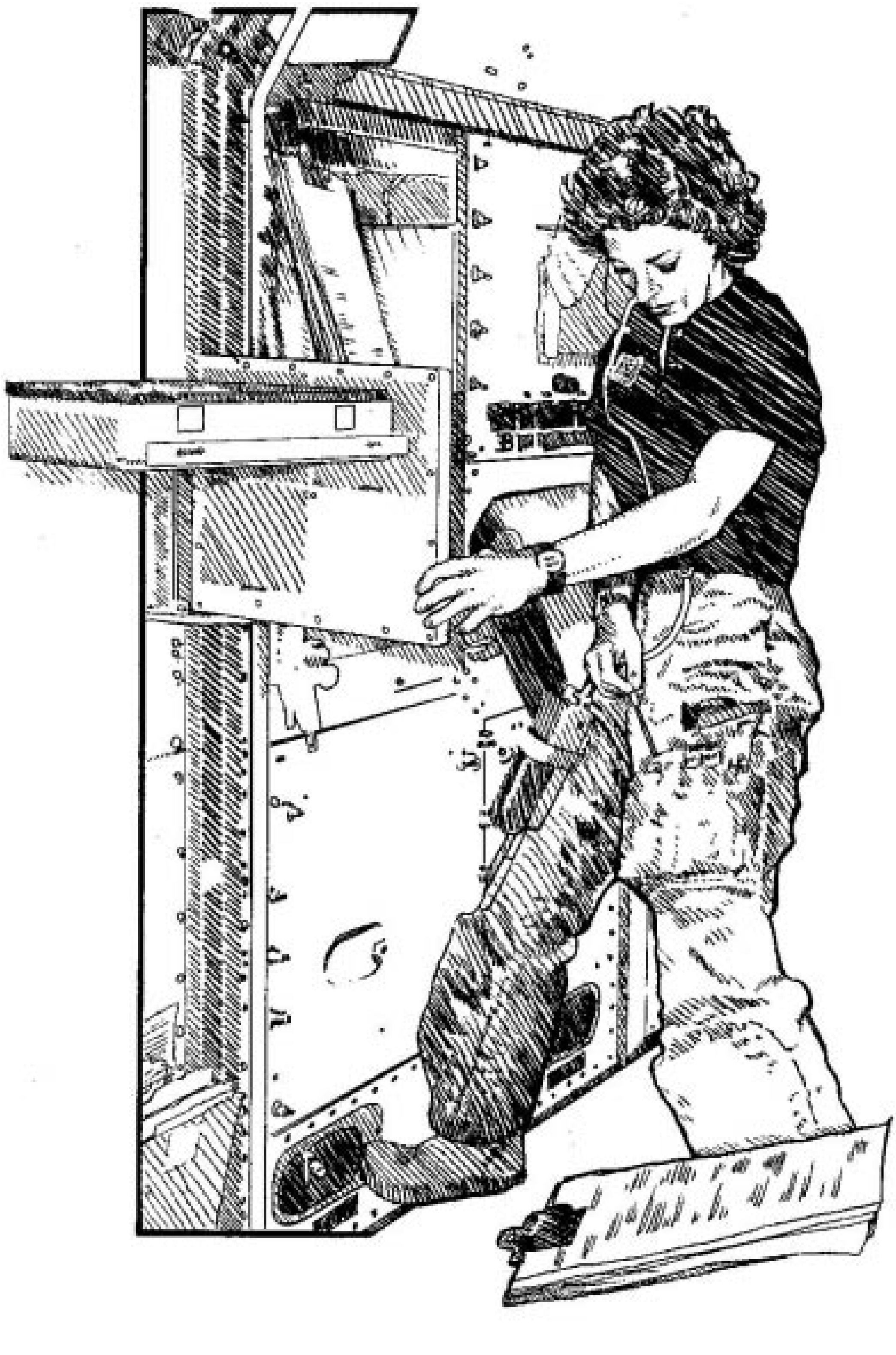

CHAPTER 15: *The Shuttle at Work*

The launch of STS-5 *(Columbia)* on November 11, 1982, brought to an end the politically and fiscally sensitive interlude between the Apollo-Soyuz mission in 1975 and the first Shuttle test flight in 1981. The focus of manned spaceflight shifted from earlier emphases on development and exploration to operations. With the return to flight, the old verve and vitality returned to JSC and throughout NASA. At JSC the collective pulse quickened as personnel turned to mission planning, flight software development, payload integration and crew training. It was time to put the Shuttle, and space, to work. Named for America's first Navy ship to circumnavigate the globe (1836) and for the command module that carried Neil Armstrong, Michael Collins and Edwin (Buzz) Aldrin to the Moon in 1969, *Columbia* began in earnest the pursuit of a new space goal—not simply getting there, but using the resources one found in space.

A reusable aerospace vehicle, the Shuttle is launched like a rocket, orbits like a spacecraft, and lands like a glider (albeit a very heavy 150,000-pound glider). Designed to reduce the cost of spaceflight and to accommodate civilian passengers, the Shuttle promised economies because of its reusable orbiter, its recoverable solid rocket boosters, its lower launch costs as compared to the Atlas-Centaur and Delta rocket alternatives, and most especially because of its cargo delivery and retrieval capacities. Congress defined the Shuttle as the key element in making space an *extension of life on Earth*. The Shuttle was to be part of a "total transportation system linking Earth with space" including "vehicles, ground facilities, a communications net, trained crews, established freight rates and flight schedules—and the prospect of numerous important and exciting tasks to be done." In 1980 NASA projected that within 5 years the Shuttle might fly weekly round-trip missions between the United States and Earth orbit.[1]

Instead, upon completion of the four orbital test flights, the Shuttle averaged closer to one flight every 2 months for the next 3 years. Between November 1982 and mid-January 1986, the Shuttle flew 20 operating missions during which 117 crewmembers accumulated a total of 17,576 hours or 2 years of flight in space. Payloads launched included 29 satellites (most of them communications and navigational satellites such as Telstar, Palapa, WESTAR), 5 of which were retrieved and repaired after operational failures. There were four spacelab missions, a number of science laboratory packages deployed or operated during flight, and two classified DoD missions. During the same interval, another 29 satellites were launched aboard unmanned and expendable Delta, Centaur, and occasionally Scout rockets. The European Space Agency had also begun to launch satellites on the French-built Ariane rocket. Independent consultants estimated in 1982 comparative satellite launch costs for the Delta at $37 million, the Ariane at $31 million, and the Shuttle at $17.5 million, but noted that the Ariane launches often offered price concessions and that Shuttle manifests were already full through 1985.[2]

Estimates of comparative launch costs vary widely, depending on the elements included in the base. Costs are, however, considerably higher than those estimated in 1982, and the cost advantage of the Shuttle considerably less than that estimated in 1982. A 1986 NASA study, for example, estimated Shuttle launch costs at $31 million and Delta launch costs at $38 million (1986 dollars). Costing has been a very problematical thing, but the following data (table 16) provided by JSC for 1990 represents a recent analysis. The analysis indicates an $8.9 billion launch cost for Apollo and a $1.8 billion cost for the Shuttle.

Although the public perceived Shuttle flights to have become largely routine by 1985, the Shuttle never became and never could be fully operational in the traditional sense of aircraft. Each flight was unique. Each mission required unique and comprehensive training of the astronauts, operations crew, launch crew, and payload operations team. Each payload required modifications to the flight operations. Each flight required a reconstitution of the computer software and information systems. Although reusable, after each flight the orbiter had to be carefully examined, repaired and reconstructed. The Shuttle required "an incredible amount of tending."[3]

TABLE 16. Comparative Shuttle and Apollo Launch Vehicle Launch Costs

Apollo

	RY $	Infl. Factor	1991 $
1962	75.7	6.063	459.0
1963	1,184.0	5.857	6,926.4
1964	2,273.0	5.605	12,740.2
1965	2,614.6	5.421	14,173.8
1966	2,992.2	5.114	15,302.1
1967	3,002.6	4.875	14,637.7
1968	2,556.0	4.625	11,821.5
1969	2,025.0	4.376	8,861.4
1970	1,684.4	4.094	6,895.9
1971	913.7	3.851	3,518.6
1972	601.2	3.643	2,190.2
1973	56.7	3.447	195.1
Total	19,979.1	—	97,721.9

*NASA Pocket Facts shows 20,444.0 total program costs.

Apollo
97,721.9 ÷ 11 = 8.9 billion/launch (8.884)

Shuttle
63,599.6 ÷ 36 (through Sep. 30, 1990) =
1.8 billion/flight (1.766)

Ratio: Apollo/Shuttle per flight = 5:1

Shuttle

		RY $	Infl. Factor	1991 $
Shuttle Prog. R&D	1970	12.5	4.094	51.2
	1971	78.5	3.851	302.3
	1972	100.0	3.643	364.3
	1973	198.6	3.447	684.6
	1974	475.0	3.215	1,527.1
	1975	797.5	2.902	2,314.4
	1976	1,206.0	2.662	3,210.4
	1977	1,291.1	2.403	3,102.5
	1978	1,401.0	2.229	3,122.8
	1979	1,707.8	2.036	3,477.1
	1980	2,054.9	1.839	3,779.0
	1981	2,301.8	1.657	3,814.1
	1982	2,689.6	1.526	4,104.3
	1983	3,357.5	1.430	4,801.2
SFCDC (Prod/Ops only)	1984	3,068.9	1.352	4,149.2
	1985	2,786.7	1.301	3,625.5
	1986	2,987.9	1.259	3,761.8
	1987	5,138.3	1.213	6,232.8
	1988	2,917.9	1.153	3,364.3
	1989	3,500.3	1.097	3,839.8
	1990	3,818.2	1.040	3,970.9
	Total	41,890.0	—	63,599.6

Source: Papers of Joseph P. Loftus, Assistant Director (Plans), JSC.

Columbia returned from the first working Shuttle flight after 5 days in orbit, having delivered its payload of the two commercial communications satellites. But the flight, like its successors, was not routine. A planned EVA was scrapped due to malfunctions of a ventilation motor in one space suit and a pressure regulator in the other.[4] A characteristic of spaceflight from the earliest days of Mercury seemed to be that no flight was uneventful or routine. Launch and flight control usually involved troubleshooting, either of problems that had developed or that might be anticipated.

Similarly, the maiden flight of *Challenger* (STS-6), April 4, 1983, became a continuing test in problem-solving. North American Rockwell delivered the *Challenger* (named for a Navy vessel which conducted extensive exploration in the Atlantic and Pacific Oceans between 1872 and 1876) to the Kennedy Space Center on July 5, 1982. Originally scheduled for its first flight on January 20, hydrogen gas leaks required the removal, repair and reinstallation of two main engines and the replacement of the third. During repair work, a severe storm broke seals on the payload changeout room and particles contaminated the payload, which had to be removed and cleaned. The realities of flight preparation and training, payload planning, and launch costs gradually changed the idea that there would be frequent or even weekly Shuttle flights with returns for repairs and reoutfitting of payloads. NASA began considering 12 Shuttle flights per year, and as the problems and realities of flight continued to unfold, administrators decided to strive for 5 to 8 launches per year and stress flight duration and mission success.[5]

At last, in April, *Challenger* successfully placed NASA's first Tracking and Data Relay Satellite (TDRS, or "Teadras") in orbit. The second stage booster of the 5000 pound satellite ceased its burn 33 seconds earlier than scheduled. Over a period of several months, ground controllers succeeded in nursing the satellite into a satisfactory orbit. The first of three planned tracking satellites, the TDRS-1, virtually made the old ground control network used for Mercury, Gemini and Apollo obsolete and considerably improved the control, communications, and response between Shuttle flights and ground control. Each TDRS satellite could maintain communications with the orbiter for nearly one-half of the globe.[6]

During the flight of STS-6, mission specialists F. Storey Musgrave, an M.D. and Ph.D. (Physiology), and Donald H. Peterson, an Air Force transfer to NASA, tested the new space suits especially designed for Shuttle EVA use.[7] The 5-day mission provided more experience for crew and flight controllers and helped build new confidence in the Space Transportation System.

That confidence seemed to be wholly warranted by the almost flawless launch and performance of *Challenger* (STS-7) on its 6-day mission beginning June 18, 1983. *Challenger* carried a shuttle pallet satellite (SPAS) built in West Germany and placed it in orbit from the cargo bay by the remote manipulator (Canadarm). Mission specialist Dr. Sally K. Ride, the first American woman in space, managed the remote manipulator arm that placed the SPAS in orbit, and then, after the Shuttle was maneuvered around the satellite, plucked it from its orbit and returned it to the orbiter cargo bay.[8]

Ride's flight finally quelled a festering public relations problem that had plagued NASA since the early 1970's when women activists began to perceive NASA and the astronaut corps as a macho, male only, antifeminist organization. When astronaut James

A. Lovell responded to a reporter's inquiry in 1972 about why there were no women being sent into space by saying that there had thus far been no reason to, but that "in the near future we will fly women into space and use them the same way we use them on Earth—for the same purpose," a storm of protest understandably swept the press, Congress, NASA administrators, and James Lovell. Whether it can be attributed to Lovell's gaffe, social consciousness, public relations consciousness, political pressures, or all of the above, once astronauts began to be picked from the science community and were no longer defined by the pool of pilots with test pilot experience, women were included in the candidate pool.[9]

In preparation for Skylab and post-Apollo operations, NASA, as early as 1973, began to encourage applications from women and minority candidates who met the established criteria for pilot astronauts and mission specialists. None were admitted, however, since there were no astronauts chosen between 1970 and 1978. Earlier classes drew from candidates with test pilot experience (but for the scientist-astronauts selected in 1967 who were required to attend jet pilot school for one year). There were few if any women with hypersonic test pilot experience before 1973. In 1978, from 659 astronaut pilot applicants (including 8 women and 10 minority applicants) NASA selected 15 finalists only one of whom came from a civilian background and none of whom were women or minority candidates. But of the 5680 who applied as mission specialists (including 1251 women and 338 minority candidates), NASA selected 20 astronaut candidates including 6 women and a number of candidates of African, Asian, and Hispanic heritage. NASA selected two additional women mission specialists in the 1980 astronaut class. Certainly by the time Sally Ride made her historic flight aboard *Challenger,* it had become well established that the "right stuff" for spaceflight included men and women of many professional, cultural and racial backgrounds. "In short, the Shuttle opened the door for a vast broadening of the human experience in space."[10]

Sally Ride obtained advanced degrees in physics (M.A. and Ph.D.) from Stanford. She received her doctorate in 1978, and that year was selected for the astronaut corps. She met her future husband, Steven A. Hawley, in the 1978 astronaut class. Another 1978 astronaut, Robert Lee (Hoot) Gibson, met and married a classmate, Margaret Rhea Seddon, an M.D. from the University of Tennessee College of Medicine. Interestingly, Anna Fisher, an astronaut classmate of Steven Hawley, met her husband, William F. Fisher in the 1980 astronaut candidate pool and became with the Hawleys and Gibsons, America's first "partners in space." Ride, after serving as CAPCOM in Mission Control for the STS-2 and STS-3 missions, joined the crew of STS-7 commanded by Robert L. Crippen, who had flown the first orbital shuttle flight (STS-1) aboard *Columbia.*[11]

The STS-7 flight crew, which included Crippen and Ride, pilot Frederick C. Hauck, and mission specialists John M. Fabian and Dr. Norman Thagard, also placed in orbit a Palapa B satellite for the Indonesian Government and a Telesat satellite. The satellites made possible the first modern communications system for the 3000 islands comprising that country. Getaway Special experiment packages included studies of an ant colony in zero gravity and the germination of radish seeds in space. Dr. Thagard conducted studies on the effects of Space Adaptation Syndrome which causes nausea and sickness during the initial hours of spaceflight.[12]

Getaway Special

Officially titled "Small Self-Contained Payloads," the Getaway Special program is offered by NASA to provide to anyone the opportunity to fly a small experiment aboard the Space Shuttle. The experiment must be of a scientific research and development nature. The Getaway Special experiments are flown on Shuttle missions on a space-available basis. A Getaway Special Flight Verification Payload was first flown aboard the STS-3 mission. The test payload, a cylindrical canister 61 cm (24 in.) in diameter and 91 cm (36 in.) deep, measured the environment in the canister during the flight. The first private sector payload was flown on STS-4. The Getaway Specials are available to industry, educational organizations, and domestic and foreign governments for legitimate scientific purposes.

Challenger (STS-8) rose in a fiery arc from Kennedy Space Center in the first night launch of the Shuttle on August 30, 1983. The mission, commanded by Richard H. Truly, carried America's first black astronaut, Guion Bluford (Ph.D. in aerospace engineering), an INSAT IB satellite for India, and 12 Getaway Special canisters—4 contained scientific experiments and 8 held U.S. first-day postal stamp covers.[13] Perhaps the lessons learned from the controversy that erupted when Apollo 15 astronauts carried unauthorized first-day covers to the Moon had not been lost on U.S. postal authorities.

More significantly, the communication satellite payloads being carried by Shuttle flights were quietly revolutionizing communications and the quality of life around the world. Twenty years earlier, on July 10, 1962, NASA had launched the Telstar 1 communications satellite built by American Telephone and Telegraph. Telstar carried the first transatlantic television broadcast between the United States and Europe. In 1964 NASA's successful placing of Syncom 3 in a geosynchronous orbit marked the beginning of a satellite communications network that would provide the capability of real-time voice and television communications between most points on Earth.[14]

Underscoring the international aspects of Shuttle missions, the next Shuttle flight would be a world-class flight with a European Space Agency-sponsored Spacelab payload. Contractors delivered the orbiter *Discovery,* named both for Henry Hudson's ship which sought the Northwest Passage in 1610 to 1611 and for Captain Cook's vessel which discovered Hawaii, to the Kennedy Space Center on November 9, 1983, while technicians readied STS-9 *(Columbia)* for a November 28 lift-off.[15]

Spacelab 1, bolted into the cargo bay of *Columbia,* carried experiments relating to atmospheric and plasma physics, astronomy, solar physics, material sciences, technology, life sciences, and Earth observations. The European Space Agency selected Ulf Merbold from West Germany as its payload specialist for the mission; and MIT (Massachusetts Institute of Technology), which managed the American experiments aboard Spacelab, selected Bryon Lichtenberg. Lichtenberg was the first non-NASA astronaut to fly in space, and Merbold the

TABLE 17. Space Shuttle Missions in Brief, 1985 to 1986

Mission Name	Astronauts	Launch Date	Orbiter	Primary Payload	Launch Pad	Result
STS 51-C	Mattingly, Shriver, Buchli, Onizuka, Payton	1-24-85	*Discovery*	DoD	39A	S
STS 51-D	Bobko, Williams, Seddon, Griggs, Hoffman, Garn, Walker	4-12-85	*Discovery*	Anik C 1/ SYNCOM IV-3	39A	S
STS 51-B	Overmyer, Gregory, Lind, Thagard, Thornton, van den Berg, Wang	4-29-85	*Challenger*	Spacelab 3	39A	S
STS 51-G	Brandenstein, Creighton, Lucid, Nagel, Fabian, Baudry, Sultan Al-Saud	6-17-85	*Discovery*	Arabsat-1B/ Telstar 3-D/ Morelos 1	39A	S
STS 51-F	Fullerton, Bridges, Musgrave, England, Henize, Acton, Bartoe	7-29-85	*Challenger*	Spacelab 2	39A	S
STS 51-I	Engle, Covey, van Hoften, Lounge, Fisher	8-27-85	*Discovery*	AUSSAT 1/ ASC 1/ SYNCOM IV-4	39A	S
STS 51-J	Bobko, Grabe, Stewart, Hilmers, Pailes	10-03-85	*Atlantis*	DoD	39A	S
STS 61-A	Hartsfield, Nagel, Buchli, Bluford, Dunbar, Furrer, Ockeis, Messerschmid	10-30-85	*Challenger*	Spacelab D-1	39A	S
STS 61-B	Shaw, O'Connor, Cleave, Spring, Ross, Vela, Walker	11-26-85	*Atlantis*	Morelos-2/ AUSSAT-2/ RCA Satcom Ku-2	39A	S
STS 61-C	Gibson, Bolden, Chang-Diaz, Hawley, Nelson, Cenker, Nelson	1-12-86	*Columbia*	RCA Satcom Ku-1	39A	S
STS 51-L	Scobee, Smith, McNair, Resnik, Onizuka, Jarvis, McAuliffe	1-28-86	*Challenger*	TDRS-B	39A	U

first non-American to fly aboard an American spacecraft. A special payload operations control center at JSC became operational and tied science managers at the center to the Shuttle crew and to remote stations at MIT, to the European Space Agency in Bonn, Germany, and to the Goddard Space Flight Center in Maryland. For the first time, the TDRS satellite became fully operational and relayed an enormous volume of data from the Shuttle and its Spacelab payload.[16]

Hans Mark, NASA Deputy Administrator, visiting the payload operations control center at JSC, said one could actually watch the crew members performing their experiments on television monitors while scientists on the ground discussed results and suggested changes in the procedures in real time. Watching those people at work, he said, removed any doubts one might have had about the necessity of having human intelligence and judgment in space. During the flight, President Ronald Reagan and Chancellor Helmut Kohl of Germany talked to the crew, and Reagan and Kohl talked to each other through the *Columbia's* communications loop. *Columbia* landed at Edwards Air Force Base on December 8, 1983, after more than 10 days and 166 orbits about the Earth.[17] In those few days the world had somehow grown smaller and more interdependent.

NASA confused the historical record thereafter by changing the designation of Shuttle flights from the simple numerical sequence (STS-1, 2, etc.) to a formula by which flights were numbered first by the year of launch, second by the launch site (1 for KSC, 2 [in theory] for Vandenberg Air Force Base), and the final alphabetical designation representing the original order in which the flights were assigned to fly. By this time NASA knew that Shuttles would not fly in the order assigned. Shuttles, as it turned out, were temperamental machines and required "enormous tending." So did their payloads.

Thus STS 41-B (*Challenger*, [4] from 1984, [1] from KSC, [B] the second flight of the year) lifted off as planned on February 3, 1984. That is about as far as actual events conformed to the planning. A commercial Westar VI communications satellite carried for Western Union was deployed from the cargo bay, but when its booster engine malfunctioned after firing for only a few seconds, the satellite coasted into a useless 600-mile-high orbit instead of the intended 22,300-mile geosynchronous orbit, where it would have maintained a fixed position above the Earth's surface. A similar Palapa satellite, also built by Hughes Aircraft Company, was scheduled for deployment for the Indonesian Government. Hughes engineers decided that the misfiring of the Westar booster was an anomaly and the Indonesian Government agreed to release the Palapa from the cargo bay the next day. But the Palapa duplicated the Westar. "Almost impossibly," the Palapa rocket "sputtered and died just as Westar's had done." Palapa too was lost. Tens of millions of dollars of communications hardware orbited uselessly about the Earth.[18]

But the *Challenger's* work was not yet done. Bruce McCandless, who joined the astronaut corps in 1966 but had never previously flown in space, tested the new manned maneuvering unit (MMU)—a device which he helped design—in the world's first untethered flight that took him some 300 feet from the Shuttle. Bob Stewart took the "Buck Rogers" device out the next day for another flawless flight. The crew also tested techniques designed to rescue and refurbish the Solar Max satellite during a subsequent Shuttle mission. Solar Max, a $235 million scientific satellite launched in February 1980 from a Delta Rocket and designed for the study of solar flares in an effort to better understand "the violent nature of the Sun and its effects on Earth," now orbited uselessly in space with blown fuses in its attitude control box. Success with the MMU convinced the crew and mission planners that not only Solar Max but the errant Westar and Palapa satellites might be successfully rescued, repaired and returned to orbit using the MMU.[19]

Subsequently, STS 41-C lifted off from Cape Kennedy on April 6, 1984. At its first orbital stage, *Challenger's* Canadarm lifted the long duration exposure facility (LDEF) into orbit some 288 miles above the Earth. LDEF weighed 21,300 pounds and carried 57 different experiments developed by 200 researchers from 8 different countries. One of those

Astronaut George Nelson practices an EVA with a mockup of the MMU.

experiments proposed to test the fertility of 12 million tomato seeds after exposure to space for one year, when the LDEF facility was to be retrieved. Another tested the ability of honey bees to build a honeycomb in a space environment. After a few unsuccessful misshapen tries, the honeybees corrected for the microgravity environment and built a very comfortable Earth-like honeycomb.[20] As it turned out, LDEF had a much longer stay in space than planned.

At a second orbital plane 300 miles high, *Challenger* "parked" some 200 feet from the Solar Max satellite while mission specialists James D. van Hoften and George D. Nelson fitted into their space suits. Nelson then piloted the MMU out to Solar Max, but after three tries was unable to secure a specially designed locking device to the satellite. Scientists and engineers at an enhanced payload operations control center (interfaced with the Mission Control Center at JSC) at Goddard Space Flight Center directed the work. Nelson's attempts to grapple the satellite caused it to begin more erratic tumbling motions. During the night, Goddard payload control crews were able to stabilize Solar Max, and the next morning *Challenger* moved in closer for a try at grappling the satellite with the Canadarm. They succeeded on the first effort and brought the satellite into the cargo bay where Van Hoften and Nelson, working in their spacesuits, replaced the attitude control module and the main electronics box for one of the instruments. Solar Max was put back into orbit and to work the next day. The mission demonstrated both the ability to retrieve and repair a satellite in orbit, and the importance of having people in space who could use their intelligence, judgment and imagination in problem solving.[21] Rather than routine, Shuttle flights had become a continuing exercise in problem solving and improvisation.

In June, after three previous launch delays, onboard computers aborted lift-off of *Discovery* 4 seconds before launch due to a fuel valve problem. An August 29, another launch attempt failed due to problems with computer software for the main engine controllers. Meanwhile, NASA canceled a previously scheduled Shuttle mission (41-E) because delays and cost overruns required pruning the schedule to conserve funds. Engineers then refitted *Discovery* to carry some of the planned cargo for mission 41-F, and canceled that mission as well.[22] A Shuttle cargo manifest, as Henry S.F. Cooper explained in his story of flight crew training, *Before Lift-Off*, "was almost a living thing." Launch problems caused "periodic massive overhauls of the manifest" through many subsequent scheduled flights.

Even after a mission had been decided on and a launch date, a cargo, and a crew assigned to it, a dozen things could change, including its cargo, its crew, its launch date, the landing site, and its duration; indeed, entire missions were canceled just before launch and their cargoes and crews combined with future missions. The reshuffling could upset a year's planning and send ripples far down the manifest.[23]

Finally, all systems were go. On August 30, *Discovery* blasted off, and orbiting high above the Earth successfully deployed three large commercial communications satellites. Mission specialists conducted a variety of tests and experiments while a payload specialist, McDonnell Douglas employee Charles D. Walker, manufactured a pharmaceutical product for his company in the installed contractor-furnished laboratory.[24]

As additional evidence of NASA's confidence in the reliability and flight-worthiness of the Shuttle, President Ronald Reagan announced a "Teacher in Space Project" on August 27, 1984. The project, intended to generate a sense of wide public participation and to expand Shuttle flight opportunities to a wider range of private citizens, generated applications from some 11,000 public school teachers. From these a special panel selected 104 individuals for a nomination list from which 10 were chosen for final interviews and testing. Two candidates, Christa McAuliffe and runner-up Barbara Morgan, were chosen to begin training for flight at JSC in September 1985. The teacher in space would telecast live classroom lessons to school children throughout the United States. In preparation for the flight, school children participated in "space" lessons, and selected teachers helped prepare the final lesson plans.[25] The program evoked widespread public interest and helped rekindle a somewhat flagging public interest in Shuttle flights for the remainder of 1984 and 1985.

In part because of the wide publicity given the Teacher in Space Project, the October 1984 *Challenger* (STS 41-G) flight seems to have attracted a bit more of the public's interest, enthusiasm, and imagination than had been true in the flights made earlier in the year. *Challenger* carried a crew of seven on a heavily science-oriented mission that included the deployment of an Earth Radiation Budget Satellite (ERBS) designed to measure the amount of energy received from the Sun and reradiated into space and to study seasonal changes in the Earth's energy levels. During the mission, astronaut Kathryn D. Sullivan made the first spacewalk by an American woman. Payload specialists Paul Scully-Power, with the Naval Research Laboratory, conducted oceanographic experiments and Marc Garneau, from Canada, managed a package of Canadian-sponsored experiments having to do with medicine, climate, materials and robotics. An experimental package prepared by NASA's Office of Space Science and Applications (OSTA 3—an acronym for the original office title which was the Office of Space and Terrestrial Applications) included radar imaging experiments and Earth air pollution measuring devices. High-resolution cameras and experiments with refueling orbiting satellites comprised part of the workload.[26] There were, as usual, problems, but they were resolved in flight.

NASA provided yet another window to the public during the STS 41-G flight by permitting author Henry S.F. Cooper to live and work with the *Challenger* crew as they trained for their mission. Cooper's book, *Before Lift-Off: The Making of a Space Shuttle Crew*, published several years after the flight, described the "human dimensions" of training a Shuttle crew for a space mission. The flight itself, Cooper pointed out, was only the tip of the iceberg of spaceflight. For every hour in space the crew spent thousands of hours in every imaginable and many unimaginable training regimes.[27] And he might have added that, for every hour of Shuttle flight, thousands of other individuals at JSC and throughout the NASA system as well as countless others in the contractor's offices, laboratories, and factories labored uncounted hours.

Within weeks of *Challenger's* return, *Discovery* took off for a rescue mission to salvage the wayward Westar and Palapa communications satellites stranded since February. Insurers, faced with a $180 million loss, decided to fund the rescue with an additional $10.5 million payload investment. Mission specialists deployed two communications satellites (an Anik D2 and SYNCOM IV-1) before maneuvering into position alongside the Palapa B-2 satellite. Joe Allen approached the satellite in his MMU. While Hughes payload controllers on the ground slowed the satellite's rotation, Allen inserted a "stinger," tying the Palapa to his MMU.[28] As he recalled:

> The tip of the stinger was just beginning to penetrate the nozzle. The lights on my helmet flooded the empty volume inside the nozzle; I let the stinger drift further in, then pulled the lever that opened the toggles. I could see the fingers pop out, called "soft dock," as they expanded, and then shortened the stinger with the crank until the ring had pressed tight against the satellite: hard dock. "Stop the clock! I've got it tied!" That was all I could think to say, but the capture had been far easier than rodeo calf-roping would be.[29]

He and Gardner then attempted to secure the satellite to the Canadarm, being operated from within the Shuttle by Anna Fisher. But when a special A-frame built to hold the satellite failed to fit, Allen and Gardner manually fixed an adapter and hauled the satellite into its berthing in the cargo bay during a physical struggle of more than 5-1/2 hours. The exhausted crew and Mission Control personnel and payload controllers on the ground spent the next day planning how to best handle the Westar salvage operation.[30] It was decided to improvise once again.

Discovery rendezvoused with Westar. Dale Gardner flew out in the MMU, captured the satellite and brought it alongside. Joe Allen, riding on the end of the Canadarm, held the satellite while Gardner fitted the adapter to it. Then Anna Fisher lowered Allen, still holding Westar, into the cargo bay and the adapter with the Westar satellite slid smoothly into the guides. "We learned later," Allen recalled, "that when the news reached officials at Lloyd's of London, one of the principal underwriters of the satellites, they ordered the ringing of the Lutine bell, the insurers traditional signal of a successful recovery . . ."[31] Space was no longer just adventure, innovative engineering, or exciting science, but in part good business—at least for insurers when there were no losses.

Space Shuttles also involved government business—that is, secret Air Force government business. STS 51-C *(Discovery)* carried a classified DoD cargo. It lifted off on January 24, 1985, and returned 3 days later. It was the first NASA mission dedicated wholly to defense. It was a milestone in the course of a long and very difficult debate and tenuous relationship between two very different government agencies and two somewhat incompatible directives. The 1958 Space Act created two separately managed space programs, one civilian (NASA) and one military. The Air Force, which had the "responsibility for conducting the national security related space program" held strong reservations about the 1972 decision that the Shuttle would eventually replace all other launch vehicles. The

Air Force regarded the Shuttle as a "truck" with the cargo a separate entity from the vehicle and flight crew. The Air Force also persisted in retaining a capability to "launch national security related payloads on conventional expendable launch vehicles . . . until such time that the Shuttle proved to be completely reliable."[32]

In 1977 and 1978, when the Shuttle program faced new cutbacks from initiatives in the OMB and Congress, Air Force concerns about the impact of Shuttle budget reductions on national security led to a study headed by Hans Mark, then Undersecretary of the Air Force, and Thomas P. Stafford, who resigned from the astronaut corps in 1975 to become commander of the Air Force Flight Test Center at Edwards Air Force Base. Stafford became Deputy Chief of Staff of the Air Force for Research and Development in 1978. The classified study entitled "The Utility of Military Man in Space" attempted to offer Air Force options should the Shuttle program be truncated or canceled.[33]

Meanwhile, Hans Mark (Director of Ames Research Center, 1969 to 1977), acting in the interests of the Air Force, helped throw Pentagon support to NASA and the Shuttle program. Gerald Griffin, who in the late seventies and early eighties left JSC for administrative positions at Dryden Flight Research Center, Kennedy Space Center, and NASA Headquarters before replacing Chris Kraft as Director of JSC in 1982, said that the Shuttle program was in deep jeopardy. That the Air Force and Hans Mark stood up and said, "we have got to have the Shuttle" had a big impact on the future of the program. Subsequently, Griffin said, the Reagan administration was 100 percent sold on NASA and the Shuttle. And Hans Mark, in his fascinating personal account of *The Space Station*—which actually tells much more about NASA, space personalities, and the intricacies of space, government agencies, administrations and Congress than it does about the Space Station—explains how that relationship with the Reagan administration came to be.[34]

Nevertheless, the alliance between the DoD and NASA behind the Shuttle was an imperfect union, if not an unholy alliance, in part because of the Air Force's necessity for security which contradicted NASA's "open door" policy, and in part because the physical packages sometimes delivered by the Air Force did not fit the dimensions of the Shuttle. Thus, the Shuttle *Discovery* completed in 1983 and *Atlantis* delivered on April 3, 1985, had been redesigned during construction to meet DoD requirements. The dependency of national defense and intelligence operations on the Shuttle became even more critical when Shuttle flights were grounded for 2 years in consequence of the loss of the *Challenger* and its crew in January 1986.[35]

Yet, in the ensuing 12 months between the flight of STS 51-C and STS 51-L, nine Shuttle missions made successful flights into space, placed satellites in orbit and completed Spacelab and Getaway Special experiments. *Discovery*, in April 1985, carried a Congressman into space (and returned him to Earth)—Senator E.J. "Jake" Garn (R-Utah), chairman of the Senate committee with oversight responsibilities for NASA's budget. Although there were astronauts who went to Congress following a career with NASA (Senator John Glenn of Ohio, Senator Harrison Schmitt of New Mexico, and Representative Jack Swigert of Colorado), Garn was the first Congressman to reverse the procedure. At the age of 52, Garn trained about 200 hours for the flight and maintained his own rigorous physical fitness program. His project as a payload specialist was to be a medical specimen for a variety of tests.[36]

Once in orbit the *Discovery* crew worked unsuccessfully on a Leasat-3 satellite whose booster stage failed to fire. Upon landing, the Shuttle blew a tire. Before the end of the month, *Challenger* (STS 51-B) carried 2 monkeys, 24 rodents, Spacelab 3, 2 Getaway Special experiments, and placed a NUSAT (Northern Utah Satellite) into orbit. A Global Low Orbiting Message Relay Satellite (GLOMR) failed to deploy and was retrieved and returned to Earth for repairs and a later try.[37]

Space Shuttle Atlantis *blasts toward orbit on two powerful solid rocket boosters. After they are dropped, the three main engines continue to fire, fueled by the large external fuel tank.*

In June, *Discovery* (STS 51-G) successfully launched three communications satellites—one for Saudi Arabia, one for Mexico, and one for AT&T. Prince Sultan Salman Al-Saud flew as payload specialist for the Arabsat 1B satellite built by Aerospatiale of France. Patrick Baudry, from France, managed a package of French biomedical experiments. Mexico's Morelos 1 satellite provided "educational and commercial television programs, telephone and facsimile services, and data and business transmission services to even the most remote parts of Mexico." AT&T's Telstar 3-D could handle 86,400 two-way telephone calls at one time. Mission specialists also deployed and later retrieved a 2223 pound Spartan carrier with astronomy-related experiments.[38] There were problems, but this time they were precious few.

Challenger experienced problems with a main engine coolant valve that delayed its scheduled lift-off for several weeks. There were then minor problems with the orbiter that delayed lift-off for 1 hour and 37 minutes on July 29, 1985, and before the planned orbit was achieved, the Shuttle's No. 1 engine shut down. But the crew nursed the craft from a 124- to a 196-mile orbit using OMS burns. Once in a satisfactory orbit, the Spacelab 2 experiments conducted cooperatively by the crew in space and scientists on Earth exceeded all expectations. *Challenger* (STS 51-F) landed at Edwards Air Force Base on August 6, after 7 days and 22 hours in space.[39]

Approximately 2 months after its return from its previous mission, *Discovery* first encountered a launch delay caused by a local thunderstorm at Cape Canaveral and then another when a computer had to be replaced, but the STS 51-I mission got underway on August 27. The crew deployed with great difficulty an AUSSAT satellite. The satellite sunshield got tangled in the antenna, but Canadarm and the crew came to the rescue. The AUSSAT provided communications services including television, radio, data transmission, and air traffic control to Australia and its offshore islands. Another satellite deployed, the ASC-1 built by RCA, provided voice, data, facsimile and videoconferencing services to U.S. businesses and government agencies. The crew deployed a SYNCOM IV-4 satellite serving DoD, and rescued and repaired SYNCOM IV-3 which had been inoperative since it was put in orbit by *Discovery* in April 1985. When Canadarm failed, mission specialists James van Hoften and William F. Fisher accomplished the retrieval and repair in some unplanned EVAs.[40]

STS 51-J, the first flight of the Shuttle *Atlantis*, lifted off on October 3, on a classified DoD mission. *Challenger* (STS 61-A) left at the end of the month with a crew of eight and a payload largely financed and operated by West Germany and the European Space Agency. German and Dutch mission specialists, working with science controllers in the German Space Operations Center at Oberpfaffenhofen, near Munich, managed the payload experiments (Spacelab Deutsch 1) while mission controllers at JSC worked with the flight crew on Shuttle operations. The crew also deployed the GLOMR satellite that had previously been deployed but retrieved after an operating failure in April.[41] The mission demonstrated the radical changes that had occurred in worldwide communications and NASA's developing ability to service space communications systems. It generated an enormous store of data relating to human physiology, biology, chemistry and physics.

Three satellites, an AUSSAT-2 (for Australia), a Morelos-2 (Mexico), and a SATCOM Ku-2 (RCA American Communications) were placed in orbit by *Atlantis* (STS 61-B) which blasted off from Kennedy Space Center on November 26.[42] Astronauts also experimented with assembling large structures in space—a permanent space station having been given the President's blessings in the State of the Union Speech delivered by Ronald Reagan on January 25, 1984:

> We can follow our dreams to distant stars, living and working in space for peaceful, economic and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade.[43]

The EASE/ACCESS construction experiments in space made a Space Station seem eminently feasible—and within the decade.

Columbia (STS 61-C), however, seemed to defy the logic of it all by being exceedingly uncooperative during repeated launch attempts. Launches were scheduled variously for December 18 and 19, 1985, January 6, 7, 9, and 10, 1986, but valves, hydraulic systems, and weather, among other things, prevented a launch until January 12, 1986. Mission and payload specialists (the latter including Congressman Bill Nelson, Chairman of the Subcommittee on Science and Technology) deployed an RCA SATCOM Ku-1 satellite and conducted 13 Getaway Special and other experiments, but failed to get photographs of Halley's Comet as planned. The mission returned on January 18.[44]

January 28, 1986, Challenger *lifted off.*

Ten days later "*Challenger* (STS 51-L) lifted off from Pad B, Launch Complex 39, Kennedy Space Center, at 11:37 a.m. on January 28, 1986. At just 73 seconds into the flight an explosion occurred, which caused the loss of the vehicle and its crew."[45] It was a terrible end to life and to a time of optimism and innocence.

Deep grief, personal trauma, and a kind of paralysis swept through the NASA community. Americans everywhere felt a sense of loss and confusion. Astronauts made space, science, and the incredible machines used in spaceflight more human, understandable and comfortable. The *Challenger* accident not only touched the heart but somehow signaled a loss of control of man over the machine. Condolences arrived from all

This photograph of 51-L shows the flame developing near the O-Ring on the solid rocket booster. Moments later the entire craft exploded in a fiery ball.

over the world. Japan, Germany, Indonesia, Russia, Australia, Arabia—all had become through the Shuttle not just observers but participants in American spaceflight. And the children in American schools who waited eagerly for Christa McAuliffe's lessons on "The Ultimate Field Trip," and "Where We've Been, Where We're Going, Why?" would, with the rest of the American people, ponder those untaught lessons deeply.[46]

The President appointed an independent investigative commission headed by William P. Rogers, former Attorney General (1957-1961) and Secretary of State (1969-1971) to "establish the probable cause or causes of the accident" and to recommend corrective actions. Members included Neil A. Armstrong (vice-chairman), the first astronaut to walk on the Moon (who left NASA in 1971 for a career in academia) and Brigadier General

In Memoriam

The future is not free: The story of all human progress is one of a struggle against all odds. We learned again that this America, which Abraham Lincoln called the last, best hope of man on Earth, was built on heroism and noble sacrifice. It was built by men and women like our seven star voyagers, who answered a call beyond duty, who gave more than was expected or required and who gave it with little thought of worldly reward."

—President Ronald Reagan *January 31, 1986*

Francis R. (Dick) Scobee
Commander

Michael John Smith
Pilot

Ellison S. Onizuka
Mission Specialist One

Judith Arlene Resnik
Mission Specialist Two

Ronald Erwin McNair
Mission Specialist Three

S. Christa McAuliffe
Payload Specialist One

Gregory Bruce Jarvis
Payload Specialist Two

The Nation deeply mourned the loss of the Challenger *astronauts. Thousands gathered at JSC for memorial services on January 31, 1986.*

Charles (Chuck) Edward Yeager, who as an Air Force test pilot helped pioneer hypersonic flight. Sally K. Ride, physicist and the first American woman in space; Dr. Albert D. Wheelon, then senior vice president of the Space and Communications Group of Hughes Aircraft Company and a former Deputy Director of Science and Technology for the Central Intelligence Agency; Robert W. Rummel an aerospace engineer, aerospace consultant, and former vice president of Trans World Airlines for 35 years; and Arthur B. C. Walker, Jr., a professor of applied physics at Stanford University served. Dr. Richard P. Feynman, professor of theoretical physics and a Nobel prize winner, and Dr. Eugene E. Covert, professor of aeronautics at Massachusetts Institute of Technology and a consultant to NASA on rocket engines, provided their special expertise. Robert B. Hotz, an author, journalist and editorial consultant for McGraw-Hill offered a broad perspective. David C. Acheson, an attorney, author, and former senior vice president for Communications Satellite Corporation, with Major General Donald J. Kutyna, Director of Space Systems for the Air Force and a much-decorated pilot, completed the panel.[47] NASA and JSC initiated their own internal investigations. Individuals officially and unofficially reached their own conclusions.

John Young, Chief of the Astronaut Office at JSC, argued that the Shuttle is "not airline machinery," but is "an inherently risky machine to operate." Young, rather bitterly, argued that there were conditions and situations existing with the Shuttle programs that were as potentially catastrophic to the program as the 51-L accident. Flight safety, he believed, was not being given preeminence, and he faulted management for inadequate testing and poor safety standards and priorities. "If the management system is not big enough to STOP the Space Shuttle Program *whenever* necessary to make flight safety corrections, it will NOT survive and neither will our three Space Shuttles or their flight crews."[48]

Richard L. (Larry) Griffin, Commander of the Space Command at Falcon Air Force Station in Colorado felt impelled to respond to Young's memorandum, which had been disseminated throughout the NASA and Air Force space community, with the observation that Young was part of management and that spaceflight and aviation were inherently risky businesses. He enjoined a witch hunt and advised fair and responsible investigations.[49]

By the end of March 1986, NASA began, at the direction of Headquarters, an intensive and exhaustive examination of virtually every element of spaceflight associated with the Shuttle. During a 2-year study, NASA and each spaceflight center reassessed its program management structure. A special panel focused on the solid rocket motor joint design. Study groups reviewed all testing, checkout, and assembly processes involving flight hardware. Launch and abort rules and systems were completely reconsidered. Kennedy Space Center and JSC cooperated on a study of Shuttle flight manifest procedures and the impact of manifest changes on launch and flight operations. A "First Stage Abort Options Group," comprising largely JSC and Kennedy Space Center personnel, examined the entire history of Shuttle first-stage failures, launch aborts, and crew safety systems and concepts.[50]

Tommy W. Holloway, Chief of the Flight Director Office, headed a Mission Planning and Operations Team which reviewed all of the mission planning processes, flight design, scheduled crew activities, training, manifests, and safety procedures relating to the 51-L mission. The JSC team met intermittently with its counterpart, the Planning and Operations Panel of the Presidential Commission led by astronaut Dr. Sally Ride, during March and April. Presentations by many and diverse JSC personnel provided information and insight into basic Shuttle operations, payload integration processes, flight rules, safety procedures and training. Panelists engaged in intense discussions regarding flight schedule pressures, the rationale for landing at Kennedy Space Center, the history of aborts during solid rocket booster thrust experiences, and crew escape systems. There were sessions focusing on program development, and evaluations for "Failure Mode and Effects Analysis" and criticality ratings. The O-Ring seals on the Shuttle rocket booster engines were given careful attention, as were the procedures for monitoring and inspecting Shuttle and engine system components. Leonard Nicholson, in JSC's Space Shuttle Integration and Operations Office, explained payload manifest processes and relationships between the payload and the launch window. Panelists discussed payload safety, manifest changes, and the integration of changes, payloads, and crew safety procedures.[51] Congress, science panels, industry groups, and every NASA center participated in the exhaustive review and study process that emerged in the June 1986 *Report of the Presidential Commission on the Space Shuttle* Challenger *Accident*.

The Report concluded that the destruction of STS 51-L was "an Accident Rooted in History": "The Space Shuttle's Solid Rocket Booster problem began with the faulty design of its joint and increased as both NASA and contractor management first failed to recognize it as a problem, then failed to fix it, and finally treated it as an acceptable flight risk."[52]

The Commission believed that "cost" considerations had been preeminent in the selection of Morton Thiokol, Inc. as the contractor for the development of the solid rocket boosters, and that NASA managers explicitly considered the dual O-Ring seals designed by Thiokol to have increased reliability and decreased operational procedures at the launch site, "indicating good attention to low cost . . . and production."[53]

TABLE 18. The Shuttle in Flight, 1981 to 1989

Mission	Crew	Date	Mission elapsed time, hr:min:sec	Cumulative U.S. manhours in space, hr:min:sec
Space Transportation System				
STS-1 (OFT)	Young, Crippen	Apr. 12 to 14, 1981	54:20:53	22612:30:02
STS-2 (OFT)	Engle, Truly	Nov. 12 to 14, 1981	54:13:13	22720:56:28
STS-3 (OFT)	Lousma, Fullerton	Mar. 22 to 30, 1982	192:04:45	23105:05:58
STS-4 (OFT)	Mattingly, Hartsfield	Jun 27 to Jul 4, 1982	169:09:40	23443:25:18
STS-5	Brand, Overmyer, J. Allen, Lenoir	Nov. 11 to 16, 1982	122:14:26	23932:23:02
STS-6	Weitz, Bobko, Peterson, Musgrave	Apr. 4 to 9, 1983	120:23:42	24413:57:50
STS-7	Crippen, Hauck, Ride, Fabian, Thagard	Jun. 18 to 24, 1983	146:23:59	25145:57:45
STS-8	Truly, Brandenstein, D. Gardner, Bluford, W. Thornton	Aug. 30 to Sep. 5, 1983	145:08:43	25871:41:20
STS-9	Young, Shaw, Garriott, Parker, Lichtenberg, Merbold	Nov. 28 to Dec. 8, 1983	247:47:24	27358:25:44
41-B	Brand, Gibson, McCandless, McNair, Stewart	Feb. 3 to 11, 1984	191:15:55	28314:45:19
41-C	Crippen, Scobee, van Hoften, Nelson, Hart	Apr. 6 to 13, 1984	167:40:07	29153:05:54
41-D	Hartsfield, Coats, Resnik, Hawley, Mullane, Walker	Aug. 30 to Sep. 5, 1984	144:56:04	30022:42:18
41-G	Crippen, McBride, Ride, Sullivan, Leestma, Garneau, Scully-Power	Oct. 5 to 13, 1984	197:23:33	31404:27:09
51-A	Hauck, Walker, D. Gardner, A. Fisher, J. Allen	Nov. 8 to 16, 1984	191:44:56	32363:11:49
51-C	Mattingly, Shriver, Onizuka, Buchli, Payton	Jan. 24 to 27, 1985	73:33:23	32730:58:44
51-D	Bobko, Williams, Seddon, Hoffman, Griggs, Walker, Garn	Apr. 12 to 19, 1985	167:55:23	33906:26:25
51-B	Overmyer, F. Gregory, Lind, Thagard, W. Thornton, van den Berg, Wang	Apr. 29 to May 6, 1985	168:08:46	35083:27:47
51-G	Brandenstein, Creighton, Lucid, Fabian, Nagel, Baudry, Al-Saud	Jun. 17 to 24, 1985	169:38:52	36270:59:51
51-F	Fullerton, Bridges, Musgrave, England, Henize, Acton, Bartoe	Jul. 29 to Aug. 6, 1985	190:45:26	37606:17:53
51-I	Engle, Covey, van Hoften, Lounge, W. Fisher	Aug. 27 to Sep. 3, 1985	170:17:42	38457:46:23
51-J	Bobko, Grabe, Hilmers, Stewart, Pailes	Oct. 3 to 7, 1985	97:44:38	38946:29:33
61-A	Hartsfield, Nagel, Buchli, Bluford, Dunbar, Furrer, Messerschmid, Ockels	Oct. 30 to Nov. 6, 1985	168:44:51	40296:28:21
61-B	Shaw, O'Connor, Cleave, Spring, Ross, Neri-Vela, C. Walker	Nov. 26 to Dec. 3, 1985	165:04:49	41452:02:04

TABLE 18. The Shuttle in Flight, 1981 to 1989 (concluded)

Mission	Crew	Date	Mission elapsed time, hr:min:sec	Cumulative U.S. manhours in space, hr:min:sec
Space Transportation System				
61-C	Gibson, Bolden, Chang-Díaz, Hawley, G. Nelson, Cenker, B. Nelson	Jan. 12 to 18, 1986	146:03:51	42474:29:01
51-L	Scobee, Smith, Resnik, Onizuka, McNair, Jarvis, McAuliffe	Jan. 28, 1986	00:01:13	42474:37:32
STS-26	Hauck, Covey, Lounge, G. Nelson, Hilmers	Sep. 29 to Oct. 3, 1988	97:00:11	42959:38:27
STS-27	Gibson, G. Gardner, Mullane, Ross, Shepard	Dec. 2 to 6, 1988	105:05:35	43485:06:22
STS-29	Coats, Blaha, Bagian, Buchli, Springer	Mar. 13 to 18, 1989	119:38:52	44083:20:42
STS-30	D. Walker, Grabe, Thagard, Cleave, Lee	May 4 to 8, 1989	96:57:31	44568:08:17
STS-28	Shaw, Richards, Adamson, Leestma, Brown	Aug. 8 to 13, 1989	121:00:09	45173:09:02
STS-34	Williams, McCulley, Chang-Díaz, Lucid, E. Baker	Oct. 18 to 23, 1989	120:39:24	45776:26:02
STS-33	F. Gregory, Blaha, Musgrave, Carter, K. Thornton	Nov. 22 to 27, 1989	120:06:46	46371:54:46
STS-32	Brandenstein, Wetherbee, Dunbar, Low, Ivins	Jan. 9 to 20, 1990	261:00:37	47676:57:51
STS-36	Creighton, Casper, Mullane, Hilmers, Thuot	Feb. 28 to Mar. 4, 1990	106:18:22	48208:29:41
STS-31	Shriver, Bolden, Hawley, McCandless, Sullivan	Apr. 24 to 29, 1990	121:16:06	48814:50:11
STS-41	Richards, Cabana, Shepherd, Melnick, Akers	Oct. 6 to 10, 1990	98:10:03	49305:40:26
STS-38	Covey, Culbertson, Springer, Meade, Gemar	Nov. 15 to 20, 1990	117:54:27	49895:12:41
STS-35	Brand, G. Gardner, Hoffman, Lounge, Parker, Durrance, Parise	Dec. 2 to 10, 1990	215:05:07	51400:48:30

U.S. Manhours in Space

Program	Mercury	Gemini	Apollo	Skylab	ASTP	STS
Manhours in space	54	1940	7506	12,352	652	20,124
Number of manned flights	6	10	11	3	1	28
Crew members	1	2	3	3	3	2 to 8

Cumulative U.S. manhours in space: 51,400 hours 48 minutes 30 seconds

Source: Shuttle Flight Data and In-Flight Anomaly List, Revision Q, July 1989.

Despite evidence provided initially by tests and later indicated by actual flight, Thiokol and NASA engineers regarded leakages or faults in the O-Ring seals on the Shuttle rocket booster engines as "not desirable" but "acceptable." Engine tests run in 1977, showed that the seal housing the O-Ring opened rather than closed (as expected in the design) under extreme pressures, thus increasing the pressure on the actual O-Ring (Viton rubber seals). Thiokol engineers called this "joint rotation," and in their reports to NASA managers at Marshall Space Flight Center noted that they did not anticipate significant problems resulting from it. Marshall engineer Leon Ray, however, through his chief, John Q. Miller, advised a redesign of the joints "to prevent hot gas leaks and resulting catastrophic failure." Although Marshall engineers pursued the problem through 1978, and Leon Ray and Glenn Eudy personally visited Precision Rubber Products and Parker Seal Company (which manufactured the O-Rings) and informed them of the test results, the O-Ring design was not changed.[54]

Inspections following the flight of STS-2 in 1981, demonstrated serious O-Ring erosion. Marshall decided that the secondary O-Rings used as a backup, or redundant system for the first set of O-Rings, actually ceased to function under a certain set of pressure conditions—but they agreed with Thiokol engineers that those conditions would be "exceptional" and that the primary O-Ring seal was reliable. Subsequent inspections and tests turned up no serious O-Ring problem until STS 41-B returned in February 1984 with O-Ring erosion damage. But laboratory tests indicated that such erosion should not constrain future launches. In January 1985, following a launch of STS 51-C under unusually cold conditions at Cape Canaveral (51 degrees F), O-Ring erosion showed on both boosters. Although some thought that cold temperatures at launch may have exacerbated the O-Ring problem, O-Ring blowby had occurred on six flights on which temperatures ranged from 51 degrees F to 80 degrees F. Each of the next four flights during 1985 showed evidence of joint seal leakage. In July, Roger Boisjoly, a Thiokol engineer, advised that unless the seal problem were resolved a flight failure might be expected—"a catastrophe of the highest order—loss of human life."[55] But continuing successful flights, perceived pressures by NASA to perform, and the unspoken elements of costs seemed to mitigate the sense of danger or the urgency to redesign and remanufacture. Thus, on a very cold day in January 1986, *Challenger* left the Earth and met disaster.

The accident traumatized NASA, left a legacy of personal sorrow, and instigated an almost unremitting public and media investigation and reinvestigation of the accident. Was the Shuttle program a policy failure? Was it a "free fall" to disaster? Was there a cover-up by NASA? Why did the Shuttle blow up? Why were they dead? And then the nagging question: "Whither America in Space?" There was a NASA internal investigation, an official Presidential Commission investigation, a Congressional Science and Technology Committee study, an official NASA implementation or response to Commission recommendations, and an "After Challenger, What Next?" study headed by Dr. Sally K. Ride that focused on goals and future programs.[56]

JSC, as the Shuttle lead center, established status review teams to implement and monitor recommendations by the Presidential Commission. They included a Design Team headed by Aaron Cohen, a Shuttle Management Structure Team under Richard (Dick) Kohrs, a Criticality Review and Hazard Analysis group led by Bill J. McCarty, a Safety Organization under Martin L. Raines, an Improved Communications Team also led by

Kohrs, and a Landing Safety Team under Bryan O'Connor. Cliff Charlesworth directed the Launch Abort and Crew Escape Team, Leonard Nicholson's Flight Rate Group helped establish new criteria for establishing the parameters of flight frequency, and Gary Coultas's team monitored new maintenance safeguard procedures. These teams reported directly to Headquarters on the progress of implementing Commission recommendations. NASA submitted a preliminary report to the President in June 1986, and a follow-up status report the following June 1987.[57]

Paradoxically, in the short term, the *Challenger* disaster appeared to strengthen support for the Shuttle program. Discussion, concentrated media attention, indications of haste and carelessness by NASA and its contractors, and some very outspoken public criticism and hostility seemed to sharpen the public's generally positive view and confidence in NASA. By January 1987, the public was expecting an early return to flight. In that, they were disappointed. Funding attitudes, however, changed markedly. Perhaps in an effort to assuage the *Challenger* trauma, Congress seemed to become more, rather than less, willing to fund new programs.[58] Although always qualified, always conditioned by costs, time, expediency, and alternative views, NASA and the Shuttle survived the *Challenger* crisis. The Agency and JSC began to mend the wounds. NASA revised its Shuttle organization. Managers and contractors worked to correct and improve the spacecraft. Ultimately, the *Challenger* disaster forced a reappraisal of national objectives in space and helped build a stronger foundation for new initiatives in space.