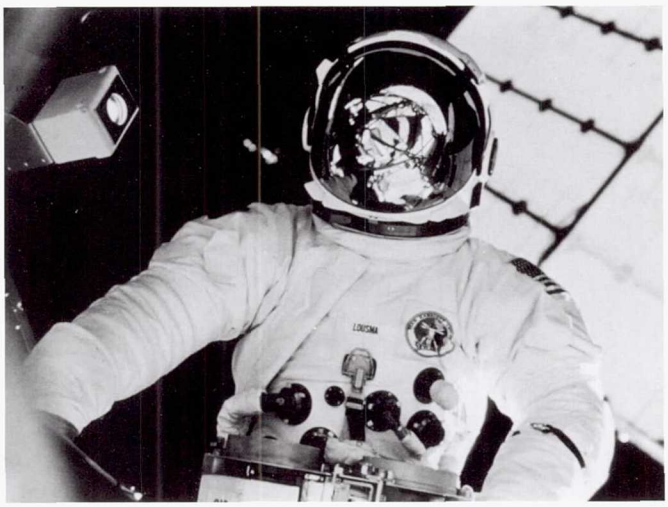
At first there were two competing concepts: the so-called "wet" workshop, where a *Saturn IB* would be launched, fueled, and its S IV-B upper stage vented and refurbished in orbit; and the "dry" workshop, where the outfitting of an empty S IV-B stage would be done on the ground beforehand and launched on a *Saturn V*. In July 1969, while the *Apollo 11* astronauts were completing their historic lunar landing mission, program managers made their decision: the "dry" workshop concept won out.

The *Skylab* space station weighed approximately 100 tons. It was placed into orbit by the *Saturn V*, the last time that giant launcher was used. Three separate astronaut crews then met up with the orbiting workshop using modified *Apollo* command and service modules launched by smaller Saturn IB rockets.

Skylab had a habitable volume of just over 283.17 cubic meters. It was divided into two levels separated by a metal floor—actually an open grid into which the astronauts' cleated shoes could be locked. The "upper" floor had storage lockers and a large empty volume for conducting experiments, plus two scientific airlocks, one pointing down at the Earth, the other toward the Sun. The lower floor had compartmented "rooms" with many of the comforts of home: a dining room table, three bedrooms, a work area, a shower and a bathroom.

The largest piece of scientific equipment, attached to one end of the cylindrical workshop, was the *Apollo* Telescope Mount, used to study the Sun in different wavelengths with no atmospheric interference. The ATM had its own electricity-generating solar panels.

Skylab also had an airlock module for space-walks (required for repairs, experiment deployments and routine changing of film in the ATM). The *Apollo* command/service module remained attached to the station's multiple docking adapter while the astronauts were on board.



Skylab 3: Lousma works outside the space station.

The space station itself was launched May 14, 1973 on the unmanned *Skylab 1* mission. Beginning only 63 seconds after the launch, however, the workshop's combination meteorite shield and sunshade was torn loose by aerodynamic stress, taking one of the two electricity-producing solar arrays with it and preventing the other from deploying properly. The crew was supposed to have launched the next day, but they waited on the ground for 10 days while a fix was worked out (see *Skylab 2*).

In the course of the next nine months, three different crews lived on board *Skylab* for one, two, then three months at a time. The station, which orbited at an altitude of 434.52 kilometers, was deactivated between flights. The nine Skylab astronauts chalked up a total of 513 man-days in orbit, during which they conducted thousands of experiments and observations, studying (in decreasing order of the amount of crew time spent): solar astronomy, life sciences, Earth observations, astrophysics, man/systems studies, Comet Kohoutek observations (*Skylab 4* only), materials science and student experiments.

Skylab showed the value of having humans working for long periods in orbit on a wide variety of scientific studies, and proved that they could survive the ordeal. More than five years after the last crew left, the empty *Skylab* station re-entered and burned up in the atmosphere on July 11, 1979.

Skylab 3: Garriott reading in the workshop's dome area.

Skylab

Dates: 1973-74

Vehicles: *Skylab* orbital workshop
Saturn IB launch vehicle (for crews)
Apollo command/service module

Number of People Flown: 9

Highlights: Longest duration space flights in U.S. history

Skylab Bibliography

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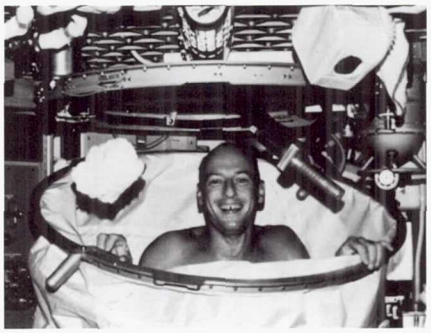
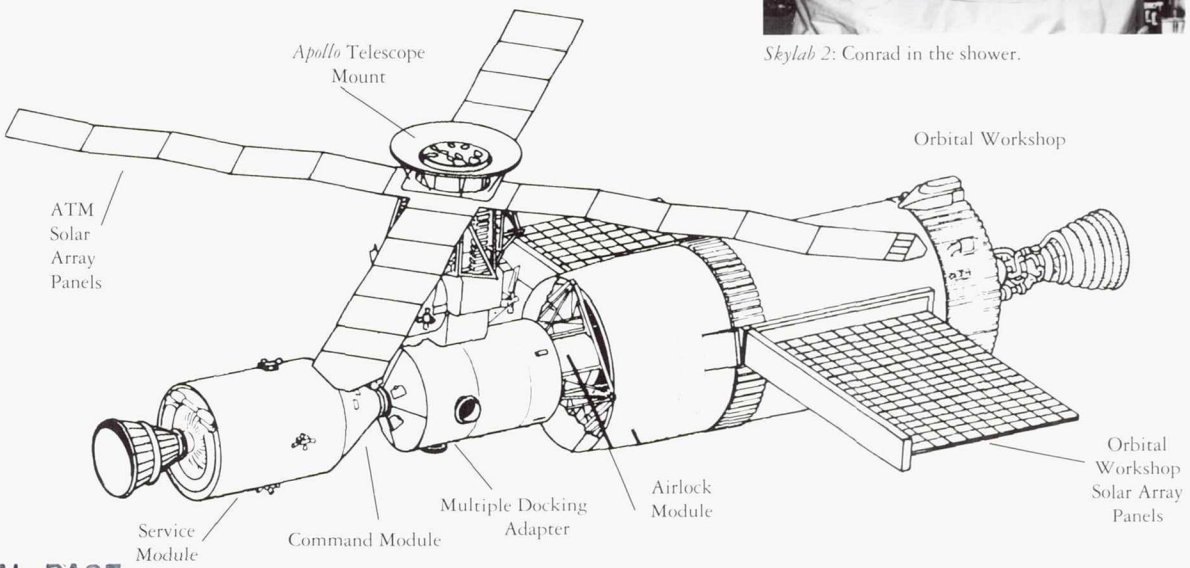


Skylab 2: Conrad in the shower.



Skylab

Skylab 2

May 25-June 22, 1973
Crew: Charles "Pete" Conrad, Jr., Paul J. Weitz, Joseph P. Kerwin

The first crew to visit the *Skylab* space station started their mission with home repairs. *Skylab's* meteorite and sunshield had torn loose during launch, and one of its two remaining solar panels was jammed (see above). Due to concerns that high temperatures inside the workshop—the result of no sunshield—would release toxic materials and ruin on-board film and food, the crew had to work fast. After a failed attempt to deploy the stuck solar panel, they set up a "parasol" as a replacement sunshade. The "fix" worked, and temperatures inside dropped low enough that the crew could enter. Two weeks later Conrad and Kerwin conducted a space-walk, and after a struggle, were able to free the stuck solar panel and begin electricity flowing to their new "home." For nearly a month they made further repairs to the workshop, conducted medical experiments, gathered solar and Earth science data and returned some 29,000 frames of film. The *Skylab 2* astronauts spent 28 days in space, which doubled the previous U.S. record.

Skylab 3

July 28-September 25, 1973
Crew: Alan L. Bean, Jack R. Lousma, Owen K. Garriott

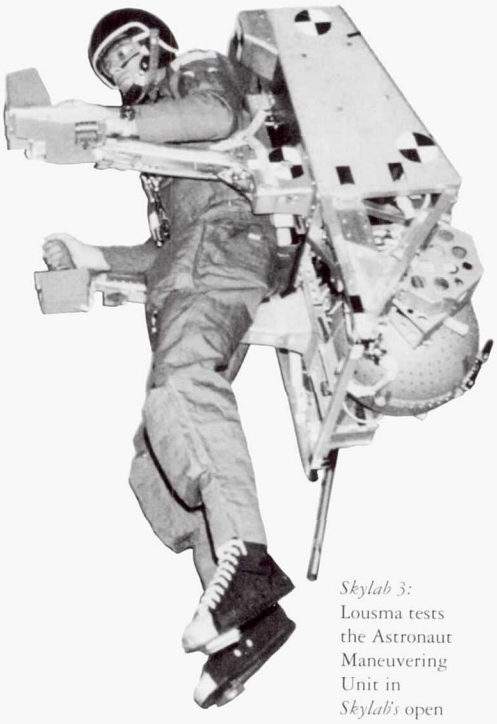
After an early bout of motion sickness, the three-man *Skylab 3* crew settled down to a 59-day stay on board the space station, during which Garriott and Lousma deployed a second sun shield on a space-walk lasting six and a half hours—the first and longest of three *Skylab 3* space-walks. During their two months in orbit, the astronauts continued a busy schedule of experiments, including a student experiment to see if spiders could spin webs in weightlessness (they could). They also tested a jet-powered Astronaut Maneuvering Unit (AMU) backpack inside the spacious volume of *Skylab's* forward compartment, which had been carried but never flown on *Gemini* missions in the 1960s. The AMU proved a capable form of one-man space transportation, and helped engineers design the more sophisticated Manned Maneuvering Unit used on the *Space Shuttle* in the 1980s.

Skylab 4

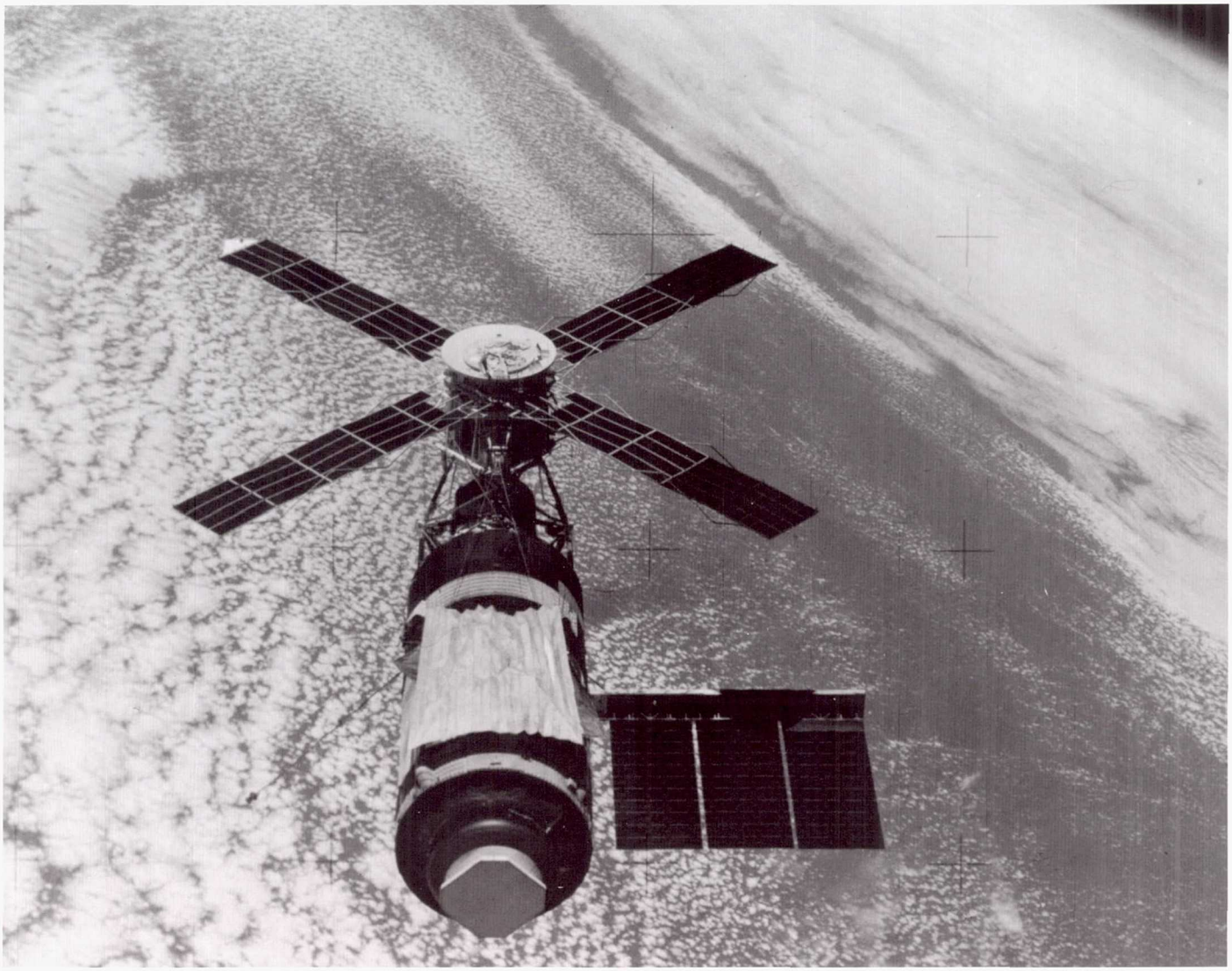
November 16, 1973-February 8, 1974
Crew: Gerald P. Carr, William R. Pogue, Edward G. Gibson

At 84 days, 1 hour, 15 minutes, and 31 seconds, *Skylab 4* remains the longest U.S. space flight to date. To help keep the crew in shape, a treadmill was added to the on-board bicyclelike ergometer. As a result of the exercise, the *Skylab 4* crew was in better physical condition upon their return to Earth than previous *Skylab* crews, even though an excessive work pace had caused some tension during the flight. Comet Kohoutek was among the special targets observed by the *Skylab 4* crew, as were a solar eclipse and solar flares. The astronauts also conducted four space-walks, including one on Christmas Day to view Kohoutek, and set records for time spent on experiments in every discipline from medical investigations to materials science.

Skylab 4: Carr, Gibson and Pogue after 84 days in orbit.



Skylab 3: Lousma tests the Astronaut Maneuvering Unit in *Skylab's* open dome area.



The orbiting space station as photographed by the *Skylab 4* astronauts.

The final mission of the *Apollo* era, in July 1975, was the first in which spacecraft from two nations rendezvoused and docked in orbit. The idea for this U.S./Soviet "handshake in space" had been initiated three years earlier with an agreement signed by U.S. President Nixon and Soviet President Kosygin.

The American crew for this goodwill flight included Thomas Stafford, a veteran of three flights, Vance Brand, who had never flown in space, and *Mercury* Astronaut Deke Slayton, the only one of the original seven astronauts who had never flown (due to a heart condition). The American astronauts traveled into orbit inside a three-man *Apollo* spacecraft.

Like the *Apollo* command module, the two-man *Soyuz* capsule flown by the Soviets had debuted in 1967. On board the Soviet spacecraft were Alexei Leonov, who had made history's first space-walk in 1965, and rookie Valeri Kubasov.

The *Apollo-Soyuz* mission, aside from its political significance, resulted in a number of technical developments, including a common docking system, which had to be specially designed so that the different spacecraft could connect in orbit. The joint mission also gave both "sides" a view of one another's space programs. In preparation for the flight, Soviet cosmonauts and their backups visited and trained at the Johnson Space Center, and the American crew and their backups paid visits to Moscow. Flight controllers from both nations also conducted joint simulations.

Although *Apollo-Soyuz* was a one-time-only event, it created a sense of goodwill that transcended the simple "handshake in space" that was its most visible symbol.

Apollo-Soyuz Test Project

July 15-24, 1975

Crew: Thomas P. Stafford, Vance D. Brand, Donald K. "Deke" Slayton

The *Soyuz 19* and *Apollo 18* craft launched within seven-and-a-half hours of each other on July 15, and docked on July 17. Three hours later, Stafford and Leonov exchanged the first international handshake in space through the open hatch of the *Soyuz*. The two spacecraft remained linked for 44 hours, long enough for the three Americans and two Soviets to exchange flags and gifts (including tree seeds which were later planted in the two countries), sign certificates, pay visits to each other's ships, eat together and converse in each other's languages. There were also docking and redocking maneuvers during which the *Soyuz* reversed roles and became the "active" ship. The Soviets remained in space for five days, the Americans for nine, during which the Soviets also conducted experiments in Earth observation.

Apollo-Soyuz: Stafford and Leonov meet in the connecting hatchway between their two ships.

Slayton and Leonov in the *Soyuz* Orbital Module.

Apollo-Soyuz Test Project

Date: 1975

Vehicles: *Saturn IB* launcher, *Apollo* command module

Number of People Flown: 3

Total Time in Space: 9 days

Highlights: First international space mission

ASTP Bibliography

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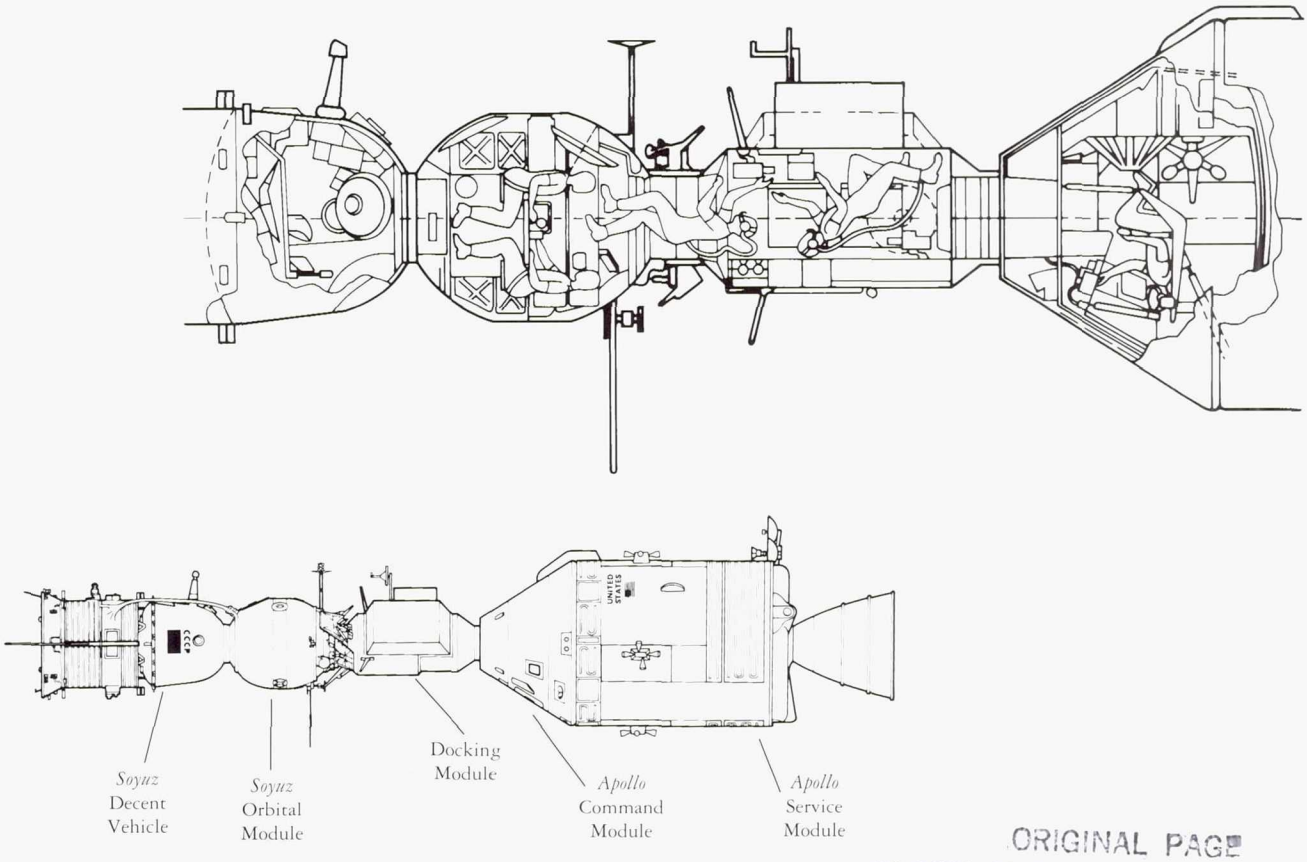


Apollo-Soyuz

1980

January: Second group of 19 *Space Shuttle* astronauts chosen

Before the *Space Shuttle,* launching cargo into space was a one-way proposition. Satellites could be sent into orbit, but could not return. The world's first reusable space vehicle—changed that, and revolutionized the way people worked in space.

The *Space Shuttle* was approved as a national program in 1972. Part spacecraft and part aircraft, it required several technological advances, including thousands of insulating tiles able to stand the heat of reentry over the course of many missions, and sophisticated engines that could be used again and again without being thrown away.

The airplane-like orbiter has three of these *Space Shuttle* Main Engines, which burn liquid hydrogen and oxygen stored in the large External Tank, the single largest structure in the Shuttle "stack." Attached to the tank are two Solid Rocket Boosters, which provide most of the vehicle's thrust at liftoff. Two minutes into the flight, the spent solids drop into the ocean to be recovered, while the orbiter's own engines continue burning until approximately eight minutes into the flight.

The Shuttle was developed throughout the 1970s. *Enterprise*, a test vehicle not suited for space flight, was used for approach and landing tests in 1977 that demonstrated the orbiter's aerodynamic qualities and ability to land (after separating from an airplane). The first spaceworthy Shuttle orbiter, *Columbia*, made its orbital debut in April 1981.

The first four missions of the new Space Transportation System (STS) were test flights to evaluate the Shuttle's engineering design, thermal characteristics and performance in space. Operational flights began with *STS-5* in November 1982, with a four-person crew on board. Over time the crews grew in size: five people flew on *STS-7* in 1983, six on *STS-9* later that same year. The first seven-person crew flew on *Mission 41-G* in 1984, and in 1985 eight people—a Shuttle record—flew on *Mission 61-A*.

The *Space Shuttle* changed the sociology of space flight. With such large crews, Shuttle astronauts were divided into two categories: pilots responsible for flying and maintaining the orbiter, and mission specialists responsible for experiments and payloads. A new class of space traveler, payload specialists—who are not even necessarily career astronauts—also was created to tend to specific on-board experiments.

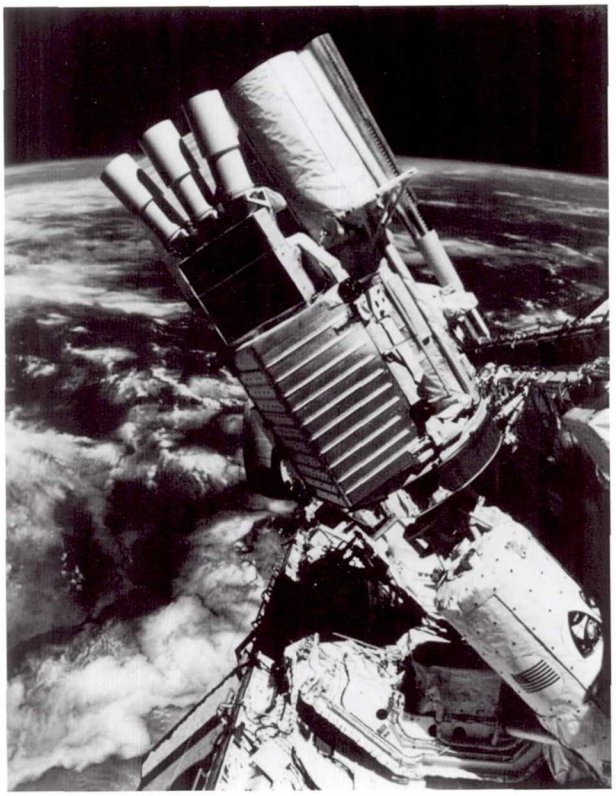
The reusable Shuttles together make up a fleet, with each vehicle continually being processed on the ground in preparation for its next flight. The second orbiter, *Challenger*, debuted in 1983, followed by *Discovery* in 1984 and *Atlantis* in 1985. A fifth orbiter, *Endeavour*, joined the fleet in 1991, to make its first flight in 1992.

The Space Transportation System introduced several new tools to the business of space flight. The Remote Manipulator System, a 15.24-meter crane built by the Canadian Space Agency and designed to mimic the human arm, is able to move large and heavy payloads in and out of the Shuttle's 18.29-meter-long cargo bay. The *Spacelab* module, built by the European Space Agency, provides a pressurized and fully equipped laboratory for scientists to conduct experiments ranging in subject matter from astronomy to materials science to biomedical investigations. The Manned Maneuvering Unit backpack allows space-walking astronauts to "fly" up to several hundred meters from the orbiter with no connecting tether.

The MMU has figured in several of the Shuttle program's most spectacular accomplishments. On *Mission 41-C* in April 1984, the ailing *Solar Max* satellite was retrieved, repaired, and re-orbited by the astronaut crew, all on the same flight. Later that same year, on *Mission 51-A*, two malfunctioning commercial communications satellites were retrieved in orbit and brought back to Earth in the Shuttle cargo bay. Another malfunctioning satellite was fixed in orbit by the crew of *Mission 51-I* in 1985.

Early in the Shuttle program, communications satellites were common payloads, with as many as three delivered into orbit on the same mission. The January 1986 *Challenger* accident, which resulted in the loss of the crew and vehicle due to a failed seal in one of the two Solid Rocket Boosters, led to a change in that policy, however. Since returning to flight in September 1988, the Shuttle has carried only those payloads unique to the Shuttle or those that require a human presence. The majority of these have been scientific and defense missions. Among those payloads have been some of the decade's most important space science projects, including the Hubble Space Telescope, the Galileo Jupiter spacecraft, and the Gamma Ray Observatory.

The *Space Shuttle* continues today as the nation's most capable form of space transportation. By the time of its tenth anniversary the Shuttle had carried 204 people and more than a half a million kilograms of payload into orbit. In that same time, astronauts had logged more than three person-years in space over the course of 39 missions—more than all previous U.S. space flights put together.



STS-35: Astro-1 looks out on the universe.

Space Shuttle

Dates: 1981-present

Vehicles: *Space Shuttle* orbiter, External Tank, Solid Rocket Boosters

Number of People Flown: 218 (through June 1991)

Highlights: First reusable spacecraft

First in-space satellite repairs and retrievals

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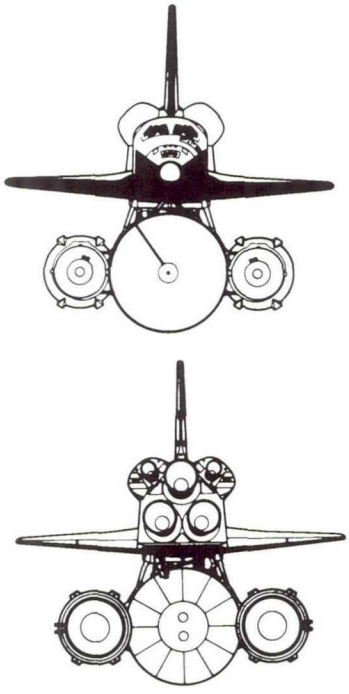
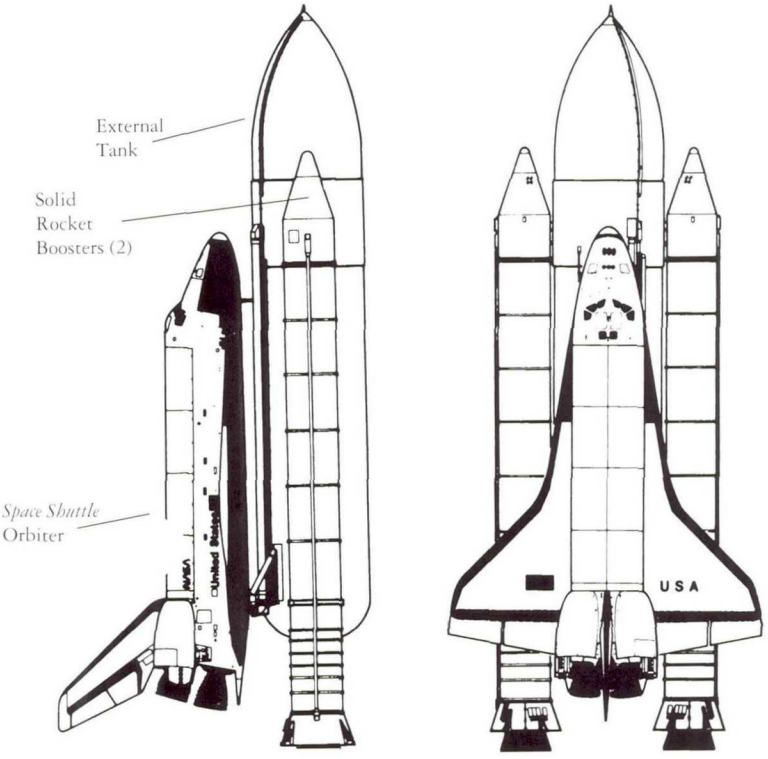




1982

March 22-30: *STS-3*

June 27-July 4: *STS-4*

November 11-16: *STS-5*
First operational Shuttle flight

NASA Space Shuttle Astronauts

Active Astronauts

James C. Adamson
Thomas D. Akers
Andrew M. Allen
Jerome Apt
James P. Bagian
Ellen L. Baker
Michael A. Baker
John E. Blaha
Guion S. Bluford
Charles F. Bolden, Jr.
Kenneth D. Bowersox
Vance D. Brand
Daniel C. Brandenstein
Curtis L. Brown
Mark N. Brown
James F. Buchli
Daniel W. Bursch
Robert D. Cabana
Kenneth D. Cameron
John H. Casper
Franklin R. Chang-Diaz
Leroy Chiao
Kevin P. Chilton
Michael R.U. Clifford
Kenneth D. Cockrell
Eileen M. Collins
Richard O. Covey
John O. Creighton
Frank L. Culbertson, Jr.
N. Jan Davis
Brian Duffy
Bonnie J. Dunbar
Anna L. Fisher
C. Michael Foale
Charles D. Gemar
Robert L. Gibson
Linda M. Godwin
Ronald J. Grabe
Frederick D. Gregory
William G. Gregory
Sidney M. Gutierrez
James D. Halsell, Jr.
L. Blaine Hammond, Jr.
Gregory J. Harbaugh
Bernard A. Harris, Jr.
Henry W. Hartsfield
Susan J. Helms
Terence T. Henricks
Richard J. Hieb
David C. Hilmers
Jeffrey A. Hoffman
Marsha S. Ivins
Mae C. Jemison
Tamara E. Jernigan
Thomas D. Jones
Mark C. Lee
David C. Leestma
David Low
Shannon W. Lucid
William S. McArthur, Jr.
Donald R. McMonagle
Carl J. Meade
Bruce E. Melnick
F. Story Musgrave
Steven R. Nagel
James H. Newman
Ellen Ochoa
Stephen S. Oswald
Charles J. Precourt
William F. Readdy
Kenneth S. Reightler, Jr.
Richard N. Richards
Jerry L. Ross
Mario Runco, Jr.
Richard A. Searfoss
Margaret Rhea Seddon
Ronald M. Sega
William M. Shepherd
Nancy J. Sherlock
Loren J. Shriver
Kathryn D. Sullivan
Norman E. Thagard
Donald A. Thomas
Kathryn C. Thornton
William E. Thornton
Pierre J. Thuot
Charles Lacy Veach
James S. Voss
Janice E. Voss
David M. Walker
Carl E. Walz
Paul J. Weitz
James D. Wetherbee
Terrence W. Wilcutt
Peter J.K. Wisoff
David A. Wolf
John W. Young

Former Astronauts

Joseph P. Allen
Karol J. Bobko
Roy D. Bridges, Jr.
Mary L. Cleave
Michael L. Coats
Robert L. Crippen
Anthony W. England
Joe H. Engle
John M. Fabian
William F. Fisher
C. Gordon Fullerton
Guy S. Gardner
Dale A. Gardner
Owen K. Garriott
Terry J. Hart
Frederick H. Hauck
Steven A. Hawley
Karl G. Henize
William B. Lenoir
Don L. Lind
John M. Lounge
Jack R. Lousma
T. Kenneth Mattingly, II
Jon A. McBride
Bruce McCandless, II
Michael J. McCulley
Richard M. Mullane
George D. Nelson
Bryan D. O'Connor
Robert F. Overmyer
Robert A. R. Parker
Donald H. Peterson
Sally K. Ride
Brewster H. Shaw, Jr.
Sherwood C. Spring
Robert C. Springer
Robert L. Stewart
Richard H. Truly
James D. A. van Hoften
Paul J. Weitz
Donald E. Williams

Deceased Astronauts

Manley L. Carter, Jr.
S. David Griggs
Ronald E. McNair
Ellison S. Onizuka
Judith A. Resnik
Francis R. Scobee
Michael J. Smith
Stephen D. Thorne

*STS-1

April 12-14, 1981
Columbia
Crew: Young, Crippen

On its debut flight, the *Space Shuttle* proved that it could safely reach Earth orbit and return through the atmosphere to land like an airplane. In space, Young and Crippen tested *Columbia's* on-board systems; fired the Orbital Maneuvering System (OMS) used for changing orbits and the Reaction Control System (RCS) engines used for attitude control; opened and closed the payload bay doors (the bay was empty for this first flight); and, after 36 orbits, made a smooth touchdown at Edwards Air Force Base in California, the primary landing site for most Shuttle missions to date.

STS-2

November 12-14, 1981
Columbia
Crew: Engle, Truly

Originally intended to last five days, the Shuttle's second test flight was cut short when problems developed with one of three on-board fuel cells that produce electricity. Engle and Truly conducted the first tests of the 50-foot Remote Manipulator System arm and operated the Shuttle's first payload: a package of Earth-viewing instruments stored in the cargo bay.

STS-3

March 22-30, 1982
Columbia
Crew: Lousma, Fullerton

The longest of the Shuttle test flights carried space-viewing instruments for the first time. The crew also continued engineering evaluations of *Columbia.* After rains flooded the dry lakebed at the primary landing site in California, Columbia made the Shuttle program's only landing to date at White Sands, New Mexico.

STS-4

June 27-July 4, 1982
Columbia
Crew: Mattingly, Hartsfield

The last Shuttle test flight was the first mission to carry payloads for the Department of Defense. It also included the first small "Getaway Special" experiments mounted in the cargo bay, and further tested the mechanical and thermal performance of Columbia, as well as the environment surrounding the spacecraft. Mattingly made the first Shuttle landing on a concrete runway instead of the dry lakebed at Edwards Air Force Base.

STS-5

November 11-16, 1982
Columbia
Crew: Brand, Overmyer, J. Allen, Lenoir

The Shuttle's first operational mission also was the first space flight with four people on board. Two commercial communications satellites, *SBS-3* and *Anik C-3*, were launched into orbit from the cargo bay—another first—using the Payload Assist Module (PAM) upper stage designed for the Shuttle. A planned space-walk was canceled when problems developed with the two on-board spacesuits.

STS-6

April 4-9, 1983
Challenger
Crew: Weitz, Bobko, Peterson, Musgrave

Challenger's debut flight included the Shuttle program's first space-walks. Musgrave and Peterson spent more than four hours testing new Shuttle spacesuits and mobility aids, and evaluated their own ability to work outside in the Shuttle's cargo bay. The first of NASA's Tracking and Data Relay Satellites was successfully launched into orbit.

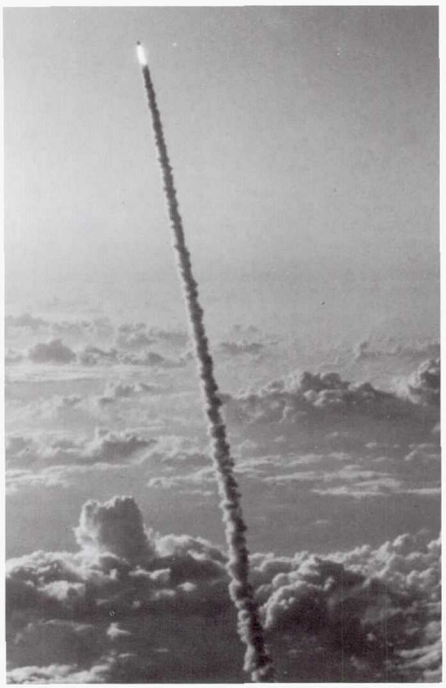
*Mission commanders are listed first, pilots second, followed by mission specialists and payload specialists (PS), if any.

61-B: Testing construction methods in space.

STS-7

June 18-24, 1983
Challenger
Crew: Crippen, Hauck, Ride, Fabian, Thagard

Except for Crippen, all the members of this crew were from the "class" of 1978, the first astronauts chosen for the Shuttle program. *STS-7* had a record five people on board, including Sally Ride, the first American woman in space. The crew deployed, rendezvoused with and retrieved the German-built SPAS experiment platform, which took the first full pictures of a Shuttle orbiter in space. The crew also released two communications satellites—*Anik C-2* and *Palapa B-1*—into orbit, and activated a series of materials processing experiments fixed in *Challenger's* cargo bay.



STS-7: Challenger climbs into orbit

STS-8

August 30-September 5, 1983
Challenger
Crew: Truly, Brandenstein, Bluford, D. Gardner, W. Thornton

STS-8 featured the Shuttle program's first night launch and landing. The crew launched India's *INSAT 1-B* communications satellite, conducted the first tests of Shuttle-to-ground communications with the new Tracking and Data Relay Satellite, and exercised the Remote Manipulator "arm" with a test article weighing nearly four tons. Thornton, an M.D., conducted biomedical experiments, and Bluford became the first African-American in space.

STS-9

November 28-December 8, 1983
Columbia
Crew: Young, Shaw, Parker, Garriott, PS: Byron Lichtenberg, Ulf Merbold

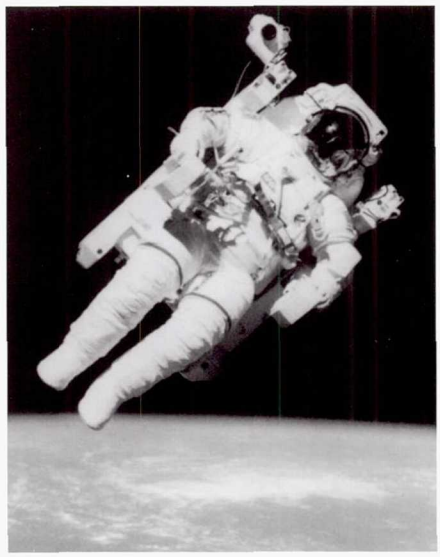
The first flight of the European-built *Spacelab* module was a multidisciplinary science mission, with 71 experiments in a wide range of fields: space physics, materials processing, life sciences, Earth and atmospheric studies, astronomy and solar physics. The record six-person crew included the first Shuttle payload specialists: Lichtenberg of MIT, and Merbold, a West German physicist who became the first non-U.S. citizen to fly on an American spacecraft.

STS-37: Ross with the Gamma Ray Observatory.

41-B

February 3-11, 1984
Challenger
Crew: Brand, Gibson, McCandless, Stewart, McNair

With this flight, the number designations for Shuttle missions changed. The "4" indicates the (originally scheduled) year of the launch—1984. The second digit represents the launch site ("1" for Florida, "2" for California), and the "B" indicates the second launch of the fiscal year. The highlights of the flight were the first untethered space-walks by McCandless and Stewart, who tested new Manned Maneuvering Unit (MMU) backpacks that allowed them to travel as far as 97.54 meters from the orbiter. Two satellites deployed from the Shuttle, *Westar VI* and *Palapa B-2*, failed to reach the proper orbits when their PAM upper stages did not ignite. Both were later retrieved and brought back to Earth (see Flight 51-A). *Challenger* made the Shuttle's first landing at the Kennedy Space Center in Florida.



41-B: McCandless soloes in a Manned Maneuvering Unit.

41-C

April 6-13, 1984
Challenger
Crew: Crippen, Scobee, Hart, van Hoften, Nelson

In the space program's first satellite service call, the crew rendezvoused with and retrieved the *Solar Maximum Mission* (*Solar Max*) satellite, which had failed after four years in orbit. With the satellite anchored in *Challenger's* cargo bay, Nelson and van Hoften replaced a faulty attitude control system and one science instrument, and the repaired satellite was re-released into orbit. The Long Duration Exposure Facility (LDEF), a passive satellite for testing the effects of space exposure on different materials, also was deployed on the flight. Originally LDEF was to have remained in orbit for only ten months, but it was not returned to Earth until *Mission STS-32* in January 1990.

41-D

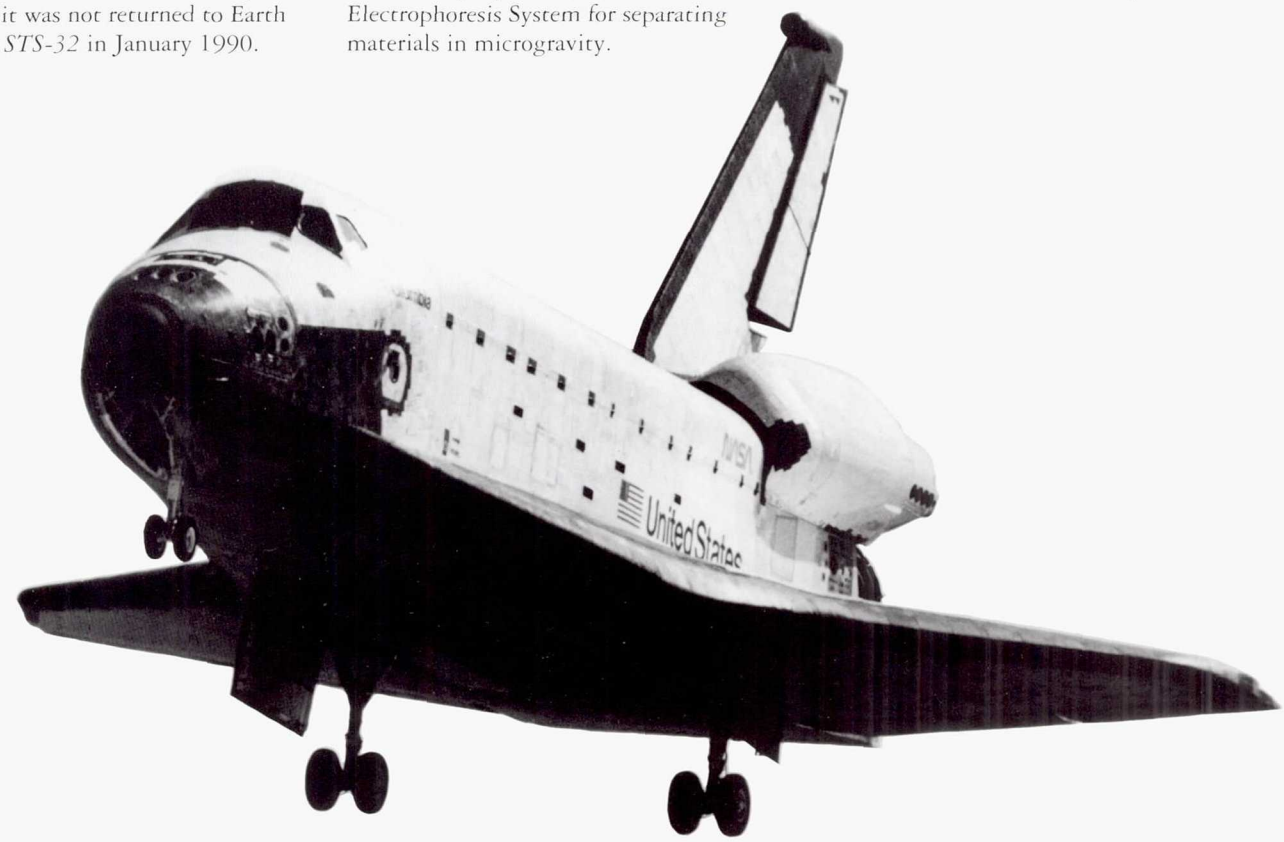
August 30-September 5, 1984
Discovery
Crew: Hartsfield, Coats, Mullane, Hawley, Resnik. PS: Charles Walker

The first flight of *Discovery* was the first Shuttle mission to deploy three communications satellites: *Syncom IV-2*, *SBS-4* and *Telstar 3-C*. The crew also experimented with a 31.09 meter-high solar cell array, which was unfurled from a stowage container only 177.8 millimeters deep located in the cargo bay. The experiments included testing the structure's stability when the Shuttle's attitude control engines were fired. Walker, a McDonnell Douglas engineer, was the Shuttle's first commercially sponsored payload specialist, on board to tend to the company's Continuous Flow Electrophoresis System for separating materials in microgravity.

41-G

October 5-13, 1984
Challenger
Crew: Crippen, McBride, Leestma, Ride, Sullivan. PS: Paul Scully-Power, Marc Garneau.

The Shuttle's first seven-member crew included two payload specialists. Scully-Power, a Navy oceanographer, was on board to observe ocean dynamics from orbit. Garneau, the first Canadian in space, operated the multidisciplinary CANEX (Canadian experiment) package. In *Challenger's* cargo bay was a suite of instruments dedicated to Earth observation—the primary purpose of *Mission 41-G*. During a three-and-a-half hour space-walk, Sullivan and Leestma also tested connections for an orbital refueling system in the bay. Sullivan was the first American woman to walk in space.



STS-40: Columbia returns to Earth.

51-A

November 8-16, 1984
Discovery
Crew: Hauck, Walker, J. Allen, A. Fisher, D. Gardner

The 51-A crew delivered two satellites—*Anik D-2* and *Syncom IV-1*—into orbit, then brought two others—*Palapa B-2* and *Westar VI*, whose on-board boosters had failed after being deployed on *Mission 41-B*—back to Earth. In separate space-walks using Manned Maneuvering Unit backpacks, Gardner and Allen each docked with an orbiting satellite, stopped its rotation, then assisted as it was stowed in *Discovery's* cargo bay. Both satellites were then returned for refurbishment on the ground in a dramatic demonstration of the Shuttle's salvage capability.

51-C

January 24-27, 1985
Discovery
Crew: Mattingly, Shriver, Onizuka, Buchli.
PS: Gary Payton

The crew for the Shuttle's first flight dedicated to the Department of Defense included payload specialist Gary Payton of the U.S. Air Force. The cargo, as well as details of the mission, were classified.

51-D

April 12-19, 1985
Discovery
Crew: Bobko, Williams, Hoffman, Griggs, Seddon. PS: Charles Walker, Jake Garn

When a booster attached to *Syncom IV-3*, the second of two communications satellites released into orbit (the other was *Anik C-1*), failed to ignite, the crew, with the help of engineers on the ground, attempted a fix. Hoffman and Griggs took an unscheduled space-walk to attach an improvised "flyswatter" device to the Remote Manipulator System arm, in the hope that it could trip the satellite booster's sequence start lever. The plan failed, however, and the satellite was eventually "jump-started" by *Mission 51-I* astronauts four months later. Utah Senator Jake Garn was the first member of Congress to fly in space.

51-B

April 29-May 6, 1985
Challenger
Crew: Overmyer, F. Gregory, Lind, Thagard, W. Thornton. PS: Taylor Wang, Lodewijk van den Berg

The Shuttle's second *Spacelab* mission included 15 experiments in materials processing, fluid behavior, atmospheric physics, astronomy and life sciences. The crew worked around the clock in shifts, and had trouble with a leaky animal-holding facility making its first test flight. Wang, a Jet Propulsion Laboratory scientist, concentrated on studies of fluid behavior in microgravity, while van den Berg of EG&G, Inc. focused on crystal growth experiments. Lind, an astronaut since 1966, made his first space flight.

STS-9: Merbold (bottom right) was the first non-American to fly on a U.S. spacecraft.

51-G

June 17-24, 1985
Discovery
Crew: Brandenstein, Creighton, Fabian, Nagel, Lucid. PS: Patrick Baudry, Sultan Salman Abdul Azziz Al Sa'ud

Baudry of France and Al Sa'ud of Saudi Arabia were the international payload specialists for this flight, which successfully launched three communications satellites into orbit: *Morelos-1*, *Arabsat 1-B* and *Telstar 3-D*. *SPARTAN-1*, a reusable free-flying payload carrier with astronomy instruments on board, also was released, then retrieved, by the Remote Manipulator System arm. The crew conducted materials science and biomedical experiments and participated in a Defense Department tracking experiment in which a laser beam directed from Hawaii was bounced from a reflector on board *Discovery* back to the ground.

51-F

July 29-August 6, 1985
Challenger
Crew: Fullerton, Bridges, Musgrave, England, Henize. PS: Loren Acton, John-David Bartoe

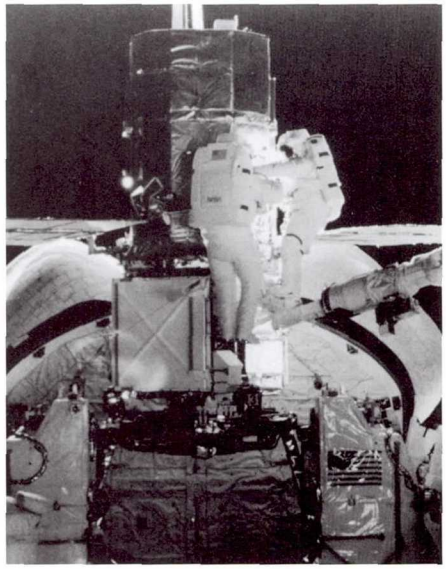
The *Spacelab 2* mission replaced the *Spacelab's* enclosed "long module" with open pallets containing 13 instruments dedicated to astronomy. Despite problems with an instrument pointing system, the crew were able to collect data on the Sun and other celestial targets. Earlier in the flight, *Challenger* made the Shuttle program's first "abort to orbit" when one of its three main engines shut down during the ascent. Henize and England had waited a long time for a space flight—both had been astronauts during the *Apollo* era. England had resigned from NASA in 1972, only to rejoin the astronauts corps in 1979.

51-I

August 27-September 3, 1985
Discovery
Crew: Engle, Covey, van Hoften, W. Fisher, Lounge

The *Syncom IV-3* satellite (also known as "Leasat") stranded in orbit on *Mission 51-D* was repaired and re-boosted as a result of two space-walks by van Hoften and Fisher that were among the most challenging in the history of the space program. After van Hoften, standing on the end of the Remote Manipulator System arm, grabbed onto the satellite manually, he and Fisher worked on the satellite in *Discovery's* cargo bay. The astronauts attached hardware that allowed ground crews to activate *Syncom's* still-live rocket motor after van Hoften re-released it into orbit with a shove from the cargo bay. Earlier in the flight, the crew had launched three new communications satellites into orbit: *ASC-1*, *AUSSAT-1* and *Syncom IV-4* (nearly identical to the one that was rescued).

A shuttle carrier aircraft ferries *Endeavour* cross-country.



41-C: Repairing *Solar Max* in *Challenger's* cargo bay.

51-J

October 3-7, 1985
Atlantis
Crew: Bobko, Grabe, Hilmers, Stewart. PS: William Pailes

The first flight of *Atlantis* was the second Shuttle mission dedicated to the Department of Defense. The payload and on-board activities were classified.

61-A

October 30-November 6, 1985
Challenger
Crew: Hartsfield, Nagel, Buchli, Bluford, Dunbar. PS: Reinhard Furrer, Wubbo Ockels, Ernst Messerschmid

The *Spacelab D-1* mission was the first U.S. manned space flight with a primary payload sponsored by another country—West Germany. On board were 76 experiments, including investigations in fluid physics, materials science, plant physiology and human adaptation to weightlessness. Science experiments were directed from a German Space Operations Center in Oberpfaffenhofen, and two of the payload specialists—Furrer and Messerschmid—were German. With eight people working around the clock in shifts, it was the largest Shuttle crew ever.

STS-31: Sullivan on *Discovery's* flight deck.

61-B

November 26-December 3, 1985
Atlantis
Crew: Shaw, O'Connor, Spring, Cleave, Ross. PS: Charles Walker, Rodolfo Neri Vela

After the crew deployed three communications satellites (*SATCOM Ku-2, Morelos 2* and *AUSSAT-2*) Spring and Ross conducted the first construction experiments in space, assembling and disassembling two tinkertoy-like structures called EASE and ACCESS in the cargo bay of *Atlantis*. The two space-walking astronauts attached beams, nodes and struts to evaluate different methods of assembling large structures in space. Vela was the first Mexican citizen in orbit, while Walker made his third flight with the commercially-sponsored electrophoresis experiment.

61-C

January 12-18, 1986
Columbia
Crew: Gibson, Bolden, Nelson, Hawley, Chang-Diaz. PS: Robert Cenker, Bill Nelson

Bill Nelson of Florida was the second member of Congress to fly on the Shuttle. The crew deployed an RCA communications satellite and conducted a number of smaller experiments, including several materials science investigations mounted in the cargo bay of *Columbia*. An attempt to photograph Comet Halley through an overhead window was unsuccessful, however, due to problems with the instrument's battery.

51-L

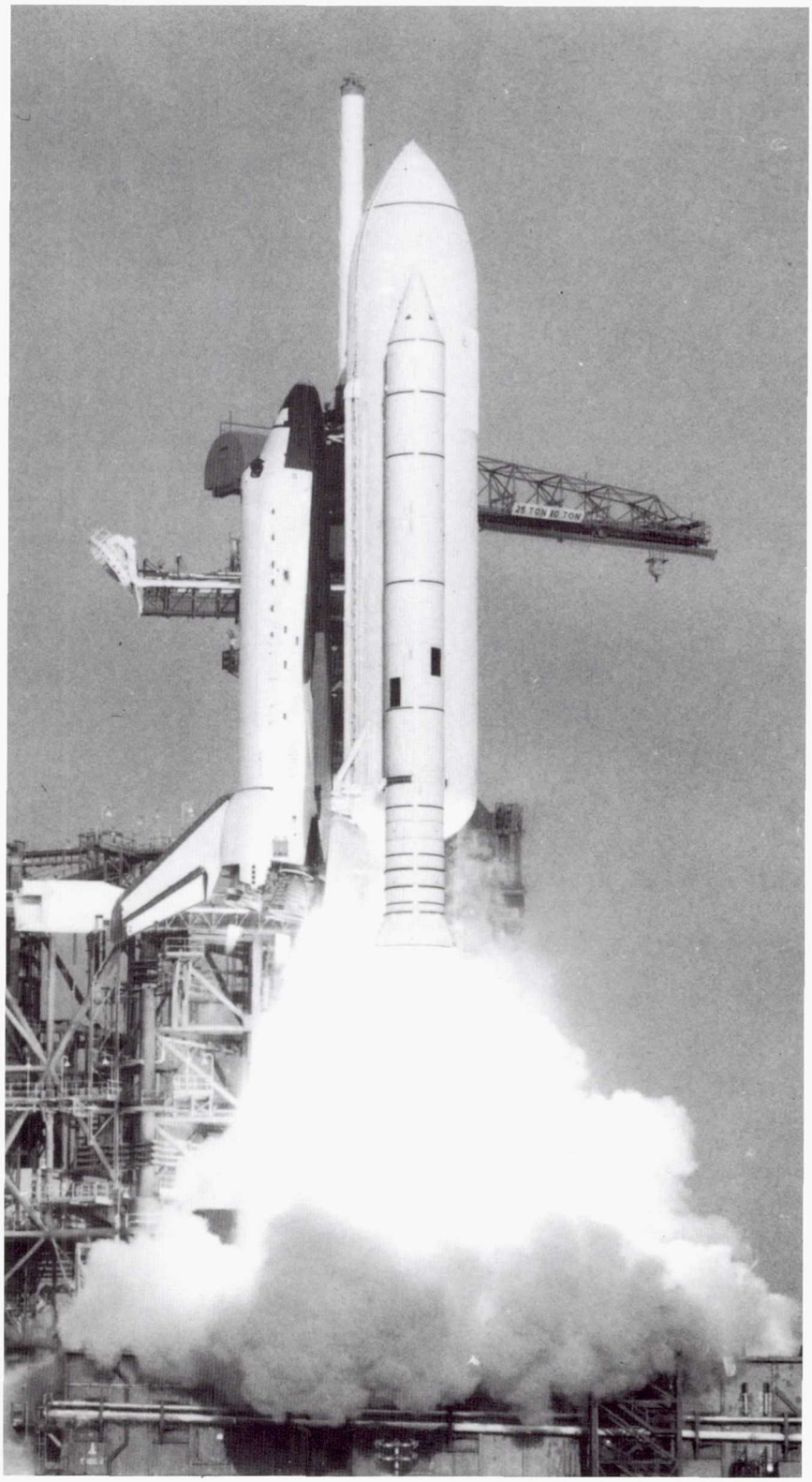
January 28, 1986
Challenger
Crew: Scobee, Smith, Onizuka, Resnik, McNair. PS: Gregory Jarvis, Christa McAuliffe

Challenger and all seven members of the crew—including Jarvis, a Hughes employee, and Christa McAuliffe, the designated "Teacher in Space"—were lost 73 seconds into the flight when the vehicle exploded as the result of a leak in one of two Solid Rocket Boosters. The Shuttle program was delayed for nearly three years while the boosters were redesigned and other safety measures were added. A change in U.S. space policy also resulted from the accident—no longer would the Shuttle carry commercial satellites into orbit.

STS-26

September 29-October 3, 1988
Discovery
Crew: Hauck, Covey, Lounge, Nelson, Hilmers

The first Shuttle mission after the *Challenger* accident was a conservative, four-day flight that proved the safety of the redesigned Solid Rocket Boosters. On board Discovery was the first all-veteran astronaut crew since *Apollo 11*. During launch and re-entry the astronauts wore new partial-pressure flight suits, and in orbit they practiced using a new emergency escape system. The principal payload was a NASA Tracking and Data Relay Satellite similar to the one lost on *Mission 51-L*, which was released into orbit on the first day.



First shuttle launch, April 1981.

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STS-27

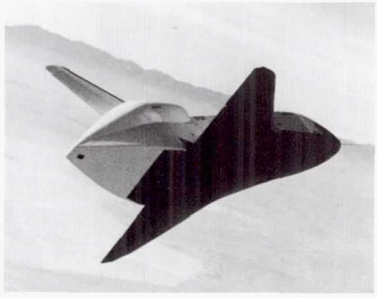
December 2-6, 1988
Atlantis
Crew: Gibson, G. Gardner, Mullane, Ross, Shepherd

Classified mission for the Department of Defense.

STS-29

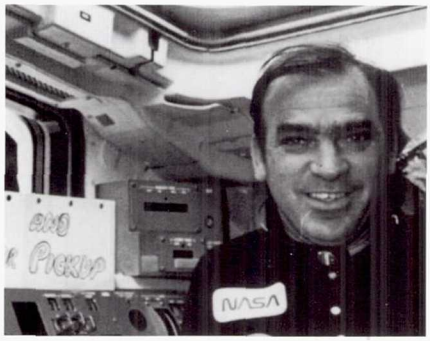
March 13-18, 1989
Discovery
Crew: Coats, Blaha, Buchli, Springer, Bagian

Six hours into the mission, the crew released the fourth of NASA's Tracking and Data Relay Satellites into orbit. The astronauts conducted experiments in plant growth, crystal growth and the human body's adaptation to weightlessness, and tested a new Shuttle "fax" machine. They also took large-format IMAX movie pictures of the Earth, and returned clear photographs of the jettisoned external fuel tank in space.



Testing *Enterprise*, 1977.

Fabian on board *Discovery*, *Mission 51-6*



STS-30

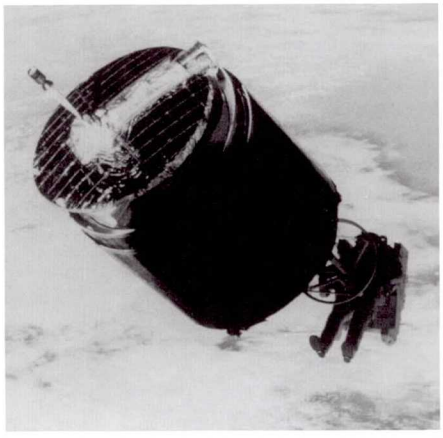
May 4-8, 1989
Atlantis
Crew: Walker, Grabe, Thagard, Cleave, Lee

The Shuttle program's first launch of a planetary spacecraft came on the first day of the mission, when the Magellan Venus Radar Mapper was released from *Atlantis'* cargo bay with an Inertial Upper Stage booster attached. The booster fired shortly thereafter to send Magellan to Venus, where it arrived in August 1990 to begin an eight-month mapping mission. Secondary experiments after the deployment included crystal growth studies and a search for thunderstorms in the atmosphere below, called the Mesoscale Lightning Experiment.

STS-28

August 8-13, 1989
Columbia
Crew: Shaw, Richards, Leestma, Adamson, M. Brown

Classified mission for the Department of Defense.



51-A: Dale Gardner docks with the *Westar VI* satellite in orbit.

STS-34

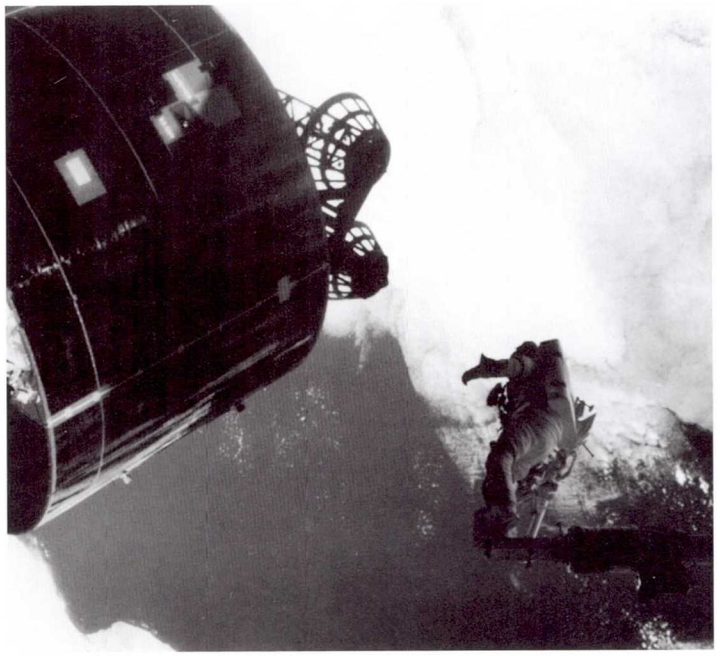
October 18-23, 1989
Atlantis
Crew: Williams, McCulley, Lucid, E. Baker, Chang-Diaz

The Jupiter-bound Galileo spacecraft was the Shuttle's second interplanetary cargo. Galileo's mission got underway during *Atlantis'* fifth orbit around the Earth, when the spacecraft was released from the cargo bay to head toward Venus, the first "stop" on its voyage to Jupiter. After releasing Galileo, the crew worked on experiments that included materials science, plant growth and measurements of ozone in the atmosphere.

STS-33

November 22-27, 1989
Discovery
Crew: F. Gregory, Blaha, Musgrave, K. Thornton, Carter

Classified mission for the Department of Defense.



51-I: Retrieving the *Syncom IV-3* satellite.

STS-32

January 9-20, 1990
Columbia
Crew: Brandenstein, Wetherbee, Dunbar, Low, Ivins

The Long Duration Exposure Facility (LDEF), released into orbit on *Mission 41-C* in 1984, was finally retrieved after nearly six years in space. After rendezvousing with the large, cylindrical satellite—one of the most complicated space rendezvous operations ever—the crew photographed the LDEF in orbit, grappled it with the Remote Manipulator System arm, then stowed it in the cargo bay of *Columbia*. Scientists who examined the LDEF after landing found evidence of erosion and micrometeorite impacts, as expected. A *Syncom* satellite also was deployed on the mission. Lasting 11 days, *STS-32* was the longest Shuttle flight to date.

STS-36

February 28-March 4, 1990
Atlantis
Crew: Creighton, Casper, Hilmers, Mullane, Thuot

Classified mission for the Department of Defense.

STS-31

April 24-29, 1990
Discovery
Crew: Shriver, Bolden, Hawley, McCandless, Sullivan

The Hubble Space Telescope, the first large optical telescope ever to be placed above the Earth's atmosphere and the first of NASA's "Great Observatories," was released into orbit by the Remote Manipulator System arm on the second day of the flight to begin at least a decade of astronomical observations in space. After the telescope was deployed, the astronauts conducted experiments in crystal growth and monitored the radiation environment on board the orbiter. Because of the need to place the telescope above most of the atmosphere, *Discovery* flew the highest Shuttle orbit to date, reaching an altitude of more than 531.08 kilometers.

STS-41

October 6-10, 1990
Discovery
Crew: Richards, Cabana, Melnick, Shepherd, Akers

Deployment of the European Space Agency's *Ulysses* spacecraft to explore the polar regions of the Sun was the highlight of this four-day mission. On the first day of the flight, the crew sprung *Ulysses* from *Discovery's* cargo bay, and on-board rockets fired to send the spacecraft toward a gravity assist at Jupiter. After the deploy, the astronauts conducted a number of secondary experiments, including taking measurements of atmospheric ozone, studying the effects of atomic oxygen on spacecraft materials and evaluating a new "hands-off" voice command system in the Shuttle crew cabin.

STS-38

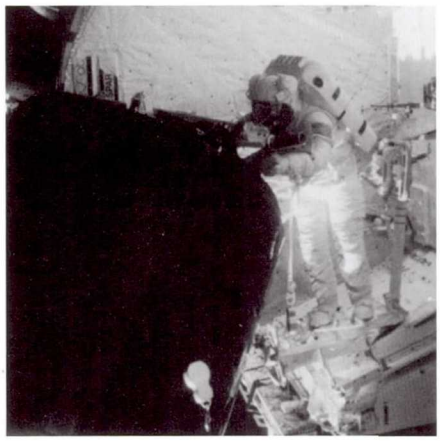
November 15-20, 1990
Atlantis
Crew: Covey, Culbertson, Springer, Meade, Gemar

Classified mission for the Department of Defense.

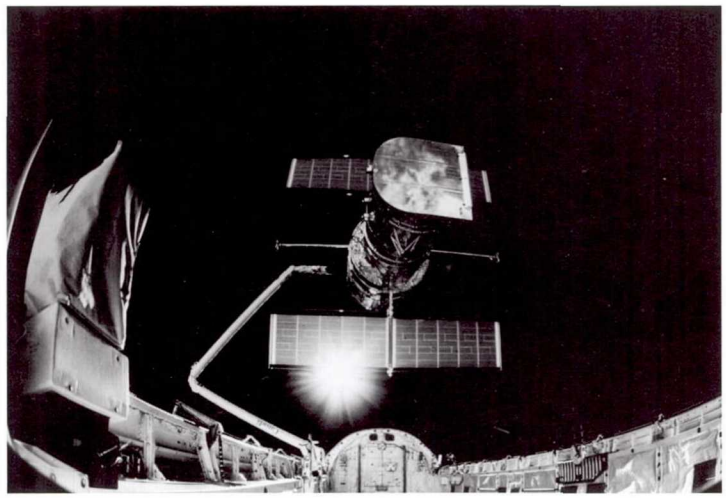
STS-35

December 2-10, 1990
Discovery
Crew: Brand, Gardner, Hoffman, Lounge, Parker. PS: Ronald Parise, Samuel Durrance

STS-35 was the first *Spacelab* mission since the *Challenger* accident, and the first Shuttle flight dedicated to a single discipline: astrophysics. *Discovery* carried a group of astronomical telescopes called ASTRO-1 in its cargo bay, as well as four PhD's in astronomy: Hoffman, Parker, Durrance of Johns Hopkins University, and Parise of the Computer Science Corporation. Despite several hardware malfunctions, the crew were able to make observations of a wide variety of astronomical targets, from comets to quasars, with particular attention to x-ray and ultraviolet wavelengths.



51-A: Bringing the Palapa satellite home.



STS-31: The Hubble Space Telescope is released into orbit.

STS-37

April 5-11, 1991
Atlantis
Crew: Nagel, Cameron, Apt, Godwin, Ross

The *Gamma Ray Observatory* (GRO), was released by *Atlantis'* Remote Manipulator System arm on the third day of the flight, after Ross and Apt made an unscheduled space-walk to repair an antenna on the spacecraft. The second of NASA's "Great Observatories" designed for a long-term program of astronomical observations from Earth orbit, the GRO was the heaviest science satellite ever launched from the Shuttle. Later in the mission, Ross and Apt returned to the cargo bay to test rail-mounted mechanical pushcarts planned for use on *Space Station Freedom*. The two space-walks were the first in more than five years.

STS-39

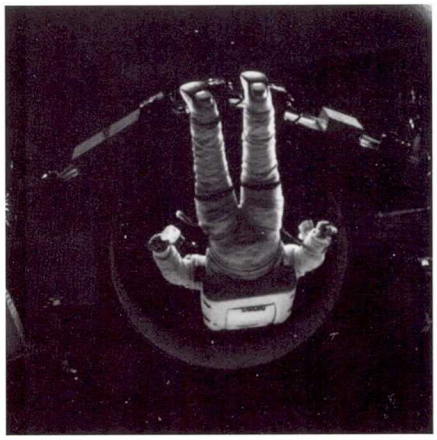
April 28-May 6, 1991
Discovery
Crew: Coats, Hammond, Bluford, Harbaugh, Hieb, McMonagle, Veach

The first unclassified defense-related mission of the Shuttle program included experiments sponsored by the Air Force and the Strategic Defense Initiative (SDI) organization. The studies included extensive infrared, ultraviolet, visible and x-ray observations of the space environment and the Shuttle itself. On-board instruments also returned high-quality images of the Earth's aurora. In an experiment related to ballistic-missile defense, *Discovery* released a *SPAS* instrument platform equipped with infrared sensors to fly in formation and observe rocket thruster plumes as the Shuttle performed a complicated series of maneuvers.

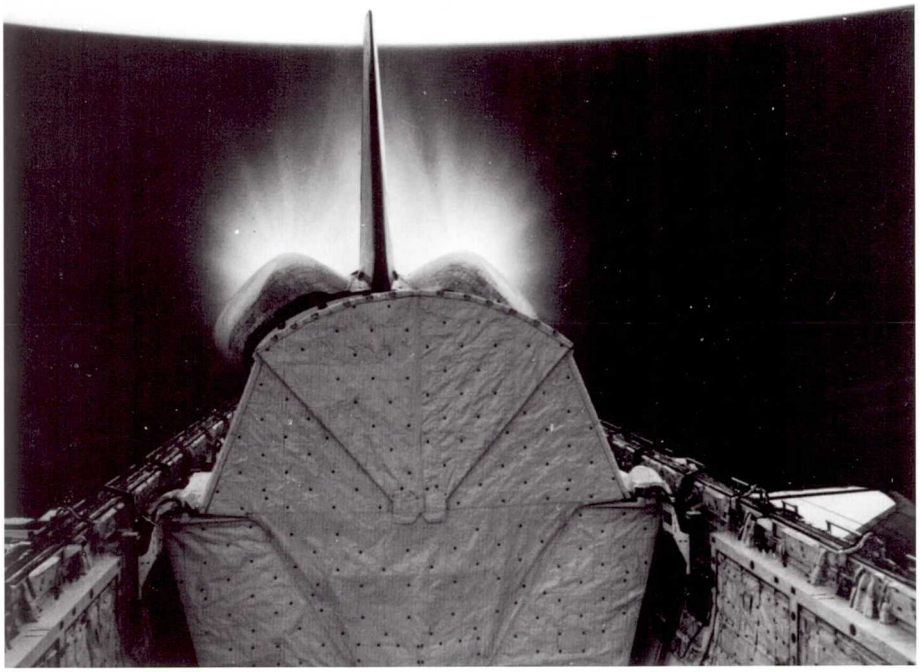
STS-40

June 5-14, 1991
Columbia
Crew: O'Connor, Gutierrez, Bagian, Jernigan, Seddon, PS: F. Drew Gaffney, Millie Hughes-Fulford

The *Spacelab Life Sciences* (*SLS-1*) mission was the first dedicated entirely to understanding the physiological effects of space flight. An extensive series of biomedical experiments were conducted on crew members during the nine-day mission, and the results were compared with baseline data collected on the ground before and after the flight. Along with the human subjects, rodents and jellyfish also were on board to test their adaptation to microgravity.



STS-6: Musgrave takes the shuttle's first space-walk.



STS-5: *Columbia's* Orbital Maneuvering System engines fire in orbit.

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NP-150