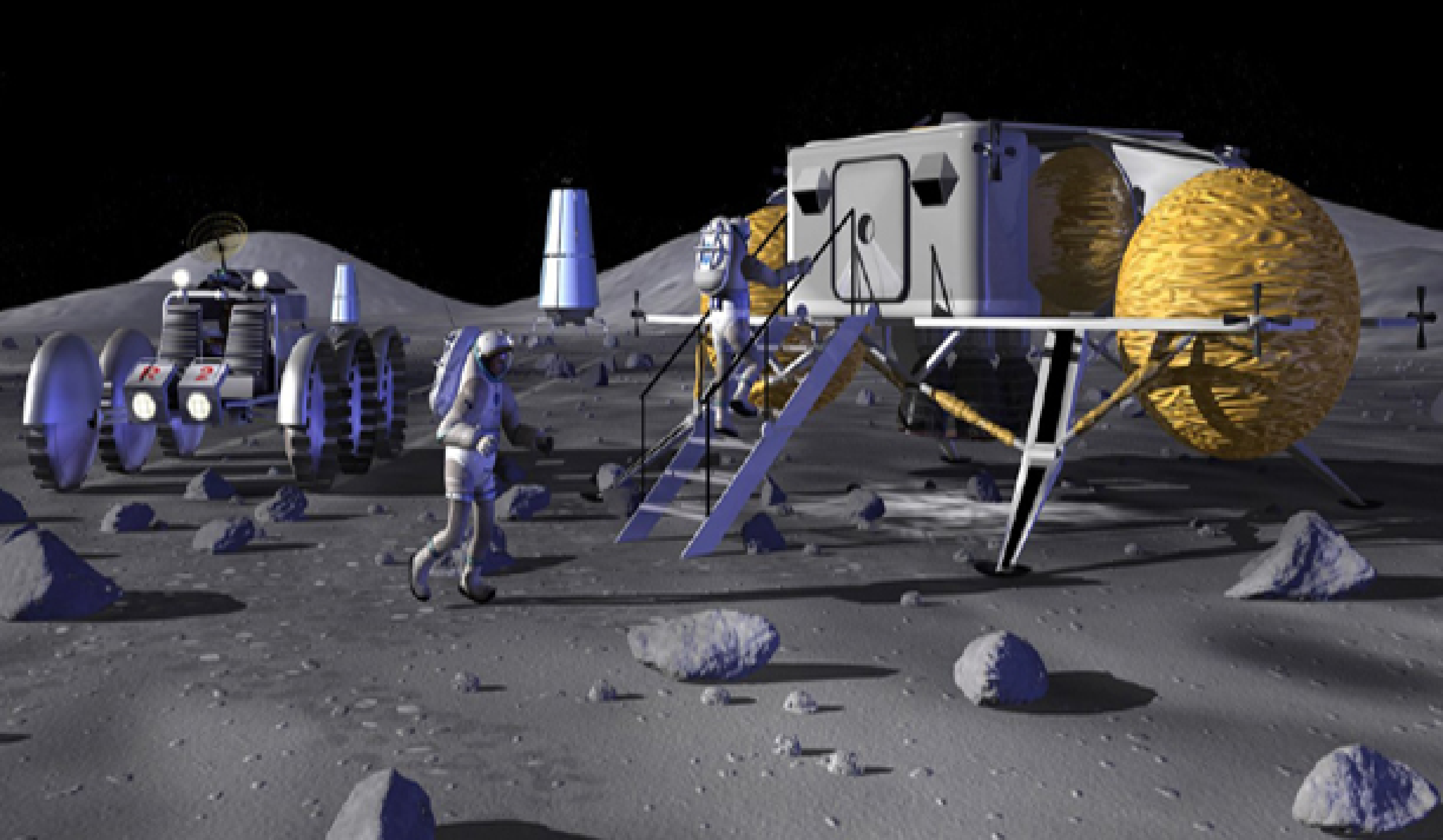
Handbook of

Human Spaceflight Missions and Programs

Aimee Wallace

Alize Scott



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Chapter 1

Human Spaceflight

Edward White on a spacewalk during the Gemini 4 mission

Human spaceflight is spaceflight with a human crew and possibly passengers. This makes it unlike robotic space probes or remotely-controlled satellites. Human spaceflight is sometimes called **manned spaceflight**, a term now deprecated by major space agencies in favor of its gender-neutral alternative.

The first human spaceflight was accomplished on April 12, 1961 by Soviet cosmonaut Yuri Gagarin. The only countries to have independent human spaceflight capability are Russia, United States and China. As of 2010, human spaceflights are being actively launched by the Soyuz programme conducted by the Russian Federal Space Agency, the Space Shuttle program conducted by NASA, and the Shenzhou program conducted by the China National Space Administration.

The US will lose governmental human spaceflight launch capability upon retirement of the Space Shuttle, expected in 2011. Under the Bush administration, the Constellation program included plans for canceling the Shuttle and replacing it with the capability for spaceflight beyond low Earth orbit. In the 2011 United States federal budget, the Obama administration proposed canceling Constellation. Under the new plan, NASA would rely on transportation services provided by the private sector, such as Space X's Falcon 9. The period between the retirement of the Shuttle and the initial operational capability of new systems (either Constellation or the new commercial proposals), similar to the gap between the cancellation of Apollo and the first Space Shuttle flight, is often referred to as the human spaceflight gap.

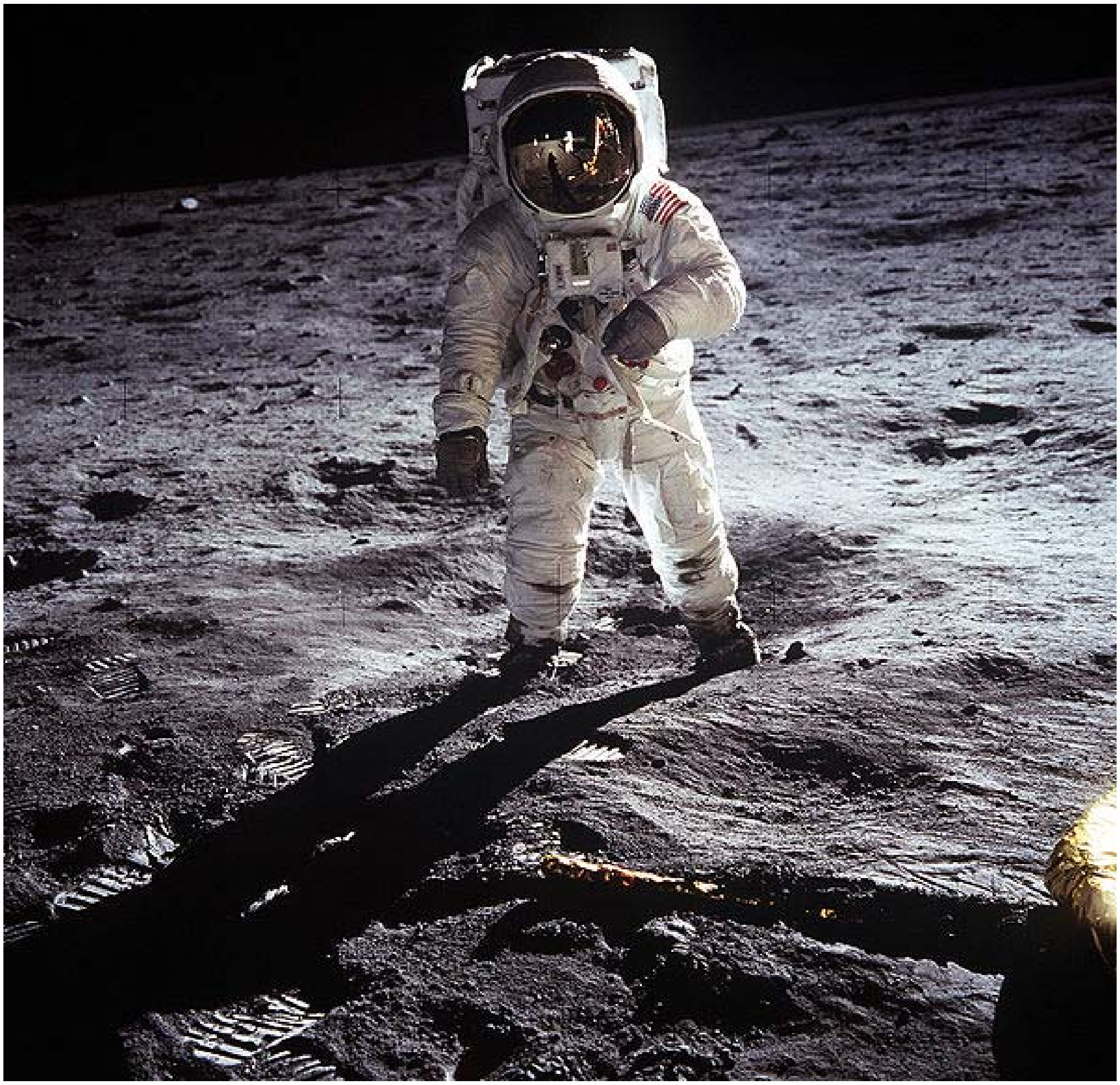
In recent years there has been a gradual movement towards more commercial forms of spaceflight. A number of non-governmental startup companies have sprung up in recent years, hoping to create a space tourism industry. For a list of such companies, and the spacecraft they are currently building. NASA has also tried to stimulate private spaceflight through programs such as Commercial Crew Development (CCDev) and Commercial Orbital Transportation Services (COTS). With its 2011 budget proposals released in early February 2010 , the Obama administration is moving towards a model where commercial companies would supply NASA with transportation services of both crew and cargo to low Earth orbit. The vehicles used for these services would then serve both NASA and potential commercial customers. NASA intends to spend $6 billion in the coming years to develop commercial crew vehicles, using a model similar to that used under COTS.

History

First human spaceflights

Yuri Gagarin, the first man in space, in his space suit during the Vostok 1 mission

The first human spaceflight took place on April 12, 1961, when cosmonaut Yuri Gagarin made one orbit around the Earth aboard the Vostok 1 spacecraft, launched by the Soviet space program and designed by the rocket scientist Sergey Korolyov. Valentina Tereshkova became the first woman in space on board Vostok 6 on June 16, 1963. Both spacecraft were launched by Vostok 3KA launch vehicles. Alexei Leonov made the first spacewalk when he left the Voskhod 2 on March 8, 1965. Svetlana Savitskaya became the first woman to do so on July 25, 1984.



Buzz Aldrin on the surface of the Moon during Apollo 11

The United States became the second nation to achieve manned spaceflight, with the suborbital flight of astronaut Alan Shepard aboard *Freedom 7*, carried out as part of Project Mercury. The spacecraft was launched on May 5, 1961 on a Redstone rocket. The first U.S. orbital flight was that of John Glenn aboard *Friendship 7*, which was launched February 20, 1962 on an Atlas rocket. Since 1981 the U.S. has conducted all its human spaceflight missions with reusable Space Shuttles. Sally Ride became the first American woman in space in 1983. Eileen Collins was the first female Shuttle pilot, and with Shuttle mission STS-93 in July 1999 she became the first woman to command a U.S. spacecraft.

The People's Republic of China became the third nation to achieve human spaceflight when Yang Liwei launched into space on a Chinese-made vehicle, the Shenzhou 5, on October 15, 2003. The flight made China the third nation to have launched its own manned spacecraft using its own launcher. Previous European (Hermes) and Japanese (HOPE-X) domestic manned programs were abandoned after years of development, as was the first Chinese attempt, the Shuguang spacecraft.

The farthest destination for a human spaceflight mission has been the Moon. The only missions to the Moon have been those conducted by NASA as part of the Apollo program. The first such mission, Apollo 8, orbited the Moon but did not land. The first Moon landing mission was Apollo 11, during which—on July 20, 1969—Neil Armstrong and Buzz Aldrin became the first people to set foot on the Moon. Six missions landed in total, numbered Apollo 11–17, excluding Apollo 13. Altogether twelve men walked on the Moon, the only humans to have been on an extraterrestrial body. The Soviet Union discontinued its program for lunar orbiting and landing of human spaceflight missions on June 24, 1974 when Valentin Glushko became General Designer of NPO Energiya.

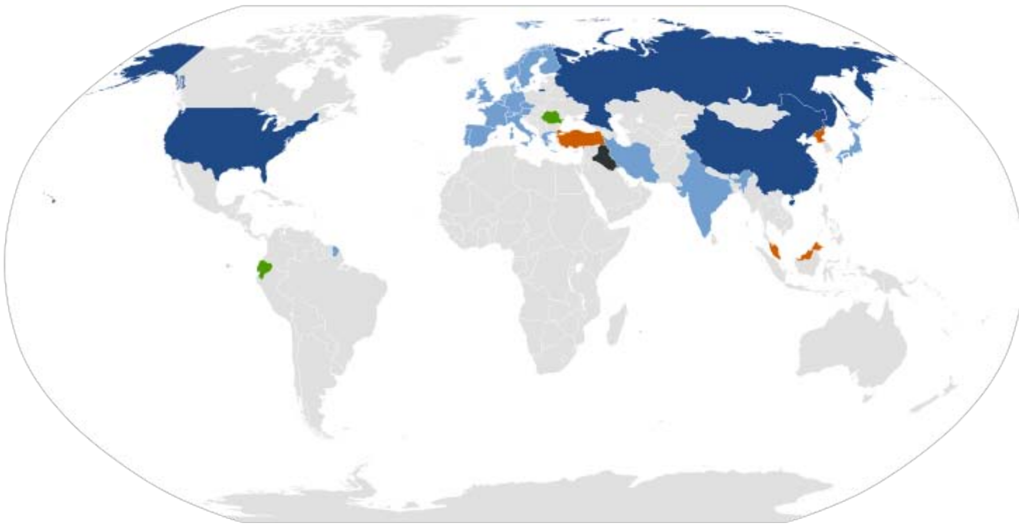
The longest single human spaceflight is that of Valeriy Polyakov, who left earth on January 8, 1994, and didn't return until March 22, 1995 (a total of 437 days 17 hr. 58 min. 16 sec. aboard). Sergei Krikalyov has spent the most time of anyone in space, 803 days, 9 hours, and 39 seconds altogether. The longest period of continuous human presence in space lasted as long as 3,644 days, eight days short of 10 years, spanning the launch of Soyuz TM-8 on September 5, 1989 to the landing of Soyuz TM-29 on August 28, 1999.

For many years beginning in 1961, only two countries, the USSR (later Russia) and United States, had their own astronauts. Citizens of other nations flew in space, beginning with the flight of Vladimir Remek, a Czech, on a Soviet spacecraft on March 2, 1978. As of 2010, citizens from 38 nations (including space tourists) have flown in space aboard Soviet, American, Russian, and Chinese spacecraft.

Space programs

As of 2010, human spaceflight missions have been conducted by the former Soviet Union/(Russia), the United States, the People's Republic of China and by the private spaceflight company Scaled Composites.

Several other countries and space agencies have announced and begun human spaceflight programs by their own technology, including India (ISRO), Ecuador (EXA), Japan (JAXA), Iran (ISA) and Malaysia (MNSA).



Countries which have human spaceflight agendas

Currently the following spacecraft and spaceports are used for launching human spaceflights:

- Soyuz with Soyuz rocket—Baikonur Cosmodrome
- Space Shuttle—Kennedy Space Center
- International Space Station (ISS)—Assembled in orbit; crews transported by the previous two spacecraft
- Shenzhou spacecraft with Long March rocket—Jiuquan Satellite Launch Center

Historically, the following spacecraft and spaceports have also been used for human spaceflight launches:

- Vostok—Baikonur Cosmodrome
- Mercury—Cape Canaveral Air Force Station
- Voskhod—Baikonur Cosmodrome
- X-15—Edwards Air Force Base, (two internationally recognized suborbital flights in program)
- Gemini—Cape Canaveral Air Force Station
- Apollo—Kennedy Space Center (Apollo 7 at Cape Canaveral Air Force Station)
- Salyut space station—Baikonur Cosmodrome
- Almaz space station—Baikonur Cosmodrome (Almaz was a series of military space stations under cover of the civilian name Salyut)
- Skylab space station—Kennedy Space Center
- Mir space station—Baikonur Cosmodrome
- SpaceShipOne with White Knight—Mojave Spaceport

Numerous private companies attempted human spaceflight programs in an effort to win the $10 million Ansari X Prize. The first private human spaceflight took place on June

21, 2004, when SpaceShipOne conducted a suborbital flight. SpaceShipOne captured the prize on October 4, 2004, when it accomplished two consecutive flights within one week. SpaceShipTwo, launching from the carrier aircraft White Knight Two, is planned to conduct regular suborbital space tourism.

Most of the time, the only humans in space are those aboard the ISS, whose crew of six spends up to six months at a time in low Earth orbit.

NASA and ESA now use the term "human spaceflight" to refer to their programs of launching people into space. Traditionally, these endeavors have been referred to as "manned space missions."

National spacefaring attempts

Successfully executed manned programs are in **bold**.
Suborbital spaceflights are in *italics*.

Nation/Organization	Space agency	National term	First launched astronaut	Date	Spacecraft	Launcher
Soviet Union	Soviet space program (OKB-1 Design Bureau)	cosmonaut космонавт (Russian) kosmonavt	Yuri Gagarin	April 12, 1961	Vostok spacecraft	Vostok
United States	National Aeronautics and Space Administration (NASA)	astronaut	Alan Shepard	May 5, 1961	Mercury spacecraft	Redstone
China	China space program	宇航员 (Chinese) yǔhángyuán 航天员 (Chinese) hángtiānyuán	...	1973 (abandoned)	Shuguang 1	Long March 2A
China	China space program	宇航员 (Chinese) yǔhángyuán 航天员 (Chinese) hángtiānyuán	...	1981 (abandoned)	Piloted FSW	Long March 2
ESA	European Space Agency (ESA)	astronaut spationaut spationaute (French)	...	1992 (abandoned)	Hermes	Ariane V
Iraq	...	رجل فضاء (Arabic) rajul faḍā رائد فضاء (Arabic) rāib faḍā ملاح فضائي (Arabic) mallāḥ faḍāiy	...	2001 (abandoned)	...	Tammouz 2 or 3
Japan	Japan Aerospace Exploration Agency (JAXA)	宇宙飛行士 (Japanese) uchūhikōshi	...	2003 (abandoned)	HOPE-X	H-II

China	China National Space Administration (CNSA)	taikonaut 太空人 (Chinese) tàikōng rén 宇航员 (Chinese) yǔhángyuán 航天员 (Chinese) hángtiānyuán	Yang Liwei	October 15, 2003	Shenzhou spacecraft	Long March 2F
India	Indian Space Research Organisation (ISRO)	vyomanaut gaganaut aakashagaami brahmāndagaami antarikshyaatri	...	2016 (approved)	Orbital Vehicle (OV)	GSLV Mk II
Iran	Iranian Space Agency (ISA)	فضانورد (Persian) faza navard	...	2017 (planned)	ISA manned spacecraft	...
ESA	European Space Agency (ESA)	astronaut spationaut spationaute (French)	...	2020 (approved conceptually but full development not begun)	ARV phase-2 (may be changed to CSTS)	Ariane V
Japan	Japan Aerospace Exploration Agency (JAXA)	宇宙飛行士 (Japanese) uchūhikōshi	...	2025 (planned)	HTV-based spacecraft	H-IIB
Romania	Romanian Cosmonautics and Aeronautics Association (ARCASPACE)	astronaut astronaut (Romanian)	...	TBA (approved)	Stabilo-mission8	ARCASPACE air-balloon

Safety concerns

Planners of human spaceflight missions face a number of safety concerns.

Life support

The immediate needs for breathable air and drinkable water are addressed by the life support system of the spacecraft.

Medical issues

Effects of microgravity

Medical data from astronauts in low earth orbits for long periods, dating back to the 1970s, show several adverse effects of a microgravity environment: loss of bone density, decreased muscle strength and endurance, postural instability, and reductions in aerobic capacity. Over time these deconditioning effects can impair astronauts' performance or increase their risk of injury.

In a weightless environment, astronauts put almost no weight on the back muscles or leg muscles used for standing up. Those muscles then start to weaken and eventually get smaller. If there is an emergency at landing, the loss of muscles, and consequently the loss of strength can be a serious problem. Sometimes, astronauts can lose up to 25% of their muscle mass on long term flights. When they get back to ground, they will be considerably weakened and will be out of action for a while.

Astronauts experiencing weightlessness will often lose their orientation, get motion sickness, and lose their sense of direction as their bodies try to get used to a weightless environment. When they get back to Earth, or any other mass with gravity, they have to readjust to the gravity and may have problems standing up, focusing their gaze, walking and turning. Importantly, those body motor disturbances after changing from different gravities only get worse the longer the exposure to little gravity. These changes will affect operational activities including approach and landing, docking, remote manipulation, and emergencies that may happen while landing. This can be a major roadblock to mission success.

Radiation

Without proper shielding the crews of missions beyond low Earth orbit (LEO) might be at risk from high-energy protons emitted by solar flares. Lawrence Townsend of the University of Tennessee and others have studied the most powerful solar flare ever recorded. That flare was seen by the British astronomer Richard Carrington in September 1859. Radiation doses astronauts would receive from a Carrington-type flare could cause acute radiation sickness and possibly even death.

Another type of radiation, galactic cosmic rays, present further challenges to human spaceflight beyond LEO.

Radiation damage to the immune system

There is also some scientific concern that extended space flight might slow down the body’s ability to protect itself against diseases. Some of the problems are a weakened immune system and the activation of dormant viruses in the body. Radiation can cause both short and long term consequences to the bone marrow stem cells which create the blood and immune systems. Because the interior of a spacecraft is so small, a weakened immune system and more active viruses in the body can lead to a fast spread of infection.

Isolation

During long missions, astronauts are isolated and confined into small spaces. Depression, cabin fever and other psychological problems may result that impact crew safety and mission success.

Astronauts may not be able to quickly return to Earth or receive medical supplies, equipment or personnel if a medical emergency occurs. The astronauts may have to rely for long periods on their limited existing resources and medical advice from the ground.

Reentry safety

Reliability

Fatality risk

As of 2009, 18 crew members have died during actual spaceflight missions (see table). Over 100 others have died in accidents during activity directly related to spaceflight missions or testing.

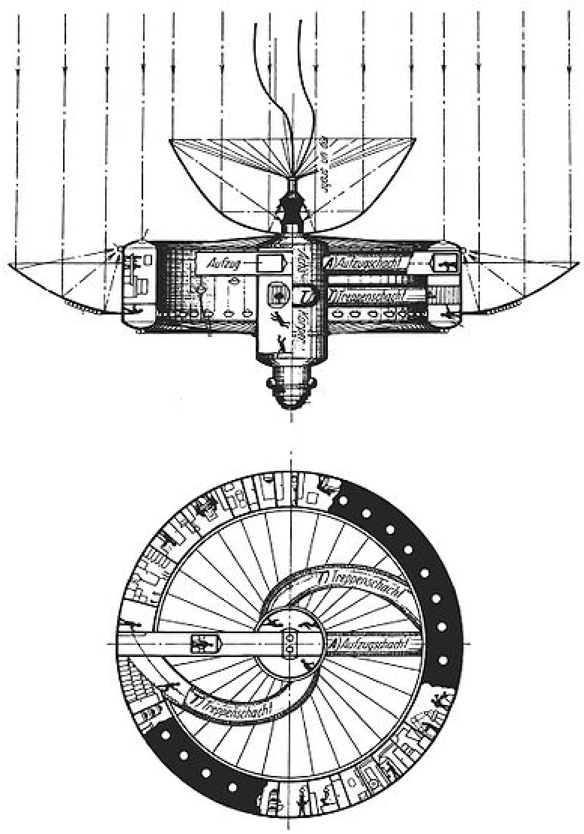
Year	#of Deaths	Mission	Known or likely cause
1967	1	Soyuz 1	
1971	3	Soyuz 11	Asphyxia
1986	7	Space Shuttle Challenger	(mission never reached space)
2003	7	Space Shuttle Columbia	Asphyxia from cabin breach, trauma from object impact, or burns from re-entry heat

Chapter 2

History of Spaceflight

Spaceflight, particularly human spaceflight, has long been a dream of humankind, but it was only in the 20th century that it became a reality.

Background



Description of a space station in Hermann Noordung's *The Problem of Space Travel* (1929).

The realistic proposal of spaceflight goes back to Konstantin Tsiolkovsky. His most famous work, "Исследование мировых пространств реактивными приборами" (*The Exploration of Cosmic Space by Means of Reaction Devices*), was published in 1903, but this theoretical work was not widely influential outside of Russia.

Spaceflight became an engineering possibility with the work of Robert H. Goddard's publication in 1919 of his paper 'A Method of Reaching Extreme Altitudes'; where his application of the de Laval nozzle to liquid fuel rockets gave sufficient power that interplanetary travel became possible. This paper was highly influential on Hermann Oberth and Wernher Von Braun, later key players in spaceflight.

In 1929, the Slovene officer Hermann Noordung was the first to imagine a quite complete space station in his book *The Problem of Space Travel*.

The first rocket to reach space was a German V-2 Rocket, on a test flight in June 1944.

Space Race

Orbital space flight, both unmanned and manned, was first developed by the Soviet Union and the United States during the Cold War, in a competition dubbed the *Space Race*.

The race began on July 29, 1957, when the US announced at the convention of the 1957-1958 International Geophysical Year, its intent to launch an artificial satellite known as Vanguard by the spring of 1958. The Soviets reacted on July 31 by announcing they would launch a satellite in the fall of 1957. They succeeded in launching Sputnik 1 on October 4, 1957. After a series of Vanguard failures, the US succeeded in launching its first satellite, Explorer 1 on February 1, 1958. This carried scientific instrumentation and detected the theorized Van Allen radiation belt.

The US public shock over Sputnik 1 became known as the Sputnik crisis. On July 29, 1958, the US Congress passed legislation turning the National Advisory Committee for Aeronautics (NACA) into the National Aeronautics and Space Administration (NASA) with responsibility for the nation's civilian space programs. In 1959, NASA began Project Mercury to launch single-man capsules into Earth orbit, and chose a corps of seven astronauts introduced as the *Mercury Seven*.

Yuri Gagarin, the first man in space, in his space suit in preparation for the Vostok 1 mission

On April 12, 1961, the USSR announced the successful launch and return of its first *cosmonaut* (their chosen term for space travelers), Yuri Gagarin who made a single orbit aboard Vostok 1. On May 5, 1961 the US launched its first Mercury astronaut Alan Shepard in a capsule he named Freedom 7, but on a suborbital flight.

John Glenn, Jr., as he enters his Friendship 7 spacecraft (NASA)

The US public was becoming increasingly shocked and alarmed at the widening lead obtained by the USSR, so President John F. Kennedy announced on May 25 a plan to land a man on the moon by 1970, launching the three-man Apollo program. In January

1962, NASA announced a two-man spacecraft program named Project Gemini to support Apollo.

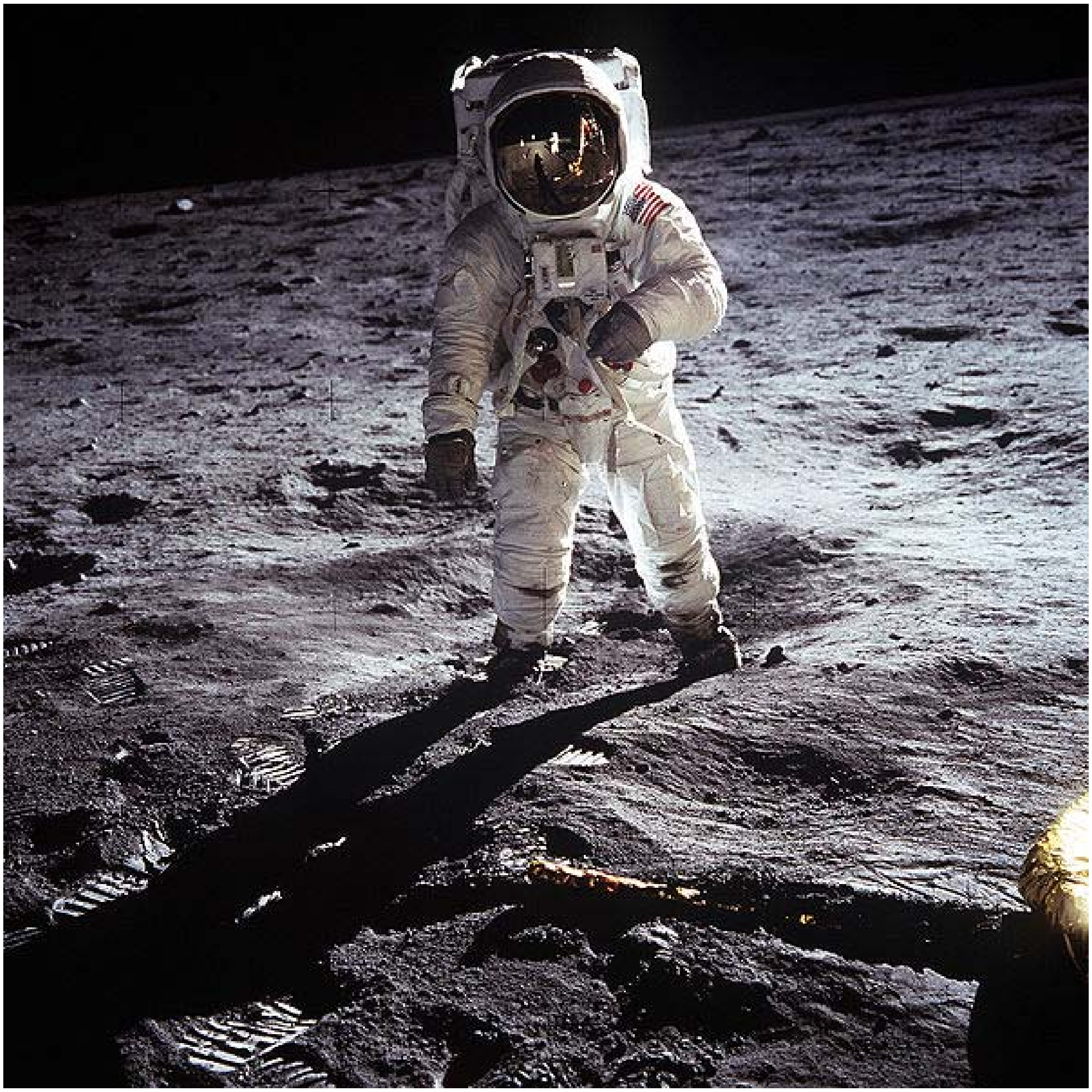
After one more suborbital Mercury flight, the US launched John Glenn to make three orbits in Friendship 7 on February 20, 1962. Project Mercury launched a total of six astronauts by May 16, 1963. The Soviets launched five more cosmonauts, including the first woman in space, the civilian parachutist Valentina Tereshkova in Vostok 6 on June 16, 1963, though this was done for political propaganda rather than a commitment to women's equality.

The Soviet government pressured its chief spacecraft designer, Sergey Korolyov, to quickly produce greater space achievements in competition with the announced Gemini and Apollo plans. Rather than allowing him to develop his plans for a crewed Soyuz spacecraft, he was forced to make modifications to squeeze two or three men into the Vostok capsule, calling the result Voskhod. Only two of these were launched. Voskhod 1 was the first spacecraft with a crew of three, who could not wear space suits because of size and weight constrictions. Alexei Leonov made the first spacewalk when he left the Voskhod 2 on March 8, 1965. He was almost lost in space when he had extreme difficulty fitting his inflated space suit back into the cabin through an airlock, and a landing error forced him and his crewmate to be lost in dangerous woods for hours before being found by the recovery crew.

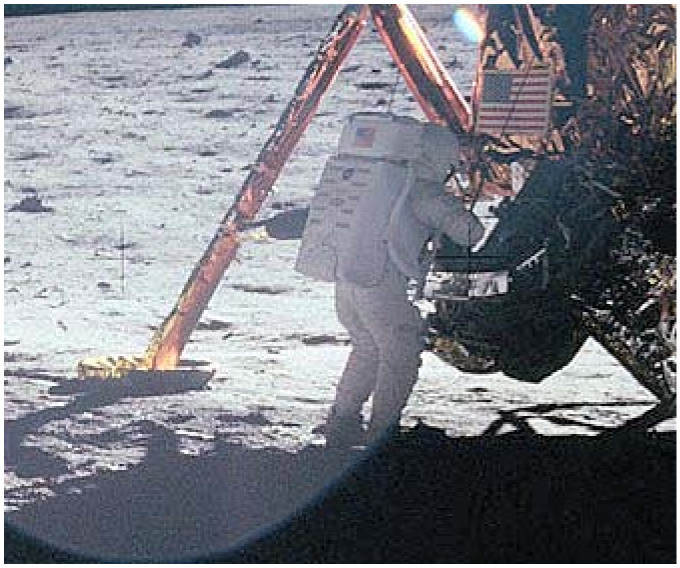
The start of manned Gemini missions was delayed a year later than NASA had planned, but ten largely successful missions were launched in 1965 and 1966, allowing the US to overtake the Soviet lead by achieving space rendezvous (Gemini 6A) and docking (Gemini 8) of two vehicles, long duration flights of eight days (Gemini 5) and fourteen days (Gemini 7), and demonstrating the use of extra-vehicular activity to do useful work outside a spacecraft (Gemini 12).

The USSR made no manned flights during this period, but continued to develop its Soyuz craft and secretly accepted Kennedy's implicit lunar challenge, designing Soyuz variants for lunar orbit and landing. They also attempted to develop the N1, a large, manned moon-capable launch vehicle similar to the US Saturn V.

As both nations rushed to get their new spacecraft flying with men, the intensity of the competition caught up to them in early 1967, when they suffered their first crew fatalities. On January 27, the entire crew of Apollo 1, "Gus" Grissom, Ed White, and Roger Chaffee, were killed by suffocation in a fire that swept through their cabin during a ground test approximately one month before their planned launch. Then on April 24, the single pilot of Soyuz 1, Vladimir Komarov, was killed in a crash when his landing parachutes tangled, after a mission cut short by electrical and control system problems. Both accidents were determined to be caused by design defects in the spacecraft, which were corrected before manned flights resumed.



Buzz Aldrin poses on the Moon allowing Neil Armstrong to photograph both of them using the visor's reflection.



Neil Armstrong works at the LM in one of the few photos taken of him from the lunar surface. NASA photo AS11-40-5886.

The US succeeded in achieving President Kennedy's goal on July 20, 1969, with the landing of Apollo 11. Neil Armstrong and Buzz Aldrin became the first men to set foot on the Moon. Six such successful landings were achieved through 1972, with one failure on Apollo 13.

The N1 rocket suffered four catastrophic unmanned launch failures between 1969 and 1972, and the Soviet government officially discontinued its manned lunar program on June 24, 1974 when Valentin Glushko succeeded Korolyov as General spacecraft Designer.

Both nations went on to fly relatively small, non-permanent manned space laboratories Salyut and Skylab, using their Soyuz and Apollo craft as shuttles. The US launched only one Skylab, but the USSR launched a total of seven "Salyuts", three of which were secretly Almaz military manned reconnaissance stations, which carried "defensive" cannons. Manned reconnaissance stations were found to be a bad idea, since unmanned satellites could do the job much more cost-effectively. The United States Air Force had planned a manned reconnaissance station, the Manned Orbital Laboratory which was cancelled in 1969. The Soviets cancelled Almaz in 1978.

In a season of detente, the two competitors declared an end to the race and shook hands (literally) on July 17, 1975 with the Apollo-Soyuz Test Project, where the two craft docked and the crews exchanged visits.

Post-Space Race US and Russian programs

US Space Shuttle

The Space Shuttle Columbia seconds after engine ignition, 1981 (NASA)

Although its pace slowed, space exploration continued after the end of the Space Race. The United States launched the first reusable spacecraft (Space Shuttle) on the 20th anniversary of Gagarin's flight, 12 April 1981. On 15 November 1988, the Soviet Union attempted to duplicate this with the Buran shuttle, its first and only reusable spacecraft. It was never been used again after the first flight; instead the Soviet Union continued to develop space stations using the Soyuz craft as the crew shuttle.

Sally Ride became the first American woman in space in 1983. Eileen Collins was the first female Shuttle pilot, and with Shuttle mission STS-93 in July 1999 she became the first woman to command a U.S. spacecraft.

The longest single human spaceflight is that of Valeriy Polyakov, who left earth on January 8, 1994, and didn't return until March 22, 1995 (a total of 437 days 17 hr. 58 min. 16 sec. aboard). Sergei Krikalyov has spent the most time of anyone in space, 803 days, 9 hours, and 39 seconds altogether. The longest period of continuous human presence in space lasted as long as 3,644 days, eight days short of 10 years, spanning the launch of Soyuz TM-8 on September 5, 1989 to the landing of Soyuz TM-29 on August 28, 1999.

International Space Station

Recent space exploration has proceeded, to some extent in worldwide cooperation, the high point of which was the construction and operation of the International Space Station. At the same time, the international space race between smaller space powers since the end of the 20th century can be considered the foundation and expansion of markets of commercial rocket launches and space tourism.

The United States continued missions to the ISS and other goals with the high-cost shuttle system, which will be retired in 2010. It also continues other space exploration, including major participation with the ISS with its own modules. It also plans a set of unmanned Mars probes, military satellites, and more. The Constellation space program, begun by President George W. Bush in 2004, aimed to launch a next-generation multifunction Orion spacecraft by 2018. A subsequent return to the Moon by 2020 was to be followed by manned flights to Mars, but the program was canceled in 2010 in favor of encouraging commercial US manned launch capabilities.

Russia, the successor to the Soviet Union, has high potential but smaller funding. Its own space programs, some of a military nature, perform several functions. They offer a wide commercial launch service while continuing to support the ISS with a several of their own modules. They also operate manned and cargo spacecrafts which will continue after US Shuttle program ends. They are developing a new multi-function PPTS manned spacecraft for use in 2018 and have plans to perform manned moon missions also. The program aims to put a man on the moon in the 2020s, becoming the second country to do so.

Programs of other nations

Later, cosmonauts and astronauts from other nations flew in space, beginning with the flight of Vladimir Remek, a Czech, on a Soviet spacecraft on March 2, 1978. As of 2007, citizens from 33 nations (including space tourists) have flown in space aboard Soviet, American, Russian, and Chinese spacecraft.

China, India, and Japan are increasingly capable of competing in space research and activity. These nations form the main players in the Asian space race.

European Union

The European Space Agency has taken the lead in commercial unmanned launches since the introduction of the Ariane 4 in 1988, but is in competition with NASA, Russia, Sea Launch (private), China, India and others. The ESA-designed manned shuttle Hermes and space station **Columbus**, were under development early on in Europe, however these projects were canceled, and Europe did not become the third major "space power".

Europe has launched various satellites, has utilized the manned Spacelab module aboard US shuttles, and has sent probes to comets and Mars. It also participates in **ISS** with its own module and the unmanned cargo spacecraft ATV.

Currently ESA has a program for development of an independent multi-function manned spacecraft CSTS scheduled for completion in 2018. Further goals include an ambitious plan called the Aurora Programme which intends to send a human mission to Mars soon after 2030. A set of various landmark missions to reach this goal are currently under consideration. The ESA has a multi-lateral partnership, and plans for spacecraft and further missions with foreign participation and co-funding.

China

The People's Republic of China, while possessing less funding than Europe's ESA and the United State's NASA, has achieved manned space flight, currently operate a commercial unmanned launch service, and owns multiple satellites. There are plans for a Chinese space station and a program to send unmanned probes to Mars in the near future. China stands poised to become the third *space power*.

China's first attempt at a manned spacecraft, Shuguang. was abandoned after years of development. But on October 15, 2003, it became the third nation to achieve human spaceflight when Yang Liwei launched into space on Shenzhou 5. This flight demonstrated China's capability to build its own manned spacecraft and launch vehicle.

The aggressiveness of China's progress has raised concerns by other nations. The US Pentagon released a report in 2006 detailing concerns of China's growing presence in space, including its capability for military action. In 2007 China tested a ballistic missile designed to destroy satellites in orbit, in violation of an international consensus against military maneuvers in space.

India

ISRO, India's national space agency, maintains an active space program and leads the group of Asian nations in major achievements and future plans. It operates a small commercial launch service and launched a successful unmanned lunar mission dubbed Chandrayaan-1 in October, 2007. India has plans for a further unmanned mission to the Moon in the near future, as well as a missions to Mars by 2012. The ISRO is currently developing a small shuttle system. With the recent success and a developing missions for manned inter-planet flights by 2025 to 2030, India has positioned itself as a contender for the third *space power*.

Japan

Japan's space agency, JAXA, is the third major player in the Asian space race. While not maintaining a commercial launch service, Japan has deployed a module in the **ISS** and operates an unmanned cargo spacecraft, the H-II Transfer Vehicle.

JAXA has plans to launch a Mars fly-by probe. Their lunar probe, SELENE, is touted as the most sophisticated lunar exploration mission in the post-Apollo era.

Although Japan developed the HOPE-X, Kankoh-maru, and Fuji manned capsule spacecraft, none of them have been launched. Japan's current ambition is to deploy a new manned spacecraft by 2025, and to establish a Moon base by 2030.

Other nations

Iran recently announced plans to begin its manned program in 2021.

Chapter 3

Vostok 1 (First Human Spaceflight)

Vostok 1

Восток-1

Mission insignia

Mission statistics

Mission name	Vostok 1 *Восток-1*
Spacecraft name	Ласточка (*Lastochka* - Swallow)
Spacecraft type	Vostok 3KA
Spacecraft mass	4,725 kg (10,420 lb)
Crew size	1
Call sign	Кедр (*Kedr* - Siberian Pine)
Booster	Vostok 8K72K
Launch pad	45°55′13″N 63°20′32″E / 45.9203°N 63.3422°E, Gagarin's Start, Baikonur Cosmodrome

Launch date	April 12, 1961 06:07 UTC
Landing site	51°16′14″N 45°59′50″E / 51.270682°N 45.99727°E
Landing	April 12, 1961 07:55
Mission duration	01:48
Number of orbits	1
Apogee	327 km (203 mi)
Perigee	169 km (105 mi)
Orbital period	89.34 minutes
Orbital inclination	64.95°

Crew photo

Yuri Gagarin in Sweden.

Related missions

Previous mission	**Subsequent mission**
Sputnik 10	Vostok 2

Vostok 1 (Russian: **Восток-1**, *Orient 1* or *East 1*) was the first human spaceflight, part of the Vostok program. The Vostok 3KA spacecraft was launched on April 12, 1961. The flight took Yuri Gagarin, a cosmonaut from the Soviet Union, into space. The flight marked the first time that a human entered outer space, as well as the first orbital flight of a manned vehicle. Vostok 1 was launched by the Soviet space program, and was designed by Soviet rocket scientists guided by Sergey Korolyov under military supervision of Kerim Kerimov and others.

Crew

Position	Cosmonaut
Pilot	Yuri Gagarin First spaceflight

Backup crew

Position	Cosmonaut
Pilot	Gherman S. Titov

Reserve crew

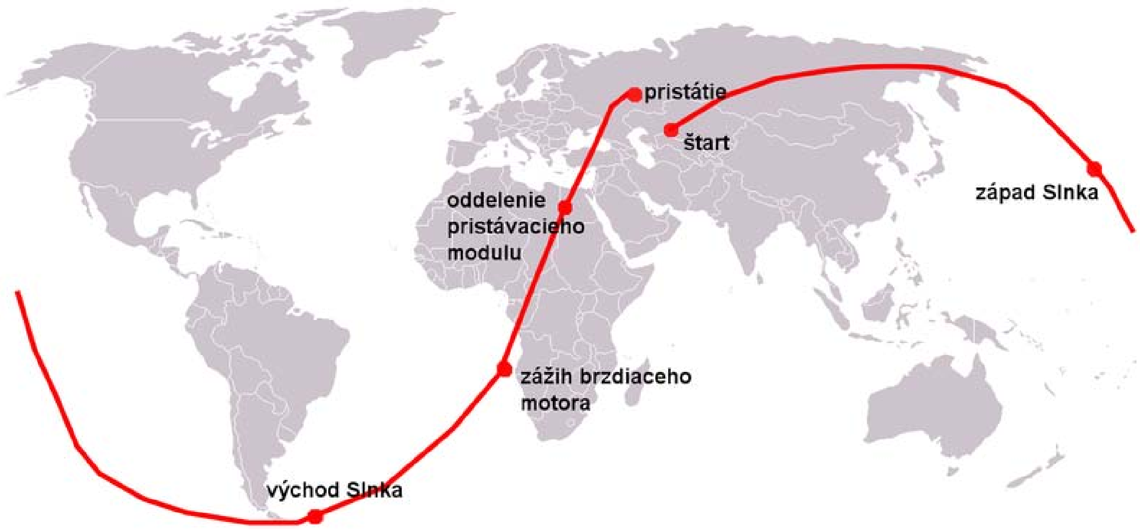
Position	Cosmonaut
Pilot	Grigori Nelyubov

Mission parameters

- **Mass:** 4,725 kg (10,420 lb)
- **Perigee:** 169 km (105 mi)
- **Apogee:** 327 km (203 mi)

- **Inclination:** 64.95°
- **Period:** 89.34 minutes

Mission highlights



Path of Gagarin's complete orbit; the landing point is west of takeoff point because of the eastward rotation of the Earth.

Gagarin orbited the Earth once in 108 minutes . He returned unharmed, ejecting from the Vostok capsule 7 km (23,000 ft) above the ground and parachuting separately to the ground since the capsule's parachute landing was deemed too rough for cosmonauts to risk.

Ground controllers did not know if a stable orbit had been achieved until 25 minutes after launch.

The spacecraft attitude control was run by an automated system. Medical staff and spacecraft engineers were unsure how a human being might react to weightlessness, and therefore the pilot's flight controls were locked out to prevent Gagarin from taking manual control. (Codes to unlock the controls were placed in an onboard envelope, for Gagarin's use in case of emergency.) Vostok could not change its orbit, only spacecraft attitude (orientation), and for much of the flight the spacecraft's attitude was allowed to drift. The automatic system brought Vostok 1 into alignment for retrofire about 1 hour into the flight.

Retrofire took place off the west coast of Africa, near Angola, about 8,000 km (5,000 mi) from the desired landing place. The liquid-fueled retrorockets fired for about 42 seconds. Because of weight constraints, there was no backup retrorocket engine. The spacecraft carried 10 days of provisions to allow for survival and natural decay of the orbit in the event the retrorockets failed.

Commemorative monument, Vostok-1 landing site near Engel's, Russia

After retrofire, the Vostok equipment module unexpectedly remained attached to the reentry module by a bundle of wires. The two halves of the craft were supposed to separate ten seconds after retrofire, but this did not happen until 10 minutes had passed. The spacecraft went through wild gyrations before the wires burned through and the descent module settled into the proper reentry attitude.

The FAI rules in 1961 required that a pilot must land with the spacecraft to be considered an official spaceflight for the FAI record books. At the time, the Soviet Union insisted that Gagarin had landed with the Vostok; the government forced the cosmonaut to lie in press conferences, and the FAI certified the flight. The Soviet Union admitted in 1971 that Gagarin had ejected and landed separately from the Vostok descent module.

The landing site coordinates are 51°16′14″N 45°59′50″E / 51.270682°N 45.99727°E, this is 4 km East of Smelovka, Province of Saratov, Russian Federation, and 29 km South South West of Engel's. At this location is a monument park. The central feature in the park is a 25 meter tall monument that consists of a silver metalic rocketship rising on a curved metalic column of flame, from a wedge shaped, white stone base. In front of this is a 3 meter tall, white stone statue of Yuri Gagarin, with one arm raised in greeting and the other holding a space helmet. The statue is wearing a spacesuit.

When Soviet officials filled out the FAI papers to register the flight of Vostok 1, they stated that the launch site was Baykonur at 47°22′00″N 65°29′00″E / 47.3666667°N 65.4833333°E. In reality, the launch site was near Tyuratam at 45°55′12.72″N 63°20′32.32″E / 45.9202°N 63.3423111°E, 250 km (160 mi) to the south west of "Baykonur". They did this to try to keep the location of the Space Center a secret. In 1995, Russian and Kazakh officials renamed Tyuratam Baikonur.

The re-entry capsule is now on display at the museum of RKK Energiya in Korolyov.

Officially the U.S. congratulated the Soviet Union on its accomplishments.

Mission timeline

Yuri Gagarin in Vostok 1

- **Wednesday, April 12, 1961** The Soviet press later reported that minutes before boarding the spacecraft, Yuri Gagarin made a speech: *"Dear friends, known and unknown to me, my dear compatriots and all people of the world! Within minutes from now, a mighty Soviet rocket will boost my ship into the vastness of outer space. What I want to tell you is this. My whole life is now before me as a single breathtaking moment. I feel I can muster up my strength for successfully carrying out what is expected of me."* Gagarin actually recorded this speech—"a stream of banalities prepared by anonymous speechwriters"—in Moscow.

- **Countdown begins** Yuri Gagarin is in the Vostok 1 spacecraft on the launchpad. His television picture appears on television screens in the launch control room from an onboard television camera. Sergey Korolyov speaks into a microphone:

"Zarya calling Kedr (Gagarin's call sign). The countdown is about to start." Gagarin replied, *"Roger. Feeling fine, excellent spirits, ready to go."*

- **06:07 UTC** Launch occurs from the Baikonur Cosmodrome Site No.1; after Gagarin's flight that launch pad became known as Gagarin's Start. At ignition and liftoff, Sergey Korolyov radios, *"Preliminary stage..... intermediate..... main..... LIFT OFF! We wish you a good flight. Everything is all right."* Gagarin replies, "Poyekhali! (*Off we go!*)."

- **06:09 UTC** Two minutes into the flight and the four strap-on booster sections of the Vostok rocket have used up the last of their propellant, they shut down and drop away from the core vehicle. (T+ 119 s)

- **06:10 UTC** The payload shroud covering Vostok 1 is released, this uncovers the window at Gagarin's feet with the optical orientation device *Vzor* (lit. "look" or "glance"). (T+ 156 s)

- **06:12 UTC** Five minutes into the flight and the Vostok rocket core stage has used up its propellant, shuts down and falls away from the Vostok spacecraft and final rocket stage. The final rocket stage ignites to continue the journey to orbit. (T+ 300 s)

- **06:13 UTC** The rocket is still firing, pushing Vostok 1 toward orbit. Gagarin reports, *" .. the flight is continuing well. I can see the Earth. The visibility is good. ... I almost see everything. There's a certain amount of space under cumulus cloud cover. I continue the flight, everything is good."*

- **06:14 UTC** The rocket continues to fire, starting to pass over central Russia now. Gagarin reports, *"Everything is working very well. All systems are working. Let's keep going!"*

- **06:15 UTC** Three minutes into the burn of the final rocket stage and Gagarin reports, *"*Zarya-1, Zarya-1*, I can't hear you very well. I feel fine. I'm in good spirits. I'm continuing the flight..."* Vostok 1 is moving further downrange from the Baikonur Cosmodrome. He is reporting back to *Zarya-1* (the Baikonur ground station) and must be starting to move out of radio range of that station.

- **06:17 UTC** The Vostok rocket final stage shuts down, ten seconds later the spacecraft separates and Vostok 1 reaches orbit. (T+ 676 s) Gagarin reports, *"The craft is operating normally. I can see Earth in the view port of the* Vzor*. Everything is proceeding as planned"*. Vostok 1 passes over Soviet Union and moves on over Siberia.

Part of the Vostok 1 control panel

- **06:21 UTC** Vostok 1 passes over the Kamchatka peninsula and out over the North Pacific Ocean. Gagarin radios, *"...the lights are on on the descent mode monitor. I'm feeling fine, and I'm in good spirits. Cockpit parameters: pressure 1; humidity 65; temperature 20; pressure in the compartment 1; first automatic 155; second automatic 155; pressure in the retro-rocket system 320 atmospheres..."*

- **06:25 UTC** As Vostok 1 begins its diagonal crossing of the Pacific Ocean from Kamchatka peninsula to the southern tip of South America, Gagarin asks, *"What can you tell me about the flight? What can you tell me?"*. He is requesting information about his orbital parameters. The ground station at Khabarovsk reports back, *"There are no instructions from No. 20 (Sergey Korolyov), and the flight is proceeding normally"* They are telling Gagarin that they don't have his orbital parameters yet because the spacecraft has been in orbit for only 6 minutes, but the spacecraft systems are performing well.

- **06:31 UTC** Gagarin transmits to the Khabarovsk ground station, *"I feel splendid, very well, very well, very well. Give me some results on the flight!"*. Vostok 1 is nearing the VHF radio horizon for Khabarovsk and they respond, *"Repeat. I can't hear you very well"*. Gagarin transmits again, *"I feel very good. Give me your data* *on the flight!"* Vostok 1 passes out of VHF range of the Khabarovsk ground station and contact is lost.

- **06:37 UTC** Vostok 1 continues on its journey as the Sun sets over the North Pacific. Gagarin crosses into night, northwest of the Hawaiian Islands. Out of VHF range with ground stations, communications must now take place via HF radio.

- **06:46 UTC** Khabarovsk ground station sends the message "KK" via telegraph (on HF radio to Vostok 1). This message means, "Report the monitoring of commands." They were asking Gagarin to report when the spacecraft automated descent system had received its instructions from the ground control. Gagarin reported back at 06:48 UTC.

- **06:48 UTC** Vostok 1 crosses the equator at about 170° West, traveling in a south east direction and begins crossing the South Pacific. Gagarin transmits over HF radio, *"I am transmitting the regular report message: 9 hours 48 minutes (Moscow Time), the flight is proceeding successfully. Spusk-1 is operating normally. The mobile index of the descent mode monitor is moving. Pressure in the cockpit is 1; humidity 65; temperature 20; pressure in the compartment 1.2 ... Manual 150; First automatic 155; second automatic 155; retro rocket system tanks 320 atmospheres. I feel fine..."*

- **06:49 UTC** Gagarin reports he is on the night side of the Earth.

- **06:51 UTC** Gagarin reports the sun-seeking attitude control system had been switched on. The sun-seeking attitude control system is used to orient Vostok 1 for retrofire. The automated orientation system consisted of two redundant systems: an automatic/solar orientation system and a manual/visual orientation system. Either system could operate the two redundant cold nitrogen gas thruster systems, each with 10 kg (22 lb) of gas.

- **06:53 UTC** The Khabarovsk ground station sends Gagarin the following message via HF radio, *"By order of No.33 (General Nikolai Kamanin) the transmitters have been switched on, and we are transmitting this: the flight is proceeding as planned and the orbit is as calculated."* They are telling Gagarin that Vostok 1 is in a stable orbit. He acknowledges the message.

- **06:57 UTC** Vostok 1 is over the South Pacific between New Zealand and Chile when Gagarin sends this message, *"...I'm continuing the flight, and I'm over America. I transmitted the telegraph signal "ON".*

- **07:00 UTC** Vostok 1 crosses the Strait of Magellan at the tip of South America. News of the Vostok 1 mission is broadcast on Radio Moscow.

- **07:04 UTC** Gagarin sends spacecraft status message, similar to the one sent at 06:48. The message is not received by ground stations.
- **07:09 UTC** Gagarin sends spacecraft status message, the message is not received by ground stations.
- **07:10 UTC** Passing over the South Atlantic, the Sun rises and Vostok 1 is in daylight again. Vostok 1 is 15 minutes from retrofire.
- **07:13 UTC** Gagarin sends spacecraft status message, similar to the one sent at 06:48. Moscow picks up this partial message from Gagarin, *"I read you well. The flight is going..."*
- **07:18 UTC** Gagarin sends spacecraft status message, the message is not received by ground stations.
- **07:23 UTC** Gagarin sends spacecraft status message, the message is not received by ground stations.

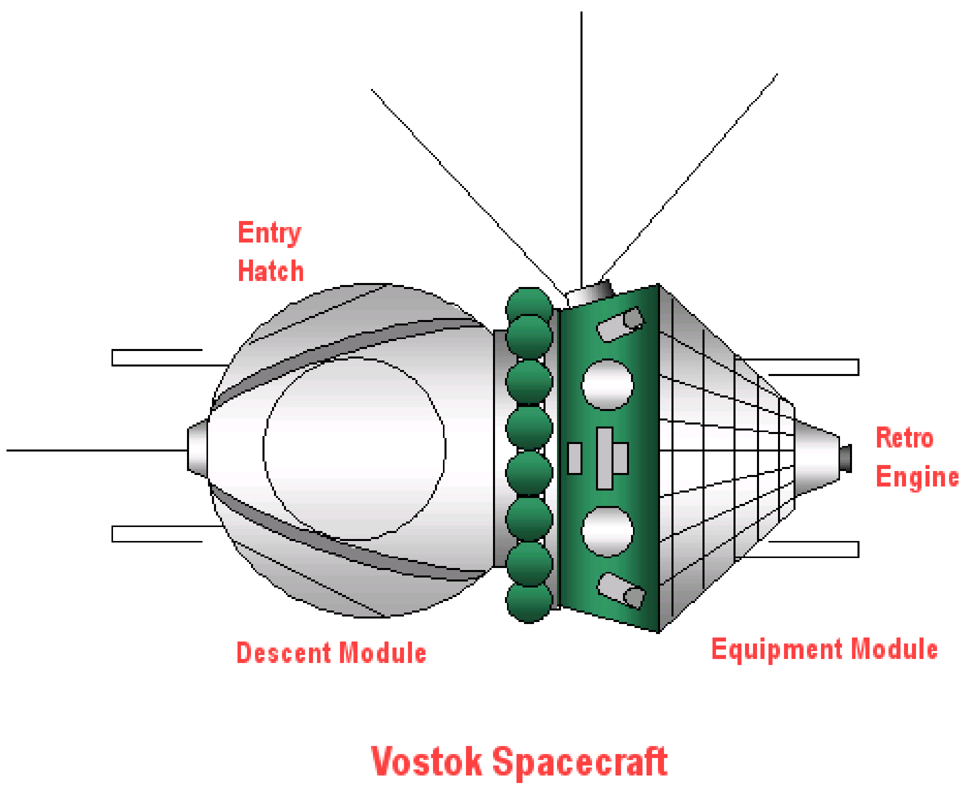


Diagram of Vostok spacecraft

- **07:25 UTC** Vostok 1 is in retrofire attitude. The retros are fired for about 42 seconds as the spacecraft nears Angola on the west coast of Africa. Retrofire takes place about 8,000 km (5,000 mi) from the planned landing point in Soviet Union.

- **07:25 to 07:35 UTC** Ten seconds after retrofire, commands are sent to separate the Vostok service module from the reentry module (*sharik*). One bundle of wires fails to release and the two sections of the spacecraft remain attached for another 10 minutes. Vostok 1 crosses the west coast of Africa and continues over central Africa heading towards Egypt.

- **07:35 UTC** The two halves of the spacecraft begin reentry and go through wild gyrations as Vostok 1 nears Egypt. Finally, the wire bundle burns through and releases the reentry module. Gagarin telegraphs "Everything is OK" despite continuing gyrations; he later reported that he did not want to "make noise" as he had (correctly) reasoned that the gyrations did not endanger the mission (and were apparently caused by the spherical shape of the reentry module).

- **07:35 to 07:55 UTC** Reentry continues over Egypt and out over the Mediterranean, near the west coast of Cyprus and then central Turkey. Continuing to drop lower, Vostok 1 crosses back into the Soviet Union on the Black Sea coast near Krasnodar. Gagarin experiences 8 g (Gagarin's own report states "over 10 g") during reentry but remains conscious.

- **07:55 UTC** Vostok 1 is still 7 km from the ground. The hatch is released and two seconds later Gagarin ejects from Vostok 1. At 2.5 km (8,200 ft) altitude, the main parachute is deployed from the Vostok spacecraft. The Vostok 1 lands at 07:55 UTC. Two schoolgirls witness the Vostok landing and described the scene: *"It was a huge ball, about two or three metres high. It fell, then it bounced and then it fell again. There was a huge hole where it hit the first time."*

The Vostok 1 capsule on display at the RKK Energiya museum

- **08:05 UTC** Gagarin, because his parachute opened at a much higher altitude than Vostok 1 (7 km (23,000 ft) vs. 2.5 km), lands about 10 minutes after his spacecraft. Both he and the spacecraft land via parachute 26 km (16 mi) south west of Engels, in the Saratov region at 51°16′14″N 45°59′50″E / 51.270682°N 45.99727°E. A farmer and her daughter observed the strange scene of a figure in a bright orange suit with a large white helmet landing near them by parachute. Gagarin later recalled, *"When they saw me in my space suit and the parachute dragging alongside as I walked, they started to back away in fear. I told them, don't be afraid, I am a Soviet like you, who has descended from space and I must find a telephone to call Moscow!"*.

Chapter 4

Vostok (spacecraft)

Vostok

model of Vostok spacecraft with 3-rd stage of launcher

Type	Space capsule
Manufacturer	Korolev
Designed by	Sergei Korolev
Maiden flight	May 15, 1960
Introduced	1960
Retired	June 19, 1963
Status	Last 7 flights cancelled
Primary users	Soviet space program
Built	10+
Variants	Voskhod spacecraft, Foton

The **Vostok** (Russian: **Восток**, translated as *East*) was a type of spacecraft built by the Soviet Union's space programme for human spaceflight.

Development

The Vostok spacecraft was originally designed for use both as a camera platform (for the Soviet Union's first spy satellite program, Zenit) and as a manned spacecraft. This dual-use design was crucial in gaining Communist Party support for the program. The basic Vostok design has remained in use for some forty years, gradually adapted for a range of other unmanned satellites. The descent module design was reused, in heavily-modified form, by the Voskhod programme.

Design

The craft consisted of a spherical descent module (mass 2.46 tonnes, diameter 2.3 meters), which housed the cosmonaut, instruments and escape system, and a conical instrument module (mass 2.27 tonnes, 2.25 m long, 2.43 m wide), which contained propellant and the engine system. On reentry, the cosmonaut would eject from the craft at about 7,000 m (23,000 ft) and descend via parachute, while the capsule would land separately.

There were several models of the Vostok leading up to the manned version:

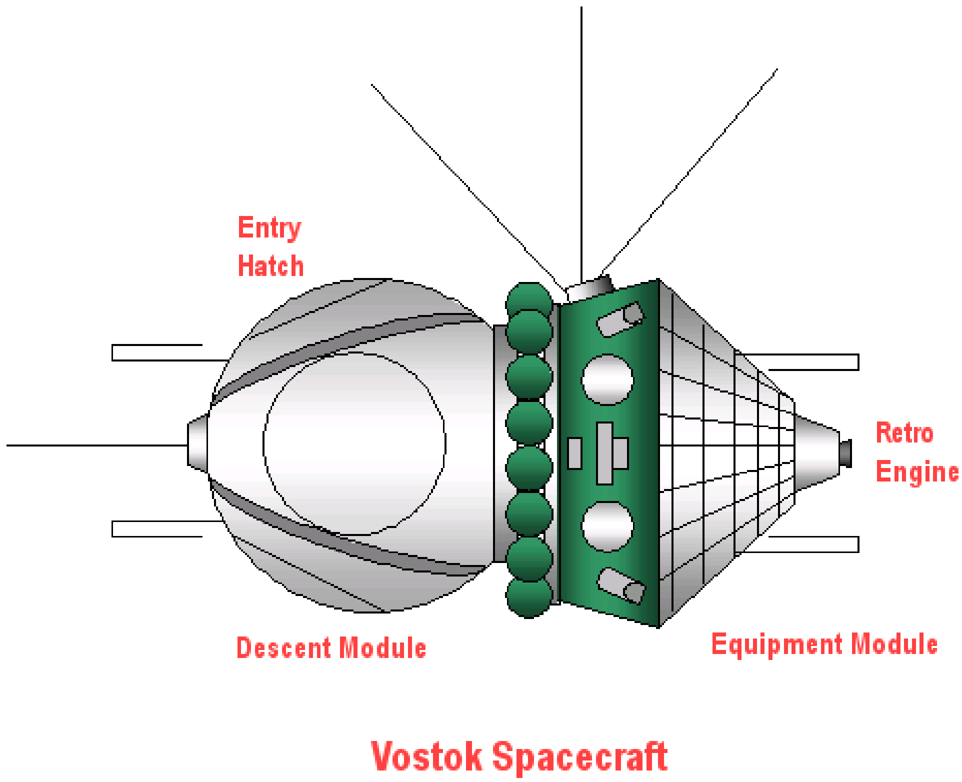
Vostok 1K

Prototype spacecraft. Used to test basic systems and prove the concept. Flew six unmanned test missions in 1960.

Vostok 2K

Photo-reconnaissance and signals intelligence spacecraft . Later named Zenit spy satellite.

Vostok 3KA



Vostok spacecraft

The Vostok 3KA was the spacecraft used for the first human spaceflights. They were launched from Baikonur Cosmodrome using Vostok 8K72K launch vehicles. The first flight of a Vostok 3KA occurred on March 9, 1961. The first flight with a crew -- Vostok 1 carrying Yuri Gagarin -- took place on April 12, 1961. The last flight -- Vostok 6 carrying the first woman in space, Valentina Tereshkova -- took place on June 16, 1963.

A total of 8 Vostok 3KA spacecraft were flown, 6 of them with a human crew.

Specifications for this version are:

Reentry Module: Vostok SA. Also known as: *Spuskaemiy apparat - Sharik* (sphere).

- Crew Size: 1
- Length: 5 m
- Diameter: 2.3 m
- Mass: 2,460 kg
- Heat Shield Mass: 837 kg

- Recovery equipment: 151 kg
- Parachute deploys at 2.5 km altitude
- Crew seat and provisions: 336 kg
- Crew ejects at 7 km altitude
- Ballistic reentry acceleration: 8 *g* (78 m/s²)

Vostok Sharik

Equipment Module: Vostok PA. Also known as: *Priborniy otsek*.

- Length: 2.25 m
- Diameter: 2.43 m
- Mass: 2,270 kg

- Equipment in pressurized compartment
- RCS Propellants: Cold gas (nitrogen)
- RCS Propellants: 20 kg
- Main Engine (TDU): 397 kg
- Main Engine Thrust: 15.83 kN
- Main Engine Propellants: Nitrous oxide/amine
- Main Engine Propellants: 275 kg
- Main Engine Isp: 266 s (2.61 kN·s/kg)
- Main Engine Burn Time: 1 minute (typical retro burn = 42 seconds)
- Spacecraft delta v: 155 m/s
- Electrical System: Batteries
- Electric System: 0.20 average kW
- Electric System: 24.0 kW·h

- Total Mass:4,730 kg
- Endurance: Supplies for 10 days in orbit
- Launch Vehicle: Vostok 8K72K
- Typical orbit: 177 km x 471 km, 64.9 inclinaton

Reentry

The Vostok capsule had limited thruster capability. As such, the reentry path and orientation could not be controlled after the capsule had separated from the engine system. This meant that the capsule had to be protected from reentry heat on all sides, thus explaining the spherical design (as opposed to Project Mercury's conical design), which allowed for maximum volume while minimizing the external surface. Some control of the capsule reentry orientation was possible by way of positioning of the heavy equipment to offset the vehicle center of gravity, which also maximized the chance of the cosmonaut surviving g-forces while in a horizontal position. Even then, the cosmonaut experienced 8 to 9g.

Chapter 5

Project Mercury

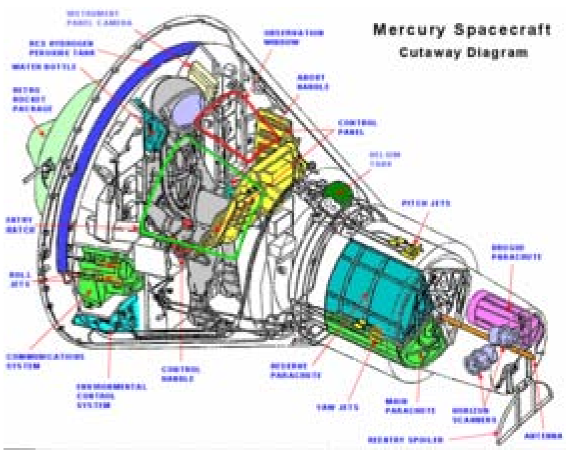
McDonnell Mercury spacecraft

The Mercury spacecraft with escape tower

	Description	
Role:	Suborbital and orbital spaceflight	
Crew:	one pilot	
	Dimensions	
Height:	11.5 ft	3.51 m
Diameter:	6.2 ft	1.89 m
Volume:	60 ft³	1.7 m³
	Weights (MA-6)	
Launch:	4,265 lb	1,935 kg
Orbit:	2,986 lb	1,354 kg
Post Retro:	2,815 lb	1,277 kg

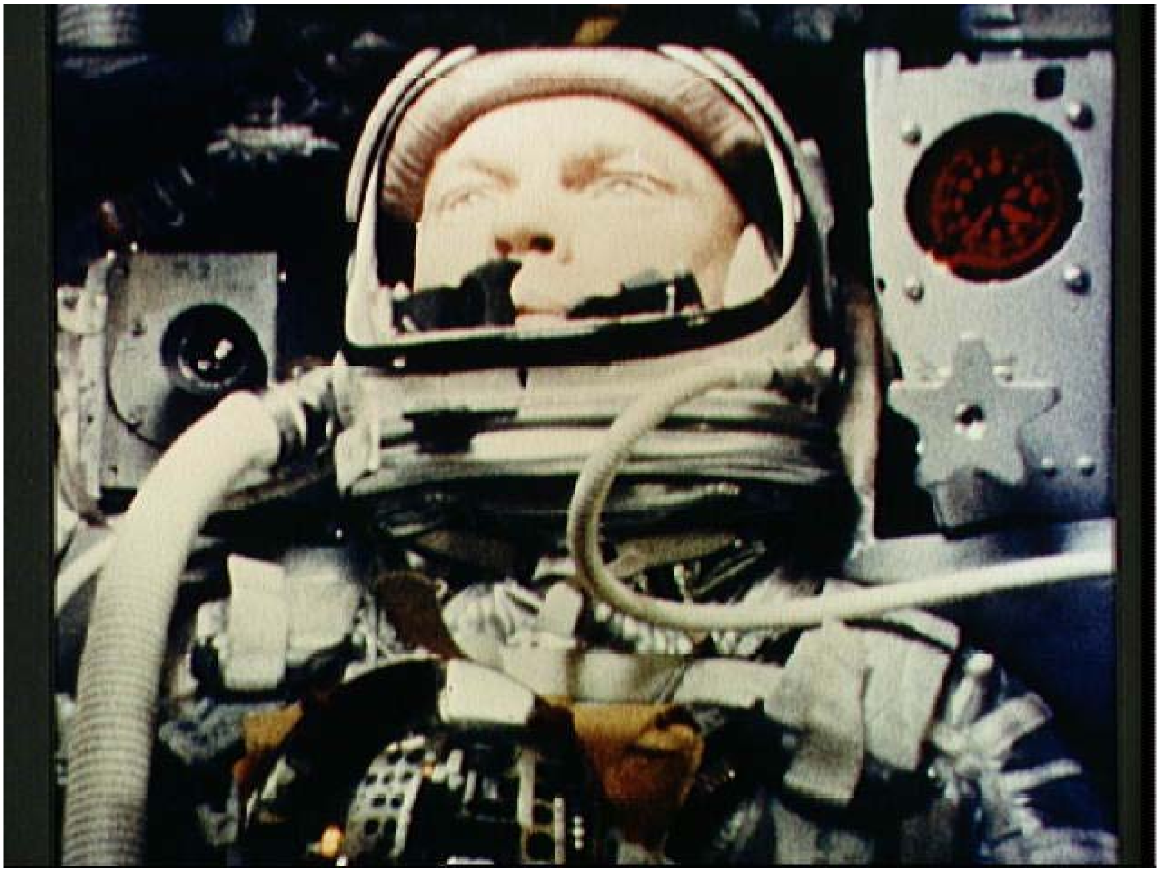
Reentry:	2,698 lb	1,224 kg
Landing:	2,421 lb	1,098 kg
Rocket engines		
Retros (solid fuel) x 3:	1,000 lbf ea	4.5 kN
Posigrade (solid fuel) x 3:	400 lbf ea	1.8 kN
RCS high (H_2O_2) x 6:	25 lbf ea	108 N
RCS low (H_2O_2) x 6:	12 lbf ea	49 N
Performance		
Endurance:	34 hours	22 orbits
Apogee:	175 miles	282 km
Perigee:	100 miles	160 km
Retro delta v:	300 mph	483 km/h

Mercury spacecraft diagram



Mercury spacecraft cutaway

Project Mercury was the first human spaceflight program of the United States. It ran from 1959 through 1963 with the goal of putting a human in orbit around the Earth. The Mercury-Atlas 6 flight on February 20, 1962, was the first American flight to achieve this goal.



John Glenn during the first orbital manned Mercury flight in 1962

The program included 20 unmanned launches, followed by two suborbital and four orbital flights with astronaut pilots. Early planning and research were carried out by the National Advisory Committee for Aeronautics, but the program was officially conducted by its successor organization, NASA. Mercury laid the groundwork for Project Gemini and the follow-on Apollo moon-landing program.

The project name came from Mercury, a Roman mythological god often seen as a symbol of speed. Mercury is also the name of the innermost planet of the Solar System, which moves faster than any other and hence provides an image of speed, although Project Mercury had no real connection to the planet.

The Mercury program cost approximately $384 million, the equivalent of about $2.9 billion in 2010 dollars.

Goals and guidelines

The goals of the program were to orbit a manned spacecraft around Earth, investigate the pilot's ability to function in space and to recover both pilot and spacecraft safely. NASA also established program guidelines: existing technology and off-the-shelf equipment should be used wherever practical, the simplest and most reliable approach to system design would be followed, an existing launch vehicle would be employed to place the spacecraft into orbit, and use of a progressive and logical test program. Project requirements for the spacecraft were that it must be fitted with a reliable launch escape system to separate the spacecraft and its crewman from the launch vehicle in case of impending failure, the pilot must be given the capability of manually controlling spacecraft attitude, the spacecraft must carry a retrorocket system capable of reliably providing the necessary impulse to bring the spacecraft out of orbit, a zero-lift body utilizing drag braking would be used for reentry, and that the spacecraft design must satisfy the requirements for a water landing.

Research and development

On October 7, 1958, T. Keith Glennan, the first administrator of NASA, approved the Mercury project. On December 17 Glennan announced Project Mercury publicly.

Mercury spacecraft at McDonnell in St. Louis, Missouri

On December 29, 1958 North American Aviation was awarded a contract to design and build Little Joe boosters for mercury launch escape system test flights. In January 1959 McDonnell Aircraft Corporation was chosen to be prime contractor for the Mercury spacecraft, and the contract for 12 spacecraft was awarded in February. In April seven astronauts, known as the Mercury Seven or more formally as Astronaut Group 1, were selected to participate in the Mercury program.

In May 1959 North American Aviation delivered the first two Little Joe boosters, and in June the Big Joe booster was delivered. In July the planned use of Jupiter boosters was canceled in favor of Redstone boosters for suborbital flights. In October General Electric delivered to McDonnell the ablative heat shield designated for installation on the first Mercury spacecraft. In December the launch vehicle for Mercury-Redstone 1 was ready to begin static tests installed on a test stand at ABMA.

In January 1960 NASA awarded Western Electric Company a contract for the Mercury tracking network. The value of the contract was over $33 million. Also in January, McDonnell delivered the first production-type Mercury spacecraft, less than a year after award of the formal contract. On February 12, Christopher C. Kraft, Jr. was appointed to head the Mercury operations coordination group. Kraft was asked to, "come up with a basic mission plan. You know, the bottom-line stuff on how we fly a man from a launch pad into space and back again. It would be good if you kept him alive." In April, the first spacecraft was delivered to Wallops Island for the beach-abort test. The test was completed successfully on May 9.

Spacecraft

Because of their small size, it was said that the Mercury spacecraft were worn, not ridden. With 1.7 m^3 of habitable volume, the spacecraft was just large enough for the single crew member. Inside were 120 controls: 55 electrical switches, 30 fuses and 35 mechanical levers. The spacecraft was designed by Max Faget and NASA's Space Task Group.

Despite the astronauts' test pilot experience NASA at first envisioned them as "minor participants" during their flights, causing many conflicts between the astronauts and engineers during the spacecraft's design. Nonetheless, contrary to other reports, the project's leaders always intended for pilots to be able to control their spacecraft, as they valued humans' ability to contribute to missions' success. John Glenn's manual attitude adjustments during the first orbital flight were an example of the value of such control. The astronauts requested—and received—a larger window and manual reentry controls.

Mercury 8 spacecraft in Hangar S at Cape Canaveral

During the launch phase of the mission, the Mercury spacecraft and astronaut were protected from launch vehicle failures by the Launch Escape System. The LES consisted of a solid fuel, 52,000 lbf (231 kN) thrust rocket with three engine bells mounted on a tower above the spacecraft. In the event of a launch abort, the LES would fire for one second, pulling the spacecraft and astronaut away from the booster and a possible explosion. The spacecraft would then descend on its parachute recovery system. After booster engine cutoff (BECO), the LES was no longer needed and was separated from the spacecraft by a solid fuel, 800 lbf (3.6 kN) thrust jettison rocket that fired for 1.5 seconds.

After a successful liftoff, the spacecraft fired three small clustered solid-fuel, 400 lbf (1.8 kN) thrust rockets for 1 second to separate the spacecraft from the launch vehicle. These rockets were called the posigrade rockets.

The spacecraft were only equipped with attitude control thrusters; after orbit insertion but before retrofire they could not change their orbit. There were three sets of high and low powered automatic control jets and separate manual jets, one for each axis (yaw, pitch, and roll), and supplied from two separate fuel tanks, one automatic and one manual. The pilot could use any one of the three thruster systems and fuel them from either of the two fuel tanks to provide spacecraft attitude control. The Mercury spacecraft was designed to be completely controllable from the ground in the event that something impaired the pilot's ability to function.

The spacecraft had three solid-fuel, 1000 lbf (4.5 kN) thrust retrorockets that fired for 10 seconds each. One was sufficient to return the spacecraft to Earth if the other two failed. The firing sequence (known as ripple firing) required firing the first retro, followed by the second retro five seconds later (while the first was still firing). Five seconds after that, the third retro fired (while the second retro was still firing).

Mercury heat shield and retrorocket pack

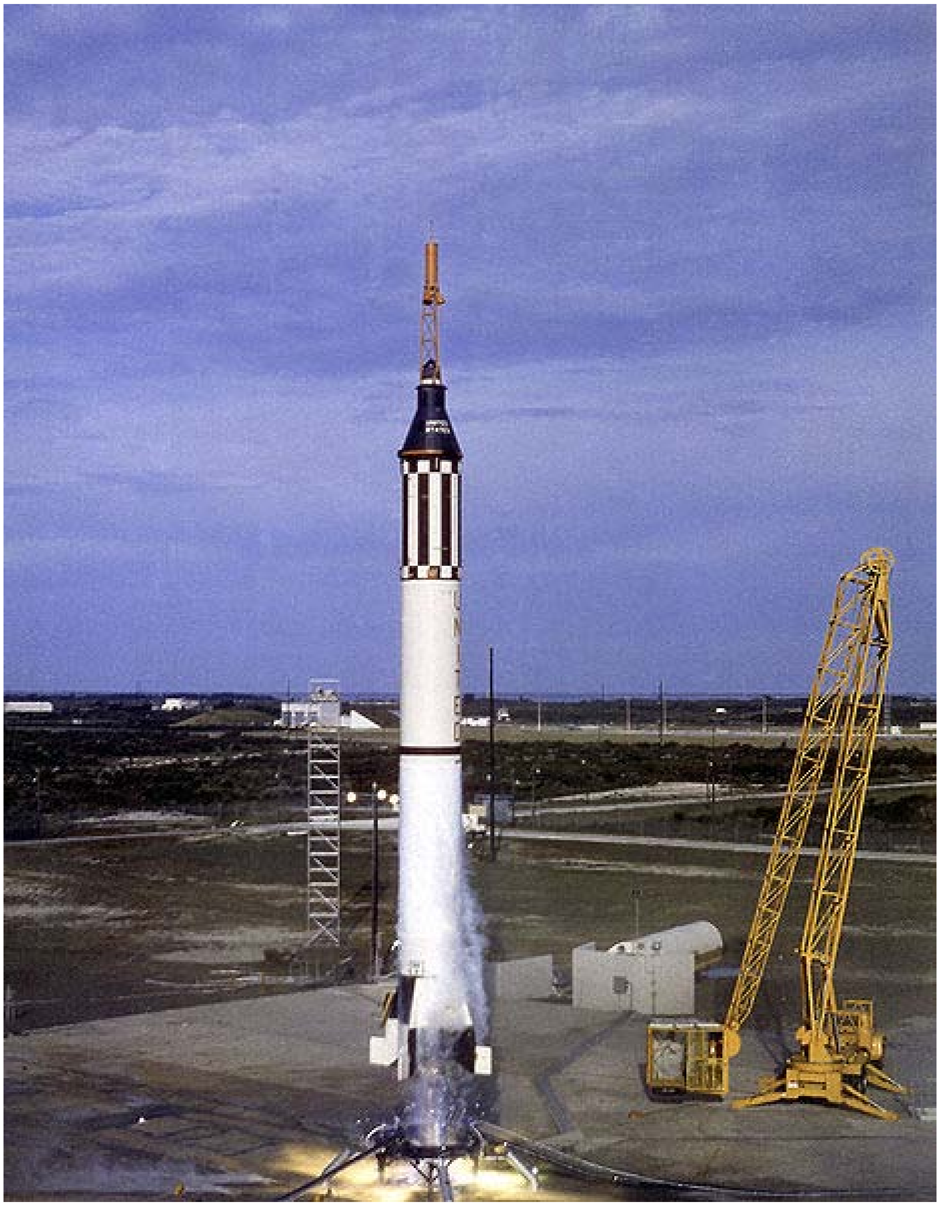
There was a small hinged metal flap at the nose of the spacecraft called the spoiler. If the spacecraft started to reenter nose first (another stable reentry attitude for the spacecraft), airflow over the spoiler would flip the spacecraft around to the proper, heatshield-first reentry attitude, a technique called shuttlecocking. During reentry, the astronaut would experience about 8 g-forces on an orbital mission, and 11–12 gs on a suborbital mission.

Initial designs for the spacecraft suggested the use of either beryllium heat-sink heat shields or an ablative shield. Extensive testing settled the issue – ablative shields proved to be reliable (so much so that the initial shield thickness was safely reduced, allowing a lower total spacecraft weight), and were easier to produce — at that time, beryllium was only produced in sufficient quantities by a single company in the U.S. — and cheaper.

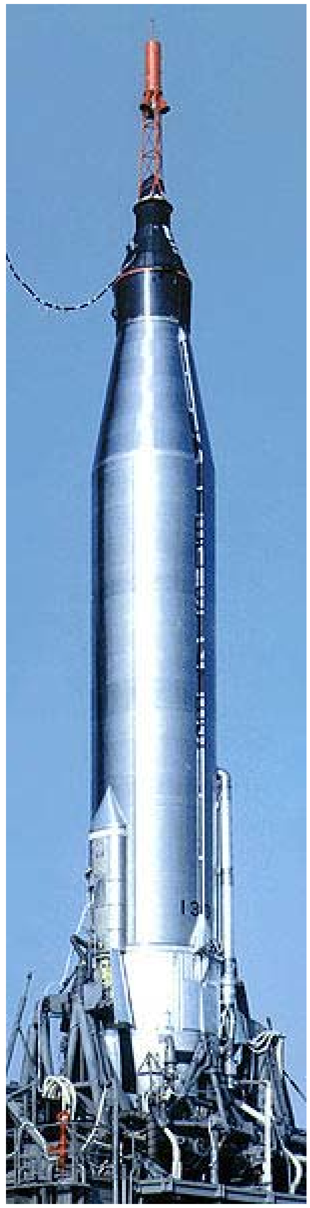
NASA ordered 20 production spacecraft, numbered 1 through 20, from McDonnell Aircraft Company, St. Louis, Missouri. Five of the 20, Nos. 10, 12, 15, 17, and 19, were not flown. Spacecraft No. 3 and No. 4 were destroyed during unmanned test flights. Spacecraft No. 11 sank and was recovered from the bottom of the Atlantic Ocean after 38 years. Some spacecraft were modified after initial production (refurbished after launch abort, modified for longer missions, etc.) and received a letter designation after their number, examples 2B, 15B. Some spacecraft were modified twice; for example, spacecraft 15 became 15A and then 15B.

A number of Mercury Boilerplate spacecraft (including mockup/prototype/replica spacecrafts, made from non-flight materials or lacking production spacecraft systems and/or hardware) were also made by NASA and McDonnell Aircraft. They were designed and used to test spacecraft recovery systems, and escape tower and rocket motors. Formal tests were done on test pad at Langley and at Wallops Island using the Little Joe and Big Joe rockets.

Boosters



Mercury-Redstone 4



Mercury-Atlas 9

The Mercury program used three boosters:

- Little Joe – eight suborbital robotic flights, two carrying monkeys. Launch escape system tests.
- Redstone – four suborbital robotic flights, one carrying a chimpanzee; two piloted suborbital flights.
- Atlas – four suborbital robotic flights; two orbital robotic flights, one carrying a chimpanzee; four piloted orbital flights.

Little Joe and a Mercury boilerplate were used to test the escape tower and abort procedures. Redstone was used for suborbital flights, and Atlas for orbital ones. Starting in October, 1958, Jupiter missiles were also considered as suborbital launch vehicles for the Mercury program, but were cut from the program in July 1959 due to budget constraints. The Atlas boosters required extra strengthening in order to handle the increased weight of the Mercury spacecraft beyond that of the nuclear warheads they were designed to carry. Little Joe was a solid-propellant booster designed specially for the Mercury program. The Titan missile was also considered for use for later Mercury missions; however, the Mercury program was terminated before these missions were flown. The Titan was used for the Gemini program which followed Mercury.

The Mercury program used a Scout booster for a single flight, Mercury-Scout 1, which intended to launch a small satellite designed to evaluate the worldwide Mercury Tracking Network. The rocket was destroyed by the Range Safety Officer after 44 seconds of flight.

Manned flights

The Mercury Seven astronauts with an Atlas model July 12, 1962. L to R: Grissom, Shepard, Carpenter, Schirra, Slayton, Glenn, Cooper

Wernher von Braun and astronaut Gordon Cooper in the blockhouse during MR-3 recovery operations May 5, 1961.

Astronauts

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. NASA announced the selection of seven of these – known as the Mercury Seven – as astronauts on 9 April 1959, though only six of the seven flew Mercury missions, after Slayton was grounded due to a heart condition.

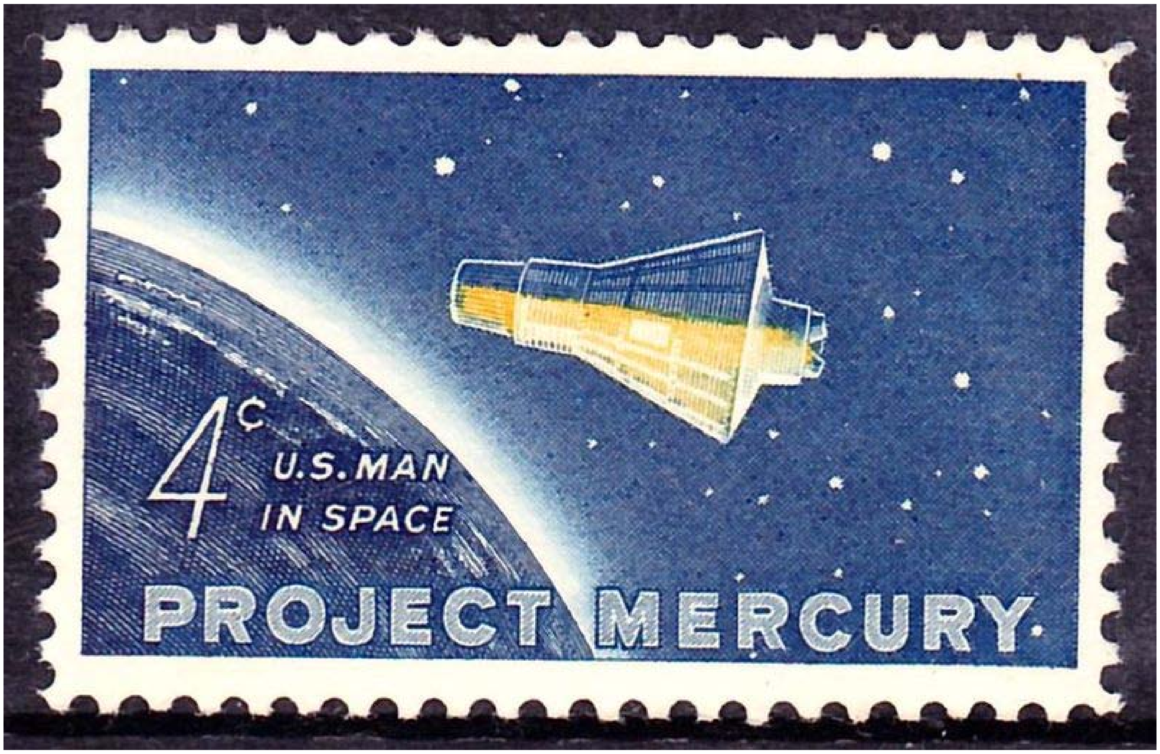
- Malcolm Scott Carpenter, USN (born 1925)
- Leroy Gordon "Gordo" Cooper, Jr., USAF (1927–2004)
- John Herschel Glenn, Jr., USMC (born 1921); first American to orbit the Earth
- Virgil Ivan "Gus" Grissom, USAF (1926–1967); Died during Apollo 1 pre-launch test
- Walter Marty "Wally" Schirra, Jr., USN (1923–2007)
- Alan Bartlett Shepard, Jr., USN (1923–1998); first American in space
- Donald Kent "Deke" Slayton, USAF (1924–1993); grounded in 1962 due to irregular heartbeat, reinstated in 1972 and flew on the Apollo-Soyuz Test Project in 1975.

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.

Mercury mission insignias

Mercury program monument at LC-14

Flight patches that purport to be patches from various Mercury missions are available to the public. In reality, these patches were designed by private entrepreneurs several years after the Mercury program. When mission patches were created by crews in the Gemini program, this caused a public demand for Mercury flight patches, which was filled by these entrepreneurs. The only patches the Mercury astronauts wore, however, were the NASA logo and a name tag. Each manned Mercury spacecraft was decorated with a flight insignia featuring the spacecraft name (*Freedom 7*, etc.).



Project Mercury Issue of 1962

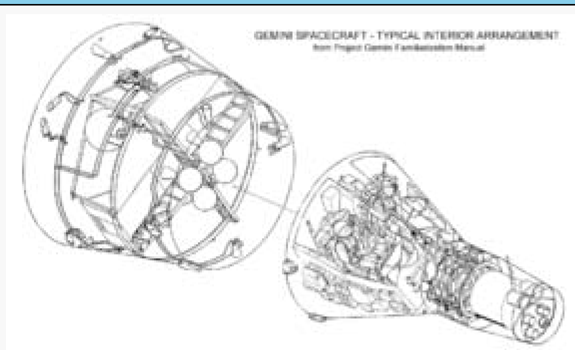
Project Mercury stamp

In 1962, the US Post Office honored the Mercury-Atlas 6 flight with the Project Mercury commemorative stamp, the first U.S. postal issue to depict a manned spacecraft. The stamp first went on sale in Cape Canaveral, Florida on February 20, 1962, the same day as the Project Mercury launch putting the first U.S. astronaut into orbit.

Chapter 6

Project Gemini

McDonnell Gemini spacecraft		
 Gemini 7 in orbit, as seen by the crew of Gemini 6.		
Volume:	90 ft³	2.55 m³
Weights		
Retrograde module:	1,303 lb	591 kilograms (1,300 lb)
Equipment module:	2,815 lb	1,277 kilograms (2,820 lb)
Total:	8,490 lb	3,851 kilograms (8,490 lb)
Rocket engines		
Retros (solid fuel) x 4:	2,500 lbf ea	11.12 kN
Reentry Control System (N_2O_4/MMHH) x 16:	25 lbf ea	111 N
OAMS	85 lbf ea	378 N

(N_2O_4/MMHH) x 2:		
OAMS (N_2O_4/MMHH) x 6:	100 lbf ea	445 N
OAMS (N_2O_4/MMHH) x 8:	25 lbf ea	111 N
Performance		
Endurance:	14 days	206 orbits
Apogee:	250 miles	402 kilometres (250 mi)
Perigee:	100 miles	160 kilometres (99 mi)
Spacecraft delta v:	728 ft/s	222 m/s
Gemini spacecraft diagram		
 Gemini spacecraft diagram (NASA)		
McDonnell Gemini Spacecraft		

Project Gemini was the second human spaceflight program of NASA, the civilian space agency of the United States government. Project Gemini was conducted between Projects Mercury and Apollo, with ten manned flights occurring in 1965 and 1966.

Its objective was to develop techniques for advanced space travel, notably those necessary for Apollo, whose objective was to land humans on the Moon. Gemini missions included missions long enough for a trip to the Moon and back, the first American spacewalks, and new orbital maneuvers including rendezvous and docking. All manned Gemini flights were launched from Cape Canaveral, Florida atop Titan II GLV boosters.

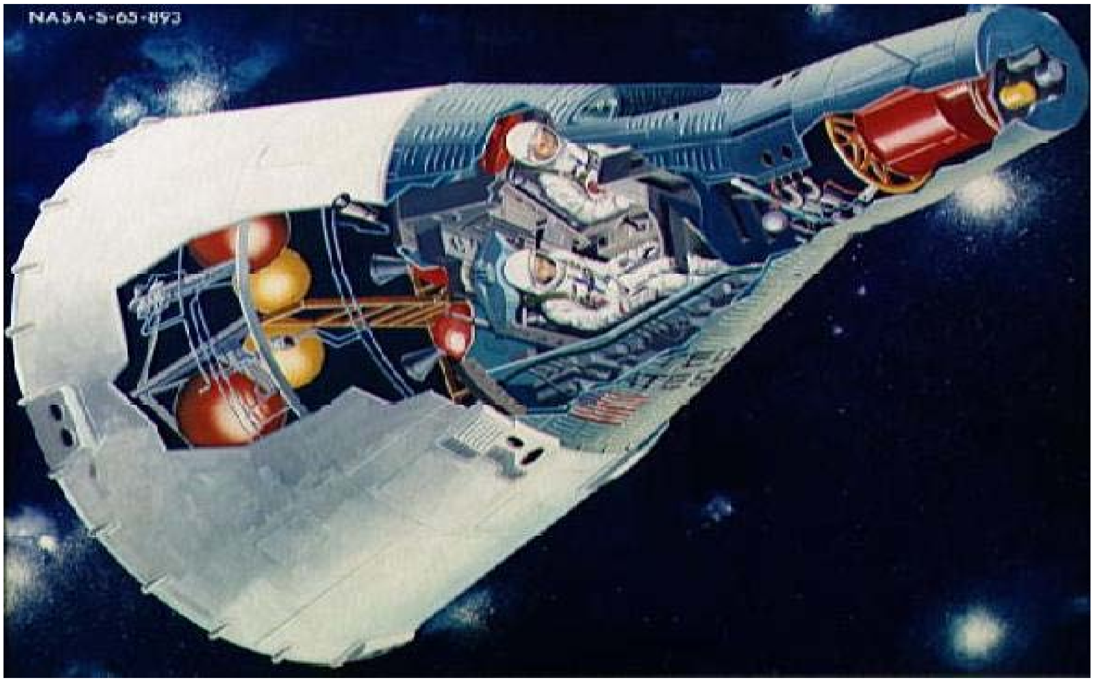
Program objectives

After the existing Apollo program was chartered by President John F. Kennedy on May 25, 1961 to land men on the Moon, it became evident to NASA officials that a follow-on to the Mercury program was required to develop certain spaceflight capabilities in support of Apollo. Originally introduced on December 7 as *Mercury Mark II*, it was re-christened Project Gemini on January 3, 1962. The major objectives were:

- To demonstrate endurance of humans and equipment to spaceflight for extended periods, at least eight days required for a Moon landing, to a maximum of two weeks
- To effect rendezvous and docking with another vehicle, and to maneuver the combined spacecraft using the propulsion system of the target vehicle
- To demonstrate Extra-Vehicular Activity (EVA), or space-"walks" outside the protection of the spacecraft, and to evaluate the astronauts' ability to perform tasks there
- To perfect techniques of atmospheric reentry and landing at a pre-selected location
- To provide the astronauts with zero-gravity, rendezvous, and docking experience required for Apollo

Spacecraft

Replica of a Gemini spacecraft at the Neil Armstrong Air and Space Museum



A cutaway of the Project Gemini spacecraft

Gemini's primary difference from Mercury was that the earlier spacecraft had all systems other than the reentry rockets situated within the capsule, most of which were accessed through the astronaut's hatchway. In contrast, Gemini housed power, propulsion, and life support systems in a detachable Equipment Module located behind the Reentry Module, which made it similar to the Apollo Command/Service Module design. Many components in the capsule itself were reachable through their own small access doors.

The original intention was for Gemini to land on solid ground instead of at sea, using a Rogallo wing paraglider rather than a parachute, with the crew seated upright controlling the forward motion of the craft. To facilitate this, the paraglider did not attach just to the nose of the craft, but to an additional attachment point for balance near the heat shield. This cord was covered by a strip of metal which ran between the twin hatches. However, this design was ultimately dropped, and parachutes were used to make a sea landing as in Project Mercury. However, the capsule was suspended at an angle closer to horizontal, so that a side of the heat shield contacted the water first. This eliminated the need for the landing bag cushion used in the Mercury capsule.

Early short-duration missions had their electrical power supplied by batteries; later endurance missions used the first fuel cells in manned spacecraft.

The "Gemini" designation comes from the fact that each spacecraft held two crewmen, as "gemini" in Latin means "twins". Gemini is also the name of the third constellation of the Zodiac and its twin stars, Castor and Pollux.

Unlike Mercury, which could only change its orientation in space, the Gemini spacecraft could translate in all six directions, and alter its orbit. It was designed to dock with the Agena Target Vehicle, which had its own large rocket engine which was used to perform large orbital changes.

Gemini was the first American manned spacecraft to include an onboard computer, the Gemini Guidance Computer, to facilitate management and control of mission maneuvers. It was also unlike other NASA craft in that it used ejection seats, in-flight radar and an artificial horizon—devices borrowed from the aviation industry. Using ejection seats to propel astronauts to safety was first employed by the Soviet Union in the Vostok craft manned by cosmonaut Yuri Gagarin.

The Gemini program cost $5.4 billion.

Team

Gemini was designed by a Canadian, Jim Chamberlin, formerly the chief aerodynamicist on the Avro Arrow fighter interceptor program with Avro Canada. Chamberlin joined NASA along with 25 senior Avro engineers after cancellation of the Arrow program, and became head of the U.S. Space Task Group’s engineering division in charge of Gemini.

The prime contractor was McDonnell Aircraft, which had also been the prime contractor for the Mercury capsule.

In addition, astronaut Gus Grissom was heavily involved in the development and design of the Gemini spacecraft. He writes in his posthumous 1968 book *Gemini!* that the realization of Project Mercury's end and the unlikelihood of his having another flight in that program prompted him to focus all of his efforts on the upcoming Gemini Program.

The Gemini program was managed by the Manned Spacecraft Center, Houston, Texas, under direction of the Office of Manned Space Flight, NASA Headquarters, Washington, D.C, Dr. George E. Mueller, Associate Administrator of NASA for Manned Space Flight, served as acting director of the Gemini program. William C. Schneider, Deputy Director of Manned Space Flight for Mission Operations, served as mission director on all Gemini flights beginning with Gemini VI.

Guenther Wendt was a McDonnell engineer who supervised launch preparations for both the Mercury and Gemini programs. His team was responsible for completion of the complex pad close-out procedures just prior to spacecraft launch, and he personally closed the hatches before flight. The astronauts appreciated his taking absolute authority over, and responsibility for, the condition of the spacecraft and developed a good-humored rapport with him.

Astronauts

The following astronauts flew on the 10 manned Gemini missions:

Group	Astronaut	Service	Mission
Astronaut Group 1	L. Gordon Cooper	USAF	Gemini V
	Virgil "Gus" Grissom		Gemini III
	Walter M. Schirra	USN	Gemini VI-A
Astronaut Group 2	Neil A. Armstrong	Civilian	Gemini VIII
	Frank Borman	USAF	Gemini VII
	Charles "Pete" Conrad	USN	Gemini V Gemini XI
	James A. Lovell	USN	Gemini VII Gemini XII
	James A. McDivitt	USAF	Gemini IV
	Thomas P. Stafford		Gemini VI-A Gemini IX-A
	Edward H. White II		Gemini IV
	John W. Young	USN	Gemini III Gemini X

	Edwin "Buzz" Aldrin	USAF	Gemini XII
	Eugene A. Cernan	USN	Gemini IX-A
Astronaut Group 3	Michael Collins	USAF	Gemini X
	Richard F. Gordon	USN	Gemini XI
	David R. Scott	USAF	Gemini VIII

Mission	Commander	Group	Flight #	Pilot	Group	Flight #
Gemini III	Grissom	1	2	Young	2	1
Gemini IV	McDivitt	2	1	White	2	1
Gemini V	Cooper	1	2	Conrad	2	1
Gemini VI	Schirra	1	2	Stafford	2	1
Gemini VII	Borman	2	1	Lovell	2	1
Gemini VIII	Armstrong	2	1	Scott	3	1
Gemini IX	Stafford	2	2	Cernan	3	1
Gemini X	Young	2	2	Collins	3	1
Gemini XI	Conrad	2	2	Gordon	3	1
Gemini XII	Lovell	2	2	Aldrin	3	1

Crew selection

Deke Slayton, as head of the Astronaut Office, had the main role in the choice of crews for the Gemini program. With Gemini it became a procedure that each flight had a primary crew and backup crew, and that the backup crew would rotate to primary crew status three flights later. Slayton also intended for first choice of mission commands to be given to the four remaining active astronauts of the Mercury Seven: Alan Shepard, Grissom, Cooper, and Schirra. (John Glenn had retired from NASA in January 1964 and Scott Carpenter, who was blamed by some in NASA management for the problematic reentry of *Aurora 7*, was on leave to participate in the Navy's SEALAB project and was grounded from flight in July 1964 due to an arm injury sustained in a motorbike accident. Slayton himself continued to be grounded due to a heart problem.)

In late 1963, Slayton selected Shepard and Stafford for Gemini 3, McDivitt and White for Gemini 4, and Schirra and Young for Gemini 5 (which was to be the first Agena rendezvous mission). Backup crew for Gemini 3 was Grissom and Borman, who were also slated for Gemini 6, to be the first long-duration mission. Finally Conrad and Lovell were assigned as backup crew for Gemini 4.

Delays in the production of the Agena Target Vehicle caused the first rearrangement of the crew rotation. The Schirra and Young mission was bumped to Gemini 6 and they now were the backup crew for Shepard and Stafford. Grissom and Borman now had their long-duration mission assigned to Gemini 5.

The second rearrangement occurred when Shepard developed Ménière's disease, an inner ear problem. Grissom was then moved to command Gemini 3. Slayton felt that Young was a better personality match with Grissom and switched Stafford and Young. Finally, Slayton tapped Cooper to command the long-duration Gemini 5. Again for reasons of compatibility, he moved Conrad from backup commander of Gemini 4 to pilot of Gemini 5, and Borman to backup command of Gemini 4. Finally he assigned Armstrong and Elliot See to be the backup crew for Gemini 5.

The third rearrangement of crew assignment occurred when Slayton felt that See wasn't up to the physical demands of EVA on Gemini 8. He reassigned See to be the prime commander of Gemini 9 and put Scott as pilot of Gemini 8 and Charles Bassett as the pilot of Gemini 9.

The fourth and final rearrangement of the Gemini crew assignment occurred after the deaths of See and Bassett when their trainer jet crashed, ironically into a McDonnell building which held their Gemini 9 capsule in St. Louis. The backup crew of Stafford and Cernan was then moved up to the new prime crew of the re-designated Gemini 9A. Lovell and Aldrin were moved from being the backup crew of Gemini 10 to be the backup crew of Gemini 9. This cleared the way through the crew rotation for Lovell and Aldrin to become the prime crew of Gemini 12.

Along with the deaths of Grissom, White, and Roger Chaffee in the fire of Apollo 1, this final arrangement helped determine the makeup of the first seven Apollo crews, and who would be in position for a chance to be the first to walk on the Moon.

In his autobiography *Deke!* Slayton relates that he would probably have replaced Aldrin with Cernan, the backup pilot for Gemini 12, on Apollo 11 if the second use of the Astronaut Maneuvering Unit (AMU) had been on Gemini 12. (The first use was by Cernan on Gemini IX-A.) Cernan makes a similar claim in his autobiography.

As it happened, despite these random substitutions and similar ones in Apollo, and a different number of unmanned flights in both programs, Slayton's rotation philosophy dominated to create a curious coincidence: most of the Gemini astronauts who went on to fly in Apollo occupied an Apollo mission numbered one more than their corresponding Gemini mission:

- Schirra commanded Gemini 6 and Apollo 7.
- Borman and Lovell flew together on Gemini 7 and Apollo 8.
- David Scott flew on Gemini 8 and Apollo 9.
- Stafford and Cernan flew together on Gemini 9A and Apollo 10.
- Collins flew on Gemini 10 and Apollo 11.
- Conrad and Gordon flew together on Gemini 11 and Apollo 12.
- Lovell commanded Gemini 12 and Apollo 13.

The only exceptions to this pattern were:

- McDivitt, who commanded Gemini 4 and Apollo 9
- Young, who flew Gemini 3, Gemini 10, Apollo 10 and Apollo 16
- Armstrong, who commanded Gemini 8 and Apollo 11

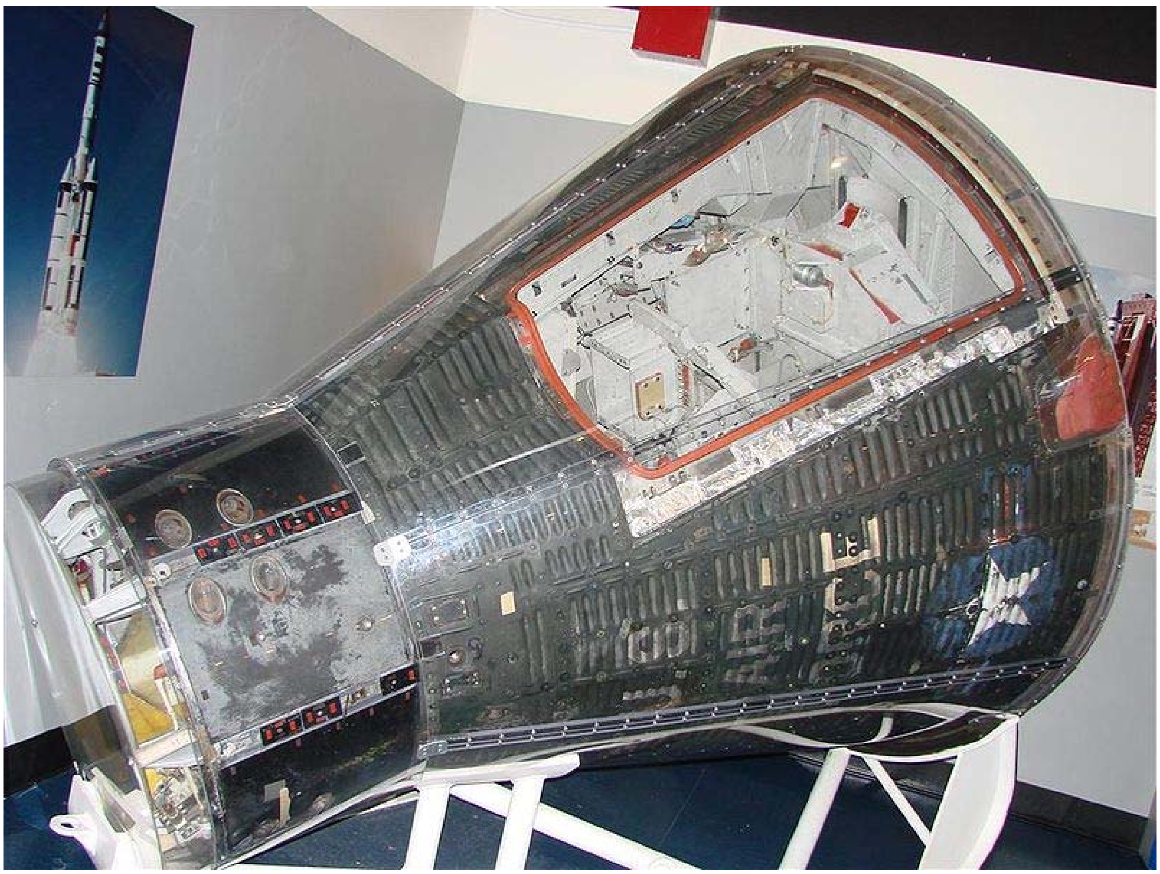
Missions

Liftoff of Gemini 6A from Pad 19 with astronauts Walter Schirra and Thomas Stafford aboard (15 December 1965)

There were 12 Gemini flights, including two unmanned flight tests. All were launched by Titan II rockets.

Unmanned events

Mission	LV Serial Nº	Mission Dates	Launch Time	Duration	Remarks
Gemini 1	GLV-1 12556	8–12 April 1964	16:01 UTC	03d 23h	First test flight of Gemini
Gemini 2	GLV-2 12557	19 January 1965	14:03 UTC	00d 00h 18m 16s	Suborbital flight to test heat shield



Gemini 2 on display at Air Force Space and Missile Museum

Manned events

Mission	LV Serial Nº	Command Pilot	Pilot	Mission Dates	Launch Time	Duration
Gemini III	GLV-3 12558	Grissom	Young	23 March 1965	14:24 UTC	00d 04h 52m 31s
	First manned Gemini flight, three orbits.					
Gemini IV	GLV-4	McDivitt	White	3–7 June	15:15 UTC	04d 01h

	12559			1965		56m 12s
	Included first extravehicular activity (EVA) by an American; White's "space walk" was a 22 minute EVA exercise.					
Gemini V	GLV-5 12560	Cooper	Conrad	21–29 August 1965	13:59 UTC	07d 22h 55m 14s
	First week-long flight; first use of fuel cells for electrical power; evaluated guidance and navigation system for future rendezvous missions. Completed 120 orbits.					
Gemini VII	GLV-7 12562	Borman	Lovell	4–18 December 1965	19:30 UTC	13d 18h 35m 01s
	When the original Gemini VI mission was scrubbed because its Agena target for rendezvous and docking failed, Gemini VII was used for the rendezvous instead. Primary objective was to determine whether humans could live in space for 14 days.					
Gemini VI-A	GLV-6 12561	Schirra	Stafford	15–16 December 1965	13:37 UTC	01d 01h 51m 24s
	First space rendezvous accomplished with Gemini VII, station-keeping for over five hours at distances from 0.3 to 90 m (1 to 300 ft).					
Gemini VIII	GLV-8 12563	Armstrong	Scott	16–17 March 1966	16:41 UTC	00d 10h 41m 26s
	Accomplished first docking with another space vehicle, an unmanned Agena stage. While docked, a Gemini spacecraft thruster malfunction caused near-fatal tumbling of the craft, which, after undocking, Armstrong was able to overcome; the crew effected the first emergency landing of a manned U.S. space mission.					
Gemini IX-A	GLV-9 12564	Stafford	Cernan	3–6 June 1966	13:39 UTC	03d 00h 21m 50s
	Rescheduled from May to rendezvous and dock with augmented target docking adapter (ATDA) after original Agena target vehicle failed to orbit. ATDA shroud did not completely separate, making docking impossible. Three different types of rendezvous, two hours of EVA, and 44 orbits were completed.					
Gemini X	GLV-10 12565	Young	Collins	18–21 July 1966	22:20 UTC	02d 22h 46m 39s
	First use of Agena target vehicle's propulsion systems. Spacecraft also rendezvoused with Gemini VIII target vehicle. Collins had 49 minutes of EVA standing in the hatch and 39 minutes of EVA to retrieve experiment from Agena stage. 43 orbits completed.					

<table>
<tr><td rowspan="2">Gemini XI</td><td>GLV-11
12566</td><td>Conrad</td><td>Gordon</td><td>12–15
September
1966</td><td>14:42 UTC</td><td>02d 23h
17m 08s</td></tr>
<tr><td colspan="6">Gemini record altitude, 1,189.3 kilometres (739.0 mi) (739.2 mi) reached using Agena propulsion system after first orbit rendezvous and docking. Gordon made 33-minute EVA and two-hour standup EVA. 44 orbits.</td></tr>
<tr><td rowspan="2">Gemini XII</td><td>GLV-12
12567</td><td>Lovell</td><td>Aldrin</td><td>11–15
November
1966</td><td>20:46 UTC</td><td>03d 22h
34m 31s</td></tr>
<tr><td colspan="6">Final Gemini flight. Rendezvoused and docked manually with its target Agena and kept station with it during EVA. Aldrin set an EVA record of 5 hours 30 minutes for one space walk and two stand-up exercises, and demonstrated improvements to previous EVA problems.</td></tr>
</table>

Gemini-Titan launches and serial numbers

Gemini 6A launch. USAF serial number location on Titan II

The Gemini-Titan launch vehicles, like the Mercury-Atlas vehicles before them, were ordered by NASA through the U. S. Air Force and were in reality missiles. The Gemini-Titan II rockets were assigned U.S. Air Force serial numbers, which were painted in four places on each Titan II (on opposite sides on each of the first and second stages). U.S. Air

Force crews maintained Launch Complex 19 and prepared and launched all of the Gemini-Titan II launch vehicles.

The USAF serial numbers assigned to the Gemini-Titan launch vehicles are given in the tables above. Fifteen Titan IIs were ordered in 1962 so the serial is "62-12XXX", but only "12XXX" is painted on the Titan II. The order for the last three of the 15 launch vehicles was cancelled on July 40, 1964, and they were never built. Serial numbers were, however, assigned to them prospectively: *12568* - GLV-13; *12569* - GLV-14; and *12570* - GLV-15.

All Gemini Launches from GT-1 through GT-12

Current location of hardware

Spacecraft

Gemini 1

Destroyed

Gemini 2

Air Force Space & Missile Museum, Cape Canaveral Air Force Station, Fla.

Gemini III

Grissom Memorial, Spring Mill State Park, Mitchell, Ind.

Gemini IV

National Air and Space Museum, Washington D.C.

Gemini V

Johnson Space Center, NASA, Houston, Texas

Gemini VI

Oklahoma History Center, Oklahoma City, Okla.

Gemini VII

Steven F. Udvar-Hazy Center, Chantilly, Va.

Gemini VIII

Armstrong Air and Space Museum, Wapakoneta, Ohio

Gemini IX

Kennedy Space Center, NASA, Cape Canaveral, Fla.

Gemini X

Kansas Cosmosphere and Space Center, Hutchinson, Kan.

Gemini XI

California Museum of Science and Industry, Los Angeles, Calif.

Gemini XII

Adler Planetarium, Chicago, Ill.

Trainers

Gemini 3A - St. Louis Science Center, St. Louis, Mo.

Gemini MOL-B - National Museum of the United States Air Force, Wright-Patterson Air Force Base, Dayton, Ohio

Gemini Trainer - U.S. Space & Rocket Center, Huntsville, Ala.

Gemini Trainer - Goddard Space Flight Center (Visitor Center), NASA, Greenbelt, Md.

Gemini Trainer - Louisville Science Center, Louisville, Ken.

6165 - National Air and Space Museum, Washington D.C. (not on display)

El Kabong - Kalamazoo Air Museum, Kalamazoo, Mich.

Gemini Trainer - Kalamazoo Air Museum, Kalamazoo, Mich.

TTV-2 Royal Museum, Edinburgh, Scotland

Trainer - Pate Museum of Transportation, Fort Worth, Texas

MSC 313 - Private residence, San Jose, Calif.

Rogallo Test Vehicle - White Sands Space Harbor, White Sands, N. M.

TTV-1 - Stephen F. Udvar-Hazy Center, Chantilly, Va.

unnamed - U.S. Air Force Space Museum, Cape Canaveral Air Force Station, Fla.

unnamed - U.S. Air Force Space Museum, Cape Canaveral Air Force Station, Fla.

Gemini Trainer - BDL Aerospace and Flight Museum, NAS Whidbey Island, Oak Harbor, Wash.

Trainer - U.S. Astronaut Hall of Fame, Titusville, Fla.

MSC-307 - USS Hornet Museum, Alameda, Calif.

Proposed applications

McDonnell Aircraft was one of the original bidders on the prime contract for Apollo, but lost out to North American Aviation. McDonnell later sought to extend the Gemini program by proposing a derivative which could be used to fly a cislunar mission and even achieve a manned lunar landing earlier and at less cost than Apollo, but these proposals were rejected by NASA.

Military

The United States Air Force had an interest in the system, and decided to use its own modification of the spacecraft as the crew vehicle for the Manned Orbital Laboratory. To this end, one of the unmanned Gemini spacecraft was refurbished and flown again atop a mockup of the MOL, sent into space by a Titan III-M. This was the first time a spacecraft went into space twice.

The USAF also had the notion of adapting the Gemini spacecraft for military applications, such as crude observation of the ground (no specialized reconnaissance camera could be carried) and practicing making rendezvous with suspicious satellites. This project was called Blue Gemini. The US Air Force did not like the fact that Gemini would have to be recovered by the US Navy, so they intended for Blue Gemini eventually to use the paraglider and land on three skids, something from the original design of Gemini.

At first some within NASA welcomed sharing of the cost with the USAF, but it was later agreed that NASA was better off operating Project Gemini by itself. MOL was cancelled in 1968 and Blue Gemini too was cancelled without any use by military astronauts.

Other proposals

Other Gemini derivatives were proposed, including Big Gemini, Gemini LOR, Gemini Lunar Lander, Gemini-Centaur, Gemini Ferry, Gemini Transport, Gemini - Saturn I, Gemini - Saturn IB, Gemini - Saturn V, Gemini Pecan, Extended Mission Gemini, Gemini - Double Transtage, Gemini Satellite Inspector, Gemini Lunar Surface Rescue Spacecraft, Gemini Observatory, Gemini Para glider, Rescue Gemini, Winged Gemini, Gemini LORV and Gemini Lunar Surface Survival Shelter.

Chapter 7

Notable Human Spaceflights

Soyuz TMA-20

Soyuz TMA-20
Союз ТМА-20

Mission insignia

Mission statistics

Mission name	Soyuz TMA-20 Союз ТМА-20
Spacecraft name	Soyuz-TMA
Crew size	3
Call sign	Варяг ("Varangian")
Launch pad	Baikonur Cosmodrome
Launch date	December 15, 2010 19:09 GMT
Landing	May 16, 2011

Crew photo

From left to right: Coleman, Kondratyev and Nespoli

Related missions

Previous mission	Subsequent mission
Soyuz TMA-01M	Soyuz TMA-21

Soyuz TMA-20 is a manned spaceflight to the International Space Station (ISS) and is part of the Soyuz programme. It lifted off from the Baikonur Cosmodrome on December 15, 2010. The link up of Soyuz TMA-20 with the ISS is planned on 17 December, following a two day autonomous flight. The three person crew of Soyuz TMA-20, Dmitri Kondratyev, Catherine Coleman and Paolo Nespoli represent the partner organizations of Roscosmos, NASA and the European Space Agency (ESA) in the ISS program.

Crew

The Soyuz TMA-20 prime and backup crews conduct their ceremonial tour of Red Square on 26 November 2010.

The Soyuz TMA-20 crew was confirmed by NASA on November 21, 2008.

Position	Crew Member
Commander	Dmitri Kondratyev, Roscosmos Expedition 26 First spaceflight
Flight Engineer 1	Catherine Coleman, NASA

	Expedition 26 Third spaceflight
Flight Engineer 2	Paolo Nespoli, ESA Expedition 26 Second spaceflight

Backup crew

Position	Crew Member
Commander	Anatoli Ivanishin, RSA
Flight Engineer 1	Satoshi Furukawa, JAXA
Flight Engineer 2	Michael Fossum, NASA

Tallest crew member

European astronaut Paolo Nespoli (height: 188 centimeters) is believed to be the tallest crew member ever to fly onboard Soyuz spacecraft. According to president of RKK Energia, Vitaly Lopota, a custom-built seat and related hardware had to be manufactured due to Nespoli's height.

Transportation damage

The Soyuz spacecraft suffered damage to its container during transport to the Baikonur cosmodrome on October 5, 2010, according to Interfax news agency. Engineers spotted damage after it was shipped by rail from Russia to Kazakhstan. After initial inspections of the damage, Russian sources said that it was not immediately clear whether the spacecraft will have to be returned to the RSC Energia factory in Moscow. Later, Russian officials replaced the damaged descent module with a new one flown aboard a cargo plane. The replacement module was originally part of the Soyuz TMA-21 spacecraft.

The Soyuz TMA-20 rocket launches from the Baikonur Cosmodrome carrying Kondratyev, Coleman and Nespoli to the International Space Station.

Despite the transportation damage, RSC-Energia president Vitaly Lopota told news media that the mission will take place in December. Roskosmos spokesman Alexander Vorobyov also told Interfax that the December launch date would not be affected because a reserve spacecraft will be available at Baikonur for the mission, if required.

Launch and docking

Launch

On 12 December 2010 the Soyuz TMA-20 payload section was integrated with the Soyuz FG rocket and the emergency escape system allowing the State commission to declare that the Soyuz TMA-20 mission was fully assembled. Rollout to the launch pad began in the morning of December 13, 2010.

The Soyuz FG rocket with Soyuz TMA-20 spacecraft blasted off from Baikonur Cosmodrome's Site 1 at 19:09 GMT (22:09:25 Moscow Time) on 15 December 2010 and successfully reached orbit ten minutes later.

Docking

The Soyuz TMA-20 spacecraft approaches the International Space Station

The Soyuz TMA-20 spacecraft docked with the Rassvet module's docking port at 20:12 GMT on December 17. The docking occurred as the space station flew over western Africa at an altitude of 224 miles.

In preparation for the day's docking activities, the automated rendezvous sequence aboard Soyuz TMA-20 began about 17:49 GMT. The Soyuz TMA-20 engines were fired at 18:09 GMT and another impulse firing occurred around 18:28 GMT. Within minutes the

Kurs rendezvous equipment on both the Soyuz and station was activated to support the linkup. The television camera on the nose of the Soyuz spacecraft was turned on at 19:29 GMT to provide views of the docking.

After checking that there are no leaks between the two spacecraft, the hatch between the Soyuz TMA-20 spacecraft and the space station was opened at 23:02 GMT. The new crew of Kondratyev, Coleman and Nespoli entered into the space station. The welcome ceremony to mark the arrival of the new crew was held shortly when the live television downlink communications session started.

Soyuz TMA-19

Soyuz TMA-19
Союз TMA-19

Mission insignia

Mission statistics

Mission name	Soyuz TMA-19 Союз TMA-19
Crew size	3
Call sign	Olympus
Booster	Soyuz-FG
Launch pad	Site 1/5, Baikonur Cosmodrome
Launch date	15 June 2010

	21:35 UTC
Landing	26 November 2010 04:46 GMT
Orbital period	88.8 minutes
Orbital inclination	51.62 degrees (initial orbit)

Crew photo

From left to right: Wheelock, Walker and Yurchikhin

Related missions

Previous mission	Subsequent mission
Soyuz TMA-18	Soyuz TMA-01M

Soyuz TMA-19 was a manned spaceflight to the International Space Station and is part of the Soyuz programme. It was launched 15 June 2010 carrying three members of the Expedition 24 crew to Space Station, who remained aboard the station for around six months. TMA-19 was the 106th manned flight of a Soyuz spacecraft, since the first mission which was launched in 1967. The spacecraft remained docked to the space station for the remainder of Expedition 24, and for Expedition 25, to serve as an emergency escape vehicle. It undocked from ISS and landed in Kazakhstan on the 26 November 2010. It was the 100th mission to be conducted as part of the International Space Station programme since assembly began in 1998.

Crew

The Soyuz TMA-19 prime and backup crews conduct their ceremonial tour of Red Square on 31 May 2010.

The Soyuz TMA-19 crew was confirmed by NASA on 21 November 2008. The mission Commander is Fyodor Yurchikhin of the Russian Federal Space Agency, who is making his third spaceflight. The other two crew members are Shannon Walker and Douglas H. Wheelock of the United States National Aeronautics and Space Administration and are designated flight engineers. TMA-19 is Wheelock's second spaceflight, and Walker's first.

Position	Crew Member
Commander (Center Seat)	Fyodor Yurchikhin, RSA Expedition 24 Third spaceflight
Flight Engineer 1 (Left Seat)	Shannon Walker, NASA Expedition 24 First spaceflight
Flight Engineer 2 (Right Seat)	Douglas H. Wheelock, NASA

Expedition 24
Second spaceflight

Backup crew

Position	Crew Member
Commander	Dmitri Kondratyev, RSA
Flight Engineer 1	Paolo Nespoli, ESA
Flight Engineer 2	Catherine Coleman, NASA

Launch

A Soyuz-FG launches Soyuz TMA-19 from Baikonur Cosmodrome, 15 June 2010

Soyuz TMA-19 was launched by a Soyuz-FG carrier rocket flying from Site 1/5 at the Baikonur Cosmodrome in Kazakhstan. The launch occurred successfully on 15 June 2010, with the rocket lifting off at 21:35 UTC. After its separation from the last stage of the Soyuz-FG rocket, Moscow Mission Control Center began controlling the Soyuz TMA-19 spacecraft. Nine minutes into the ascent, the spacecraft settled into a preliminary orbit of 200.16 by 259.16 km (124.37 by 161.03 mi) with the inclination 51.62 degrees toward the Equator. The Soyuz spacecraft successfully deployed the solar arrays for power generation and the antennas for navigational and communication systems. Telemetry data received from the Soyuz confirmed that the spacecraft was performing nominally.

Prior to launch, assembly of the rocket and spacecraft had been underway for several months. The Soyuz-FG rocket arrived at Baikonur on 11 March 2010, along with a Soyuz-U which was slated to launch Progress M-06M. The spacecraft itself was shipped from Korolyov on 16 April 2010, arriving at Baikonur by train three days later. Upon delivery, the spacecraft was moved to Site 254.

On 11 June 2010, final inspections of the spacecraft were conducted, and the spacecraft was then encapsulated in its payload fairing to form the upper composite of the rocket. The next day, the upper composite was integrated with the upper stage of the rocket that was to launch it, and subsequently the launch escape system. This assembly work took place at Site 112 of the Baikonur Cosmodrome. Once this was complete, the upper stage was attached to the remainder of the rocket in the MIK. A State Commission met of 12 June to approve rollout, which was authorised.

Rollout to the launch pad began at 01:00 UTC (5 a.m. Moscow Time) on 13 June 2010, with the rocket departing the MIK propelled by a locomotive. Rollout lasted around two hours, with the rocket travelling 2 kilometres (1.2 mi) from the MIK to the launch pad. The winner and runner-up in the patch design competition were present to observe the rollout. Rollout operations were completed by 05:00 UTC (9 a.m. Moscow Time), when the rocket was erected on the launch pad.

Docking

Soyuz TMA-19 spacecraft docked to Rassvet Mini-Research Module 1 (MRM1).

Soyuz TMA-19 arrives at the ISS

Soyuz TMA-19 docked with the International Space Station on 17 June 2010at 22:25 UTC. It docked with the aft port of the Zvezda module. Ahead of docking, the ISS handed over attitude control to the Russian Orbital Segment at 19:00 UTC, and at 19:17 maneuvered to provide an optimum attitude for docking. At 20:06, the automated rendezvous sequence started. The Kurs docking systems aboard the Soyuz and the Space Station were activated at 20:52 and 20:54 respectively. TMA-19 began station keeping at around 20:08 UTC, before it commenced its final approach at 20:16.

Twenty minutes after docking, hooks were closed securing the Soyuz to the station. Once this was completed, the ISS returned to its normal attitude. Attitude control was returned to the US Orbital Segment at 23:45 UTC.

Relocation

Soyuz TMA-19 relocates from the Zvezda Service Module's aft port to the Rassvet Mini-Research Module 1.

On June 28, cosmonaut Fyodor Yurchikhin along with NASA astronauts Douglas Wheelock and Shannon Walker boarded their Soyuz TMA-19 spacecraft and undocked from Zvezda Service Module's aft port at 3:13 p.m. EDT. They re docked it to its new location on the Rassvet module 25 minutes later as the two spacecraft were flying just off the coast of the Western Sahara on the west coast of Africa. The repositioning of the Soyuz TMA-19 was temporarily delayed due to an electrical breaker problem that delayed proper orientation of the 4B solar array on the space station's P4 truss. The flight went according to plan.

The event marked the first ever docking to the Rassvet module. The change of location released the Zvezda port for the docking of Progress M-06M.

Undocking and landing

The Soyuz TMA-19 spacecraft departs the International Space Station

Soyuz TMA-19 lands in Kazakhstan on 26 November 2010

Soyuz TMA-19 crewmembers after landing

Soyuz TMA-19 undocked from the space station at 01:19 GMT on 26 November, 2010. The descent module landed on the central steppes of Kazakhstan at 04:46 GMT, four days earlier than originally planned. The landing had been set for 30 November, but Kazakh officials decided to restrict air traffic before the start of the Organization for Security and Cooperation in Europe summit in Astana, Kazakhstan, set for 1-2 December. The landing site was located 84 km away from the city of Arkalyk.

On 25 November, 2010, the crew boarded Soyuz TMA-19 to return to Earth. After closing the hatchway between the Soyuz and the station at 22:14 GMT, they donned their Sokol spacesuits and continued with the power up operations. The crew also activated the Soyuz systems and removed the docking clamps. The undock command was issued at 01:20 GMT when the Soyuz and the station was flying above the Russian-Mongolian border. . The physical separation occurred three minutes later at 01:23:13 GMT

After the separation from the station and at a short distance away, Soyuz TMA-19 executed the so called "separation burn" (a 15 seconds burn) to vacate the proximity of the space station. About two and half hours later, at 03:55:12 GMT, the Soyuz spacecraft performed the deorbit maneuver which lasted for 4 minutes and 21 seconds, while it flew backwards over the south-central Atlantic Ocean on a north easterly trajectory towards Asia. With the deorbit burn nominally accomplished, the recovery forces comprising 14 helicopters, 4 airplanes and 7 search and rescue vehicles were dispatched to the landing zone. At an altitude of 140 kilometers, just above the first traces of the Earth's atmosphere, onboard computers commanded the separation of the three Soyuz TMA-19 modules. With the crew inside the Descent Module, the forward Orbital Module and the rear Instrumentation Module were pyrotechnically nominally jettisoned at 04:21 GMT. Three minutes after the separation, with the heat shield of the Descent Module pointing towards the direction of travel, the Soyuz capsule experienced the first traces of the atmosphere ("entry interface") at 04:23 GMT at an altitude of 400,000 feet above the Earth. Around 04:28 GMT, the flight path of the capsule crossed the Mediterranean, Turkey and the Black Sea before flying over southern Russia and into Kazakhstan.

At an altitude of about 10 kilometers, onboard computers started a commanded sequence to unfurl the parachutes. Two "pilot" parachutes deployed first, extracting a 24-square-meter drogue parachute. The parachute deployment reduced the velocity of the Soyuz capsule from 230 m/s to 80 m/s and assisted in the capsule's stability by creating a gentle spin for the Soyuz spacecraft. Once the drogue chute was released, the main parachutes were deployed. They further reduced the descent to 7.2 m/s. Initially, the Descent Module hung underneath the main parachute at a 30-degree angle with respect to the horizon and for the few minutes before the landing, then following the detachment of the bottom-most harness it hung vertically. At this time, flight controllers reported the Soyuz spacecraft was operating as expected on the automatic sequence. During the same time, they were successful in contacting the crew via the fixed-wing aircraft that served as the central command for the search and recovery forces. The recovery forces spotted the Soyuz TMA-19 around 04:36 GMT. At an altitude of five kilometers, the module's heat shield was jettisoned.

At the end of the 163-day voyage, Soyuz TMA-19's landing was confirmed at 04:46 GMT. The recovery team assisted the crew to exit the capsule. First out of the capsule was cosmonaut Fyodor Yurchikhin followed by NASA astronauts Shannon Walker and Douglas Wheelock.

After the successful landing, the Soyuz TMA-19 crew flew to Kustanai in Kazakhstan for the welcoming ceremony. Wheelock and Walker boarded a NASA jet waiting for them in Kustanai for the trip back to the Johnson Space Center in Houston. Yurchikhin headed for Star City - the home of the Gagarin Cosmonaut Training Center in Russia.

Mission insignia

The Soyuz TMA-19 patch design is based on a drawing by Evgeny Emelianov, the winner of the traditional patch contest organized by the Russian Federal Space Agency. His design shows the ISS and the Earth waiting for the crew to come back.

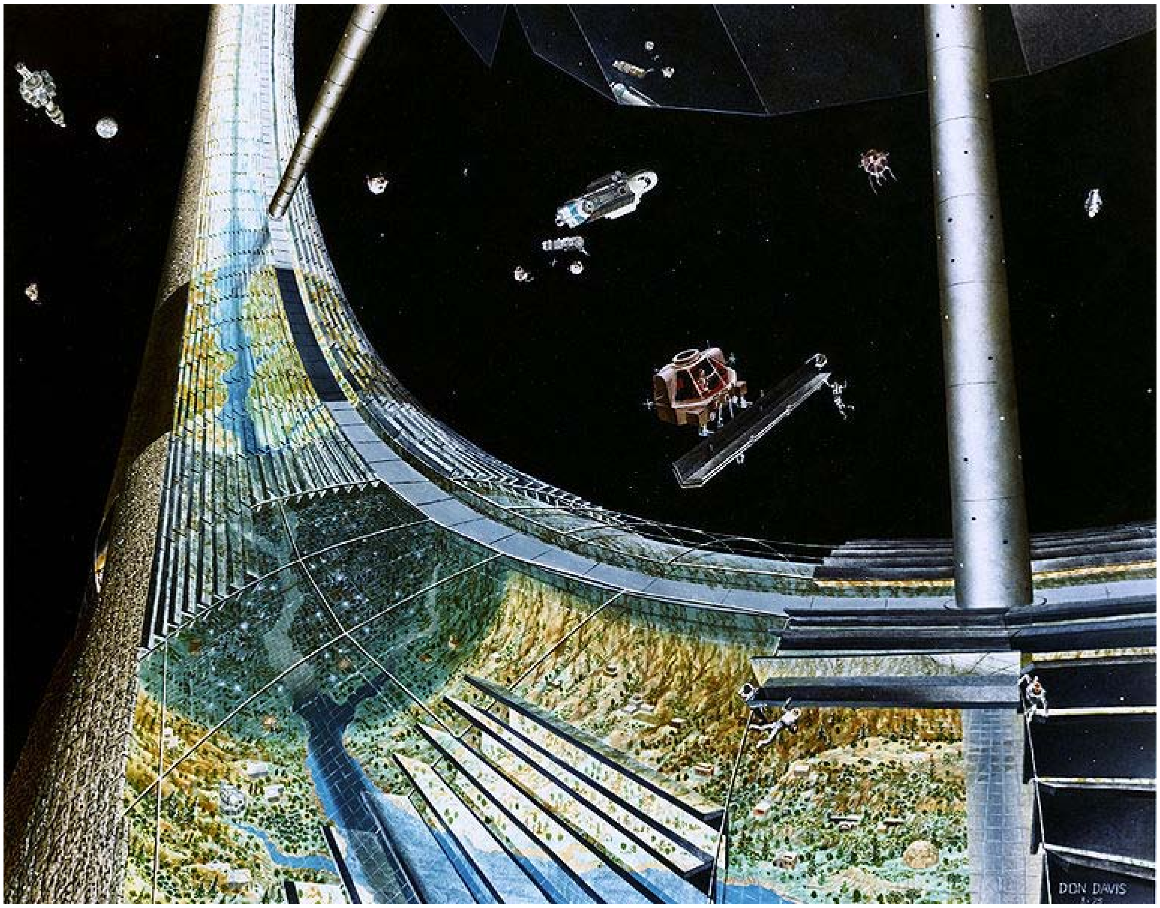
Chapter 8

Human Adaptation to Spaceflight

Human physiological adaptation to the conditions of space is a challenge faced in the development of human spaceflight.

The fundamental engineering problems of escaping Earth's gravity well and developing systems for in-space propulsion have been examined for well over a century, and millions of man-hours of research have been spent on them. In recent years there has been an increase in research into the issue of how humans can survive and work in space for extended and possibly indefinite periods of time. This question requires input from the whole gamut of physical and biological sciences and has now become the greatest challenge, other than funding, to human space exploration. A fundamental step in overcoming this challenge is trying to understand the effects and the impact long-term space travel has on the human body.

Importance



Space colonization efforts must take into account the effects of space on the body

The sum of mankind's experience has resulted in the accumulation of 58 solar years in space and a much better understanding of how the human body adapts. In the future, industrialisation of space and exploration of inner and outer planets will require humans to endure longer and longer periods in space. The majority of current data comes from missions of short duration and so some of the long-term physiological effects of living in space are still unknown. A round trip to Mars with current technology is estimated to involve at least 18 months in transit alone. How the human body reacts to such time periods in space is a vital part of the preparation for such journeys. On-board medical facilities need to be able to cope with any type of trauma or emergency as well as contain a huge variety of diagnostic and medical instruments in order to keep a crew healthy over a long period of time, as these will be the only facilities available on board a spacecraft to cope with not only trauma, but also the adaptive responses of the human body in space.

Effects on humans

The effects of space conditions on humans can be separated into two areas, the physical and the psychological.

Unprotected effects

The environment of space is lethal without appropriate protection. The greatest threat is from the lack of pressure in the vacuum environment, while temperature and radiation effects also have an influence. In the low pressure environment, gas exchange in the lungs would continue as normal but would result in the removal of all gases, including oxygen, from the bloodstream. After 9 to 12 seconds, the deoxygenated blood would reach the brain, and loss of consciousness would result. Death would gradually follow after two minutes of exposure—though the limits are uncertain. As shown in the film depiction of Arthur C. Clarke's vignette in *2001: A Space Odyssey* (1968), if actions are taken quickly, and normal pressure restored within around 90 seconds, the victim may well make a full recovery.

This painting, *An Experiment on a Bird in the Air Pump* by Joseph Wright of Derby, 1768, depicts an experiment performed by Robert Boyle in 1660.

Humans and other animals exposed to vacuum will lose consciousness after a few seconds and die of hypoxia within minutes, but the symptoms are not nearly as graphic as the imagery in the public media. Blood and other body fluids do boil when their pressure drops below 6.3 kPa (47 Torr), the vapour pressure of water at body temperature. This condition is called ebullism. The steam may bloat the body to twice its normal size and slow circulation, but tissues are elastic and porous enough to prevent rupture. Ebullism is slowed by the pressure containment of blood vessels, so some blood remains liquid. Swelling and ebullism can be reduced by containment in a flight suit. Shuttle astronauts wear a fitted elastic garment called the Crew Altitude Protection Suit (CAPS) which prevents ebullism at pressures as low as 2 kPa (15 Torr). Rapid evaporative cooling of the skin will create frost, particularly in the mouth, but this is not a significant hazard.

A short term exposure to vacuum of up to 30 seconds is unlikely to cause permanent physical damage. Animal experiments show that rapid and complete recovery is normal for exposures shorter than 90 seconds, while longer full-body exposures are fatal and resuscitation has never been successful. There is only a limited amount of data available from human accidents, but it is consistent with animal data. Limbs may be exposed for much longer if breathing is not impaired. Robert Boyle was the first to show in 1660 that vacuum is lethal to small animals. In 1942, in one of a series of experiments on human subjects for the Luftwaffe, the Nazi regime exposed Dachau concentration camp prisoners to vacuum in order to determine the human body's capacity to survive high-altitude conditions.

As well as experimentation with humans and monkeys, a few cases of loss of pressure have occurred in the past, especially in experimentation on spaceflight projects. One such case is discussed in a NASA technical report: *Rapid (Explosive) Decompression Emergencies in Pressure-Suited Subjects*:

> "At NASA's Manned Spacecraft Center (now renamed Johnson Space Center) we had a test subject accidentally exposed to a near vacuum (less than 1 psi) [7 kPa] in an incident involving a leaking space suit in a vacuum chamber back in '65. He remained conscious for about 14 seconds, which is about the time it takes for O_2 deprived blood to go from the lungs to the brain. The suit probably did not reach a hard vacuum, and we began repressurizing the chamber within 15 seconds. The subject regained consciousness at around 15,000 feet [4600 m] equivalent altitude. The subject later reported that he could feel and hear the air leaking out, and his last conscious memory was of the water on his tongue beginning to boil."

There has been one recorded incident of death from decompression in spaceflight, the Soyuz 11 decompression accident, in 1971.

Cold or oxygen-rich atmospheres can sustain life at pressures much lower than atmospheric, as long as the density of oxygen is similar to that of standard sea-level atmosphere. The colder air temperatures found at altitudes of up to 3 km generally compensate for the lower pressures there. Above this altitude, oxygen enrichment is necessary to prevent altitude sickness, and spacesuits are necessary to prevent ebullism above 19 km. Most spacesuits use only 20 kPa (150 Torr) of pure oxygen, just enough to sustain full consciousness. This pressure is high enough to prevent ebullism, but simple evaporation of blood, or of gases dissolved in the blood, can still cause decompression sickness (the bends) and gas embolisms if not managed.

Rapid decompression can be much more dangerous than vacuum exposure itself. Even if the victim does not hold his breath, venting through the windpipe may be too slow to prevent the fatal rupture of the delicate alveoli of the lungs. Eardrums and sinuses may be ruptured by rapid decompression, soft tissues may bruise and seep blood, and the stress of shock will accelerate oxygen consumption leading to hypoxia. Injuries caused by rapid decompression are called barotrauma, and are well known from scuba diving accidents. A pressure drop as small as 100 Torr (13 kPa), which produces no symptoms if it is gradual, may be fatal if it occurs suddenly.

In a vacuum there is no medium for removing heat from the body by conduction or convection. Loss of heat is by radiation from the 310 K person to the 3 K of outer space. This is a slow process, especially in a clothed person, so there is no danger of immediately freezing. (Evaporation of skin moisture in the vacuum would cause immediate cooling but only by a very small amount.) Exposure to the 600 K radiation from the Sun would lead to local heating that would be well distributed by the body's conductivity and blood circulation. Other solar radiation, particularly ultraviolet rays, may cause severe sunburn in a few seconds.

Protected effects

Despite modern technology, some hazards still prove impossible to remove. The most important factor affecting human physical well-being in space is weightlessness, more accurately defined as microgravity environments. Living in this type of environment impacts on three types of human tissue:

- gravity receptors
- fluids
- weight bearing structures

Gravity receptors

Living on earth we constantly feel the gravitational pull and our bodies react automatically to maintain posture and locomotion in a downward pulling world. In microgravity environments, these constant signals the body is adapted to are absent. The otolith organs in the middle ear sensitive to linear accelerations no longer perceive a downwards bias, muscles are no longer required to contract to maintain posture and pressure receptors in the feet and ankles no longer signal the direction of down. These changes can immediately result in visual-orientation illusions where the astronaut feels he has flipped 180 degrees. Over time however the brain adapts and although these illusions can still occur most astronauts begin to see "down" as where the feet are. People returning to Earth after extended weightless periods initially have great difficulty maintaining their balance but recover the ability very quickly, highlighting the remarkable ability of the human body to adapt. Over half of astronauts also experience symptoms of motion sickness for the first three days of travel due to the conflict between what the body expects and what the body actually perceives.

Fluids

The second effect of weightlessness takes place in human fluids. The body is made up of 60% water, much of it intra-vascular and inter-cellular. Within a few moments of entering a microgravity environment, fluid is immediately re-distributed to the upper body resulting in bulging neck veins, puffy face and sinus and nasal congestion which can last throughout the duration of the trip and is very much like the symptoms of the common cold. In space the autonomic reactions of the body to maintain blood pressure are not required and fluid is distributed more widely around the whole body. This results in a decrease in plasma (water in the blood stream) volume of around 20%. These fluid shifts initiate a cascade of adaptive systemic effects that can be dangerous upon return to earth. Orthostatic intolerance results in astronauts returning to Earth after extended space missions being unable to stand unassisted for more than 10 minutes at a time without fainting. This is due in part to changes in the autonomic regulation of blood pressure and the loss of plasma volume. Although this effect becomes worse the longer the time spent in space, as yet all individuals have returned to normal within at most a few weeks of landing.

Weight-bearing structures

The third and most worrying effect of long-term weightlessness involves bones and muscles. Without the effects of gravity, skeletal muscle is no longer required to maintain our posture and the muscle groups used in moving around in a weightless environment are very different to those required in terrestrial locomotion. Consequently some muscles atrophy rapidly. The types of muscle fibre prominent in muscles also change. Slow twitch endurance fibres used to maintain posture are replaced by fast twitch rapidly contracting fibres that are insufficient for any heavy labour. Bone metabolism also changes. Normally bone is laid down in the direction of mechanical stress, however in a microgravity environment there is very little mechanical stress. This results in a loss of bone tissue approximately 1.5% per month especially from the lower vertebrae, hip and femur. Elevated blood calcium levels from the lost bone result in dangerous calcification of soft tissues and potential kidney stone formation. It is still unknown whether bone recovers completely. Loss of bone and muscle make it very difficult for humans to move and even breathe under the weight of Earth's pull upon their return.

Effects of radiation

Weightlessness is not the only factor to affect the human body in space. Without the protection of the Earth's atmosphere and magnetosphere astronauts are exposed to high levels of radiation through a steady flux of cosmic rays which pose a serious health threat. A year in even low-earth orbit results in a dose of radiation 10 times that of the annual dose on earth resulting in a high risk of astronauts developing cancer. High levels of radiation can create 'chromosomal aberrations' in blood lymphocytes. These cells are heavily involved in the immune system and so any damage may contribute to the lowered immunity experienced by astronauts. Over time immunodeficiency results in the rapid spread of infection between crew members, especially in such confined areas. Radiation has also recently been linked to a higher incidence of cataracts in astronauts. Protective shielding and protective drugs may lower the risks to astronauts to an acceptable level, but data is scarce, and longer-term exposure will result in greater risks.

Sense of taste

One effect of weightlessness on humans is that some astronauts report a change in their sense of taste in space. Some astronauts find that their food is bland, others find that their favorite foods no longer taste as good, some astronauts enjoy eating certain foods that they would not normally eat and some find no change whatsoever. The reason for this is uncertain, and several theories have been suggested:

- Congestion: Microgravity may cause fluid buildup in the sinuses, changing the taste in a similar fashion to holding one's nose while eating.
- Physical food degradation: Food in orbit is often stored for some months before being consumed. This and the stellar radiation may cause a breakdown in the groups of chemicals that give food its taste, resulting in bland food.
- Boredom: Menus for the ISS astronauts are planned on a repeating 8-day cycle, which are selected from a menu designed by NASA, and taken into space with the astronaut. This constant repetition may lead to some astronauts getting tired of food that they had previously liked.
- Psychological changes: The loss of taste may be purely psychological.

Astronauts often choose strong-tasting food such as salsa or shrimp cocktail.

Other physical effects

Studies of Russian cosmonauts, such as those on Mir, provide data on the long-term effects of space on the human body.

Other physical discomforts such as back and abdominal pain are commonly experienced with no clear cause. These may be part of the asthenia syndrome reported by cosmonauts living in space over an extended period of time, but seen as anecdotal by astronauts. Fatigue, listlessness, and psychosomatic worries are also part of the syndrome. The data is inconclusive, however the syndrome does appear to exist as a manifestation of all the internal and external stress crews in space must face. The amount and quality of sleep experienced in space is poor due to highly variable light and dark cycles on flight decks and poor illumination during daytime hours in the space craft. Even the habit of looking out of the window before retiring can send the wrong messages to the brain resulting in poor sleep patterns. These disturbances in circadian rhythm have profound effects on the neurobehavioural responses of crew and aggravate the psychological stresses they already experience.

Psychological effects

The psychological effects of living in space have not been clearly analyzed but analogies on Earth do exist, such as Arctic research stations and submarines. The enormous stress on the crew, coupled with the body adapting to other environmental changes, can result in anxiety, insomnia and depression. According to current data however astronauts and cosmonauts seem extremely resilient to psychological stresses. Interpersonal issues can have an enormous influence on a human's well-being and yet little research has been undertaken to examine crew selection issues in relation to this. The Mars Arctic Research Station and Mars Desert Research Station have examined the influence of different crew selections when living in a completely isolated environment and may provide vital data for future experiences.

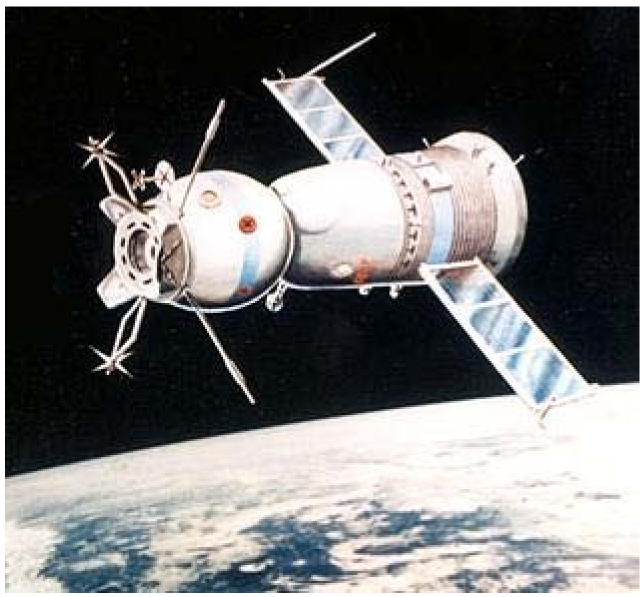
Future prospects

At the moment only rigorously tested humans have experienced the conditions of space. If off-world colonization someday begins, many types of people will be exposed to these dangers, and the effects on the elderly and on the very young are completely unknown. Factors such as nutritional requirements and physical environments which have not been examined here will become important. Overall, there is little data on the manifold effects of living in space and this makes working to mitigate the risks during a lengthy space habitation difficult. Test beds such as the International Space Station (ISS) are presently being utilized to research some of these risks.

The environment of space is still largely unknown, and there will likely be hazards of which we are not currently aware. Meanwhile, future technologies such as artificial gravity and more complex bioregenerative life support systems may someday be capable of mitigating some hazards.

Chapter 9

Soyuz Programme



Soyuz spacecraft from the Apollo-Soyuz Test Project

The **Soyuz programme** is a human spaceflight programme that was initiated by the Soviet Union in the early 1960's. It was originally part of a Moon landing programme intended to put a Soviet cosmonaut on the Moon. Both the Soyuz spacecraft and the Soyuz rocket are part of this programme, which is now the responsibility of the Russian Federal Space Agency.

Soyuz rocket

Soyuz rocket on launch pad

The launch vehicles used in the Soyuz expendable launch system are manufactured at the Progress State Research and Production Rocket Space Center (TsSKB-Progress) in Samara, Russia. As well as being used in the Soyuz programme as the launcher for the manned Soyuz spacecraft, Soyuz launch vehicles are now also used to launch unmanned Progress supply spacecraft to the International Space Station and commercial launches marketed and operated by TsSKB-Progress and the Starsem company. There were 11 Soyuz launches in 2001 and 9 in 2002. Currently Soyuz vehicles are launched from the Baikonur Cosmodrome in Kazakhstan and the Plesetsk Cosmodrome in northwest Russia. Starting in 2010 Soyuz launch vehicles will also be launched from the Guiana Space Centre in French Guiana.

Soyuz spacecraft

The basic Soyuz spacecraft design was the basis for many projects, many of which never came to light. Its earliest form was intended to travel to the moon without employing a huge booster like the Saturn V or the Soviet N-1 by repeatedly docking with upper stages that had been put in orbit using the same rocket as the Soyuz. This and the initial civilian designs were done under the Soviet Chief Designer Sergei Pavlovich Korolev, who did not live to see the craft take flight. Several military derivatives actually took precedence in the Soviet design process, though they never came to pass.

A Soyuz spacecraft consists of three parts (from front to back):

- a spheroid orbital module
- a small aerodynamic reentry module
- a cylindrical service module with solar panels attached

There are several variants of the Soyuz spacecraft, including:

- Soyuz A 7K-9K-11K circumlunar complex proposal(1963)
- Soyuz 7K-OK (1967-1971)
    - Soyuz 7K-L1 Zond (1967-1970)
    - Soyuz 7K-L3 LOK
    - Soyuz 7K-OKS (1971)
        - Soyuz 7K-T or "ferry" (1973-1981)
        - Soyuz 7K-TM (1975-1976)
- Military Soyuz (7K-P, 7K-PPK, R, 7K-VI Zvezda, and OIS)
- Soyuz-T (1976-1986)
- Soyuz-TM (1986-2003)
- Soyuz-TMA (2003-....)
- Soyuz-TMAT (2010/....)
- Soyuz-ACTS (2012/....)

Derivatives

The Zond spacecraft was another derivative, designed to take a crew traveling in a figure-eight orbit around the Earth and the moon but never achieving the degree of safety or political need to be used for such.

Finally, the Progress series of unmanned cargo ships for the Salyut and Mir space laboratories used the automatic navigation and docking mechanism (but not the re-entry capsule) of Soyuz.

As of 2007, Soyuz derivatives provide Russia's human spaceflight capability and are used to ferry personnel and supplies to and from the International Space Station.

While not a direct derivative, the Chinese Shenzhou spacecraft follows the basic template originally pioneered by Soyuz.

Additional images

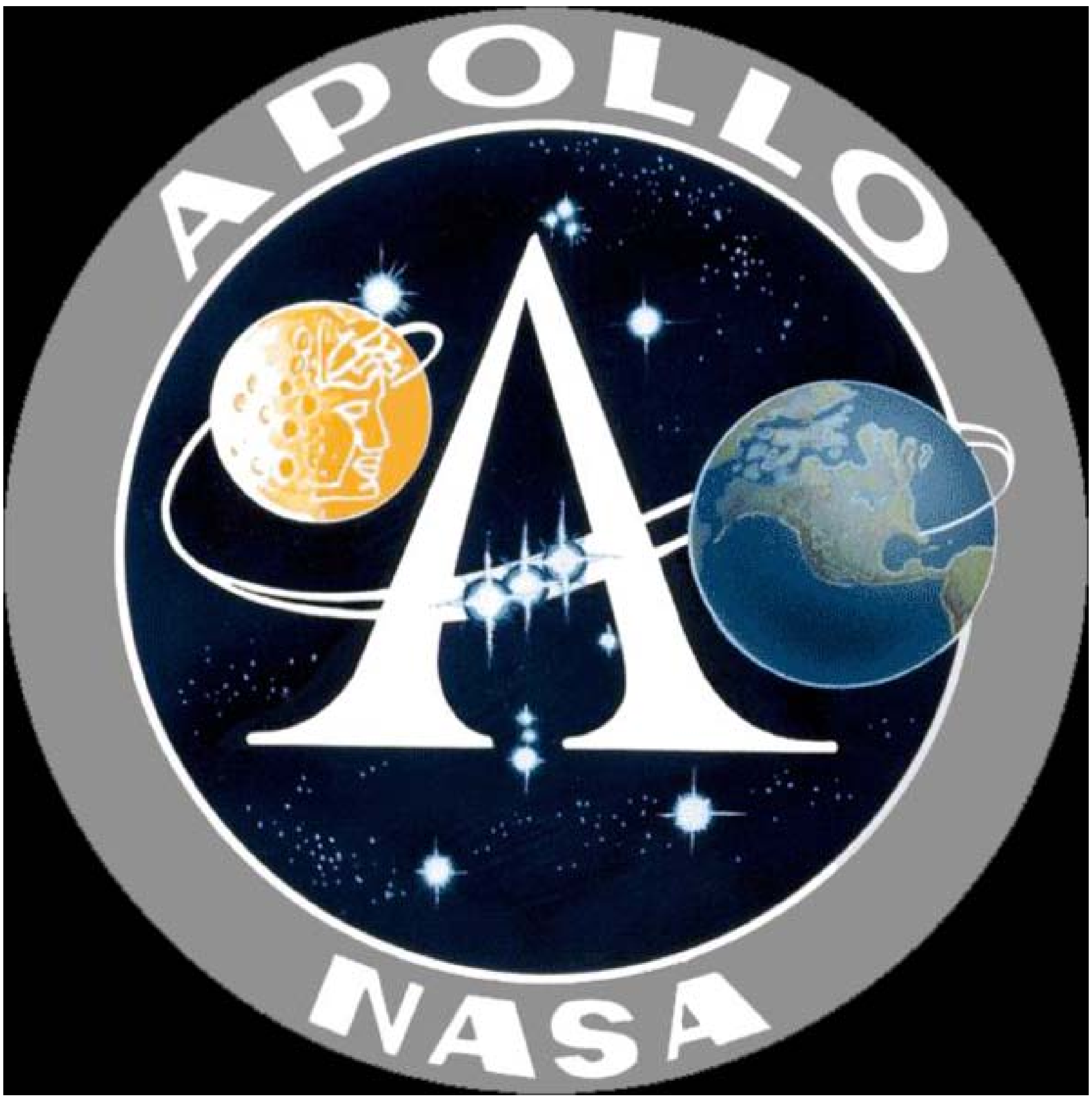
Soyuz TMA-3 launch

Soyuz 19 as seen from the Apollo spacecraft during ASTP Mission July, 1975

Soyuz TMA-3 landing

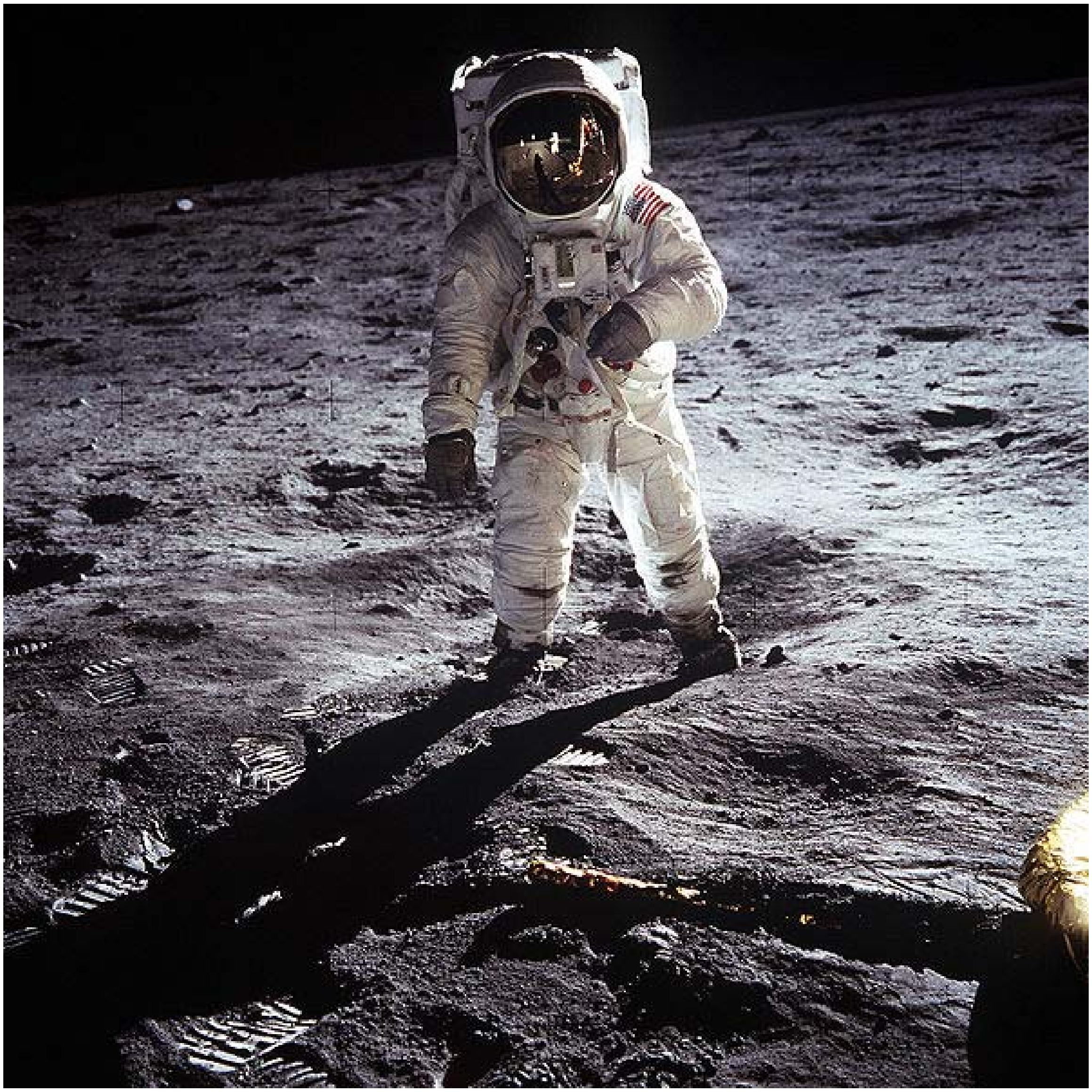
Chapter 10

Apollo Program



Apollo program insignia

The **Apollo program** was the United States spaceflight effort which landed the first humans on Earth's Moon. Conceived during the Eisenhower administration and conducted by the National Aeronautics and Space Administration (NASA), Apollo began in earnest after President John F. Kennedy's 1961 address to Congress declaring a national goal of "landing a man on the Moon" by the end of the decade in a competition with the Soviet Union for supremacy in space.



Buzz Aldrin during Apollo 11's first moon landing mission in 1969

This goal was first accomplished during the Apollo 11 mission on July 20, 1969 when astronauts Neil Armstrong and Buzz Aldrin landed, while Michael Collins remained in lunar orbit. Five subsequent Apollo missions also landed astronauts on the Moon, the last in December 1972. In these six Apollo spaceflights, 12 men walked on the Moon. These are the only times humans have landed on another celestial body.

The Apollo program ran from 1961 until 1975, and was America's third human spaceflight program (following Mercury and Gemini). It used Apollo spacecraft and Saturn launch vehicles, which were also used for the Skylab program in 1973–74, and a joint U.S.–Soviet mission in 1975. These subsequent programs are thus often considered part of the Apollo program.

The program was successfully carried out despite two major setbacks: the 1967 Apollo 1 launch pad fire that killed three astronauts; and an oxygen tank rupture during the 1970 Apollo 13 flight which disabled the Command Module. Using the Lunar Excursion Module as a "lifeboat", the three crewmen narrowly escaped with their lives, thanks to their skills and the efforts of flight controllers, project engineers, and backup crew members.

Apollo set major milestones in human spaceflight. It stands alone in sending manned missions beyond low Earth orbit; Apollo 8 was the first manned spacecraft to orbit another celestial body, while Apollo 17 marked the last moonwalk and the last manned mission beyond low Earth orbit. The program spurred advances in many areas of technology incidental to rocketry and manned spaceflight, including avionics, telecommunications, and computers. Apollo also sparked interest in many fields of engineering and left many physical facilities and machines developed for the program as landmarks. Its command modules and other objects and artifacts are displayed throughout the world, notably in the Smithsonian's Air and Space Museums in Washington, DC and at NASA's centers in Florida, Texas and Alabama.

Background

The Apollo program was conceived early in 1960, during the Eisenhower administration, as a follow-up to America's Mercury program. While the Mercury capsule could only support one astronaut on a limited earth orbital mission, the Apollo spacecraft was to be able to carry three astronauts on a circumlunar flight and eventually to a lunar landing. The program was named after the Greek god of light and music by NASA manager Abe Silverstein, who later said that "I was naming the spacecraft like I'd name my baby." While NASA went ahead with planning for Apollo, funding for the program was far from certain given Eisenhower's ambivalent attitude to manned spaceflight.

May 25, 1961: President John Kennedy addresses Congress on his plan to put a man on the Moon within nine years.

In November 1960, John F. Kennedy was elected president after a campaign that promised American superiority over the Soviet Union in the fields of space exploration and missile defense. Using space exploration as a symbol of national prestige, he warned of a "missile gap" between the two nations, pledging to make the U.S. not "first but, first and, first if, but first period." Despite Kennedy's rhetoric, he did not immediately come to a decision on the status of the Apollo program once he became president. He knew little about the technical details of the space program, and was put off by the massive financial commitment required by a manned Moon landing. When NASA Administrator James Webb requested a 30 percent budget increase for his agency, Kennedy supported an acceleration of NASA's large booster program but deferred a decision on the broader issue.

President Kennedy delivers a speech at Rice University on the American space program, September 12, 1962.

On April 12, 1961, Soviet cosmonaut Yuri Gagarin became the first person to fly in space, reinforcing American fears about being left behind in a technological competition with the Soviet Union. At a meeting of the U.S. House Committee on Science and Astronautics one day after Gagarin's flight, many congressmen pledged their support for a crash program aimed at ensuring that America would catch up. Kennedy, however, was circumspect in his response to the news, refusing to make a commitment on America's response to the Soviets. On April 20, Kennedy sent a memo to Vice President Lyndon B. Johnson, asking Johnson to look into the status of America's space program, and into programs that could offer NASA the opportunity to catch up. Johnson responded approximately one week later, concluding that "we are neither making maximum effort nor achieving results necessary if this country is to reach a position of leadership." His memo concluded that a manned Moon landing was far enough in the future that it was likely the United States would achieve it first.

On May 25, 1961, Kennedy announced his support for the Apollo program during a special address to a joint session of Congress:

I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important in the long-range exploration of space; and none will be so difficult or expensive to accomplish.

—John F. Kennedy

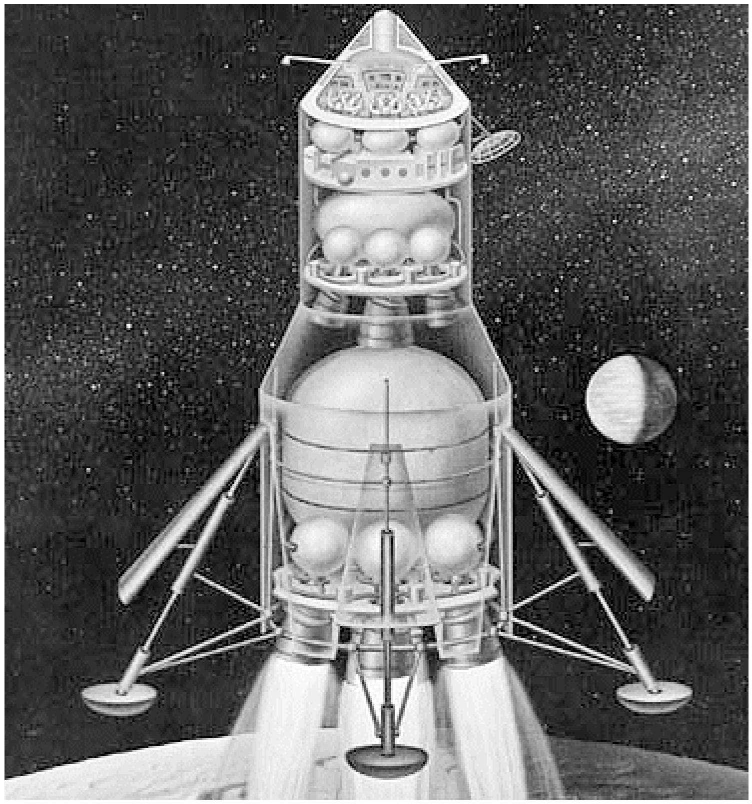
At the time of Kennedy's speech, only one American had flown in space—less than a month earlier—and NASA had not yet sent an astronaut into orbit. Even some NASA employees doubted whether Kennedy's ambitious goal could be met.

Landing men on the Moon by the end of 1969 required the most sudden burst of technological creativity, and the largest commitment of resources ($24 billion), ever made by any nation in peacetime. At its peak, the Apollo program employed 400,000 people and required the support of over 20,000 industrial firms and universities.

> “We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too... Many years ago the great British explorer George Mallory, who was to die on Mount Everest, was asked why did he want to climb it. He said, "Because it is there." Well, space is there, and we're going to climb it, and the Moon and the planets are there, and new hopes for knowledge and peace are there. And, therefore, as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked.”

Choosing a mission mode

Once Kennedy had defined a goal, the Apollo mission planners were faced with the challenge of designing a set of flights that could meet it while minimizing risk to human life, cost, and demands on technology and astronaut skill. Four possible mission modes were considered:



Early Apollo configuration for Direct Ascent and Earth Orbit Rendezvous (1961)

- **Direct Ascent:** A spacecraft would travel directly to the Moon, landing and returning as a unit. This plan would have required a more powerful booster, the planned Nova rocket.
- **Earth Orbit Rendezvous (EOR):** Multiple rockets (up to fifteen in some claims) would be launched, each carrying various parts of a Direct Ascent spacecraft and propulsion units that would have enabled the spacecraft to escape earth orbit. After a docking in earth orbit, the spacecraft would have landed on the Moon as a unit.
- **Lunar Surface Rendezvous:** Two spacecraft would be launched in succession. The first, an automated vehicle carrying propellants, would land on the Moon and would be followed some time later by the manned vehicle. Propellant would be transferred from the automated vehicle to the manned vehicle before the manned vehicle could return to Earth.
- **Lunar Orbit Rendezvous (LOR):** One Saturn V would launch a spacecraft that was composed of modular parts. A command module would remain in orbit around the Moon, while a lunar excursion module would descend to the Moon and then return to dock with the command ship while still in lunar orbit. In contrast with the other plans, LOR required only a small part of the spacecraft to land on the Moon, thereby minimizing the mass to be launched from the Moon's surface for the return trip.

In early 1961, direct ascent was generally the mission mode in favor at NASA. Many engineers feared that a rendezvous —let alone a docking— neither of which had been attempted even in Earth orbit, would be extremely difficult in lunar orbit. However, dissenters including John Houbolt at Langley Research Center emphasized the important weight reductions that were offered by the LOR approach. Throughout 1960 and 1961, Houbolt campaigned for the recognition of LOR as a viable and practical option. Bypassing the NASA hierarchy, he sent a series of memos and reports on the issue to Associate Administrator Robert Seamans; while acknowledging that he spoke "somewhat as a voice in the wilderness," Houbolt pleaded that LOR should not be discounted in studies of the question.

Seamans' establishment of the Golovin committee in July 1961 represented a turning point in NASA's mission mode decision. While the ad-hoc committee was intended to provide a recommendation on the boosters to be used in the Apollo program, it recognized that the mode decision was an important part of this question. The committee recommended in favor of a hybrid EOR-LOR mode, but its consideration of LOR —as well as Houbolt's ceaseless work— played an important role in publicizing the workability of the approach. In late 1961 and early 1962, members of NASA's Space Task Group at the Manned Spacecraft Center in Houston began to come around to support for LOR. The engineers at Marshall Space Flight Center took longer to become convinced of its merits, but their conversion was announced by Wernher von Braun at a briefing in June 1962. NASA's formal decision in favor of LOR was announced on July 11, 1962. Space historian James Hansen concludes that:

Without NASA's adoption of this stubbornly held minority opinion in 1962, the United States may still have reached the Moon, but almost certainly it would not have been accomplished by the end of the 1960s, President Kennedy's target date.

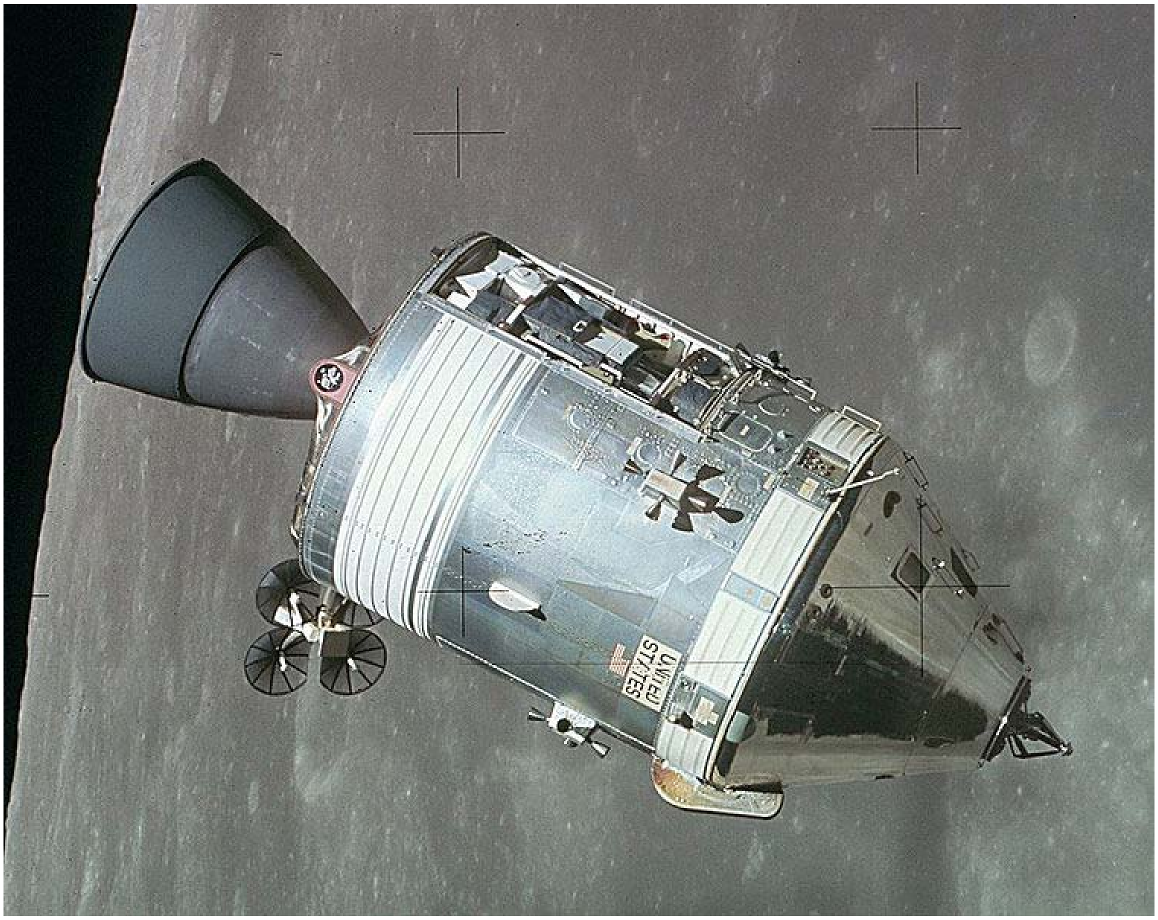
—James Hansen, *Enchanted Rendezvous*

The LOR method had the advantage of allowing the lander spacecraft to be used as a "life boat" in the event of a failure of the command ship. This happened on Apollo 13 when an oxygen tank failure left the command ship without electrical power. The Lunar Module provided propulsion, electrical power and life support to get the crew home safely.

Spacecraft

The decision in favor of lunar orbit rendezvous dictated the basic design of the Apollo spacecraft. It would consist of two main sections: the **Command/Service Module** (CSM), in which the crew would spend most of the mission, and the **Lunar Module** (LM), which would descend to and return from the lunar surface.

Command/Service Module



Apollo 15 CSM in lunar orbit

The Command Module (CM) was the crew cabin, surrounded by a conical re-entry heat shield, designed to carry three astronauts from launch to lunar orbit and back to an Earth ocean splashdown. As such, it was the only component of the Apollo spacecraft to survive without major configuration changes as the program evolved from the early Apollo study designs. Equipment carried by the Command Module included reaction control engines, a docking tunnel, guidance and navigation systems and the Apollo Guidance Computer.

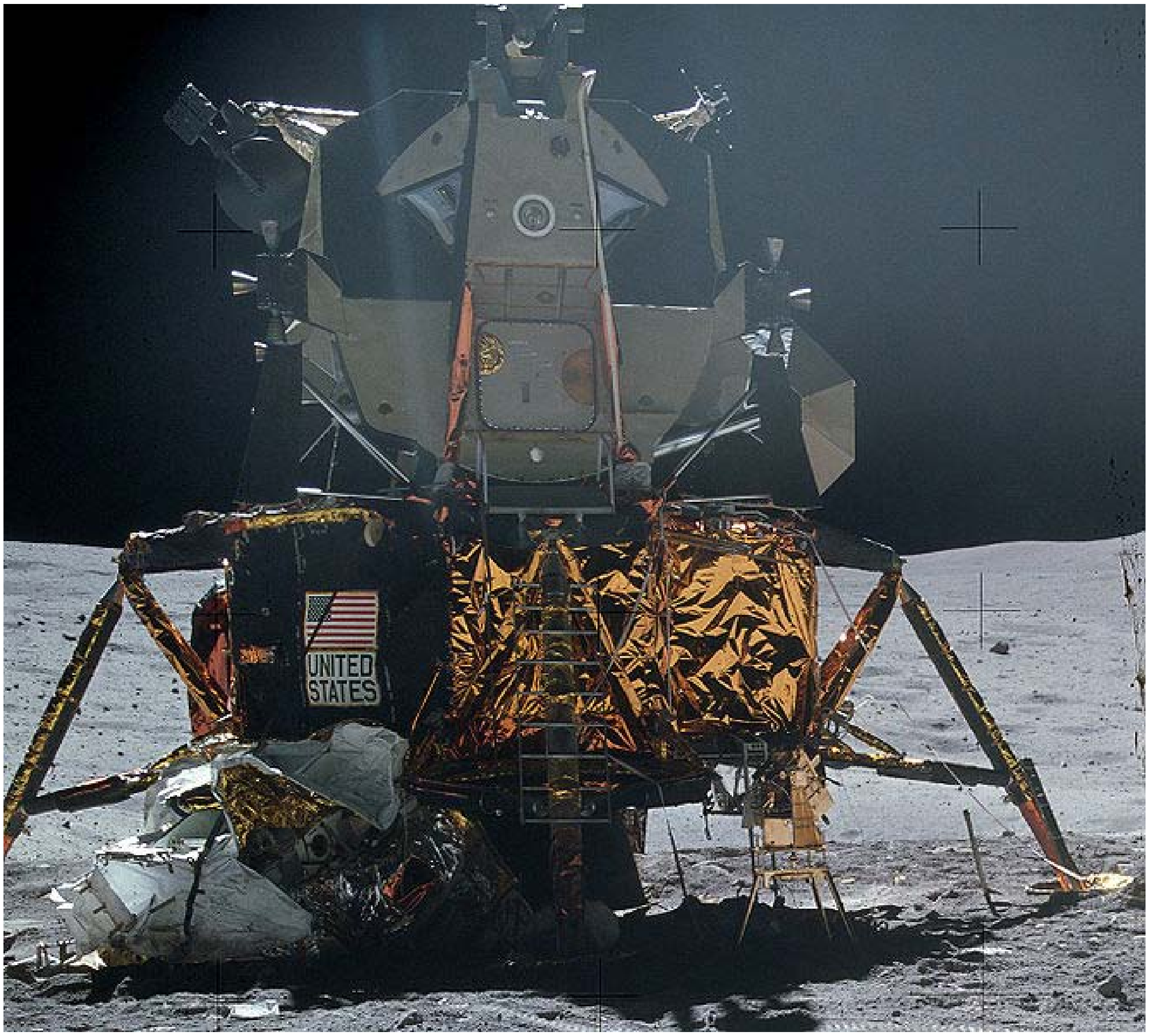
Attached to the Command Module was the cylindrical Service Module (SM), which housed the service propulsion system and its propellants, the fuel cell power system, four maneuvering thruster quads, a high-gain S-band antenna for communications between the Moon and Earth, and storage tanks for water and oxygen. On the last three lunar missions, it also carried a scientific instrument package.

As the program concept evolved, use of the term "module" changed from its true meaning of an interchangeable component of systems with multiple variants, to simply a component of the complete lunar landing system. The original pre-1961 studies contemplated a single Command Module with different sized Service Modules for various missions such as an earth-orbit shuttle to a space station, a ferry to lunar orbit, or return to Earth from a lunar landing (which would require an even larger descent stage attached to the SM.)

As used in the actual lunar program, the two modules remained attached throughout most of the flight to make a single ferry craft, somewhat awkwardly known as the Command/Service Module (CSM) which carried a separate lunar lander (only half as heavy as the CSM) to the Moon, and the astronauts home to Earth. Just before re-entry, the Service Module was discarded and only the Command Module re-entered the atmosphere, using its heat shield to survive the intense heat caused by air friction. After re-entry it deployed parachutes that slowed its descent, allowing a smooth splashdown in the ocean.

Under the leadership of Harrison Storms, North American Aviation won the contract to build the CSM, and also the second stage of the Saturn V launch vehicle for NASA. Relations between North American and NASA were strained during the winter of 1965-66 by delivery delays, quality shortfalls, and cost overruns in both components. They were strained even more a year later when a cabin fire killed the crew of Apollo 1 during a ground test. The cause was determined to be an electrical short in the wiring of the Command Module; while the determination of responsibility for the accident was complex, the review board concluded that "deficiencies existed in Command Module design, workmanship and quality control." This eventually led to the removal of Storms as Command Module program manager.

Lunar Module



Apollo 16 LM on the lunar surface

The Lunar Module (LM) (originally known as the Lunar Excursion Module, or LEM), was designed to fly between lunar orbit and the surface, landing two astronauts on the Moon and taking them back to the Command Module. It had no aerodynamic heat shield and was of a construction so lightweight that it would not have been able to fly through the Earth's atmosphere. It consisted of two stages, a descent and an ascent stage. The descent stage contained compartments which carried cargo such as the Apollo Lunar Surface Experiment Package and Lunar Rover.

The contract for design and construction of the Lunar Module was awarded to Grumman Aircraft Engineering Corporation, and the project was overseen by Tom Kelly. There were also problems with the Lunar Module; due to delays in the test program, the LM became a "pacing item," meaning that it was in danger of delaying the schedule of the whole Apollo program. Because of these issues, the Apollo missions were rescheduled so that the first manned mission with the Lunar Module would be Apollo 9, rather than Apollo 8 as was originally planned.

Launch vehicles

When the team of engineers led by Wernher von Braun began planning for the Apollo program, it was not yet clear what mission their rockets would have to support. Direct ascent would require a more powerful launch vehicle, the planned Nova, which could carry a very large payload to the Moon. NASA's decision in favor of Lunar Orbit Rendezvous re-oriented the work of the Marshall Space Flight Center towards the development of the Saturn I, Saturn IB and Saturn V. While the Saturn V was less powerful than the Nova would have been, it was still much more powerful than any rocket developed before, or since. (The USSR N1 was approximately as powerful, but it was never successful.)

Saturn IB

A Saturn IB rocket launches Apollo 7 into Earth orbit, October 11, 1968

The Saturn IB was an upgraded version of the earlier Saturn I rocket, which was used in early Apollo boilerplate launches. It consisted of:

- An S-IB first stage powered by eight H-1 engines burning RP-1 with LOX oxidizer, to produce 1,600,000 pounds-force (7,100 kN) of thrust;
- An S-IVB-200 second stage, powered by one J-2 engine burning liquid hydrogen with LOX oxidizer, to produce 225,000 lbf (1,000 kN) of thrust; and
- An Instrument Unit which contained the rocket's guidance system.

The Saturn IB was capable of putting a partially-fueled Command/Service Module, or a Lunar Module, into earth orbit. It was used in five of the Apollo test missions including the first manned mission. It was also used in the manned missions for the Skylab program and the Apollo-Soyuz Test Project.

Saturn V

A Saturn V rocket launches Apollo 11 in 1969

The Saturn V was a three-stage rocket consisting of:

- An S-IC first stage, powered by five F-1 engines arranged in a cross pattern, burning RP-1 with LOX oxidizer to produce 7,500,000 lbf (33,000 kN) of thrust. They burned for 2.5 minutes, accelerating the spacecraft to a speed of approximately 6,000 miles per hour (2.68 km/s).
- An S-II second stage, powered by five of the J-2 engines used in the S-IVB. They burned for approximately six minutes, taking the spacecraft to a speed of 15,300 miles per hour (6.84 km/s) and an altitude of about 115 miles (185 km).
- An S-IVB-500 third stage similar to the Saturn IB's second stage, with capability to restart the J-2 engine. The engine would burn for approximately two and a half minutes and shut down when a low-Earth parking orbit was achieved. After approximately two orbits to confirm the spacecraft was ready to commit to the lunar trip, the engine was restarted to make the translunar injection maneuver taking the spacecraft into an extremely high orbit where it would be captured by the Moon's gravity.
- An instrument unit with a guidance system similar to that used on the Saturn IB.

Three Saturn V vehicles launched on Earth orbital flights. Two of the three (Apollo 4 and 6) were unmanned tests of the command and service modules, and the third was a manned flight, Apollo 9, testing the lunar module. Nine Saturn Vs launched manned Apollo missions to the Moon, including Apollo 11. It was also used for the unmanned launch of Skylab.

Astronauts

The following astronauts flew on the 11 manned Apollo missions, plus the Apollo 1 crew who were killed in a ground test one month before they were to have flown the first manned mission. Not included are the astronauts who subsequently flew on the Skylab (Apollo Applications Program) or Apollo-Soyuz Test Project missions which used the Apollo CSM.

From Astronaut Group 1			
Astronaut	**Service**	**Mission**	**Mercury/Gemini Flights**
Virgil "Gus" Grissom	USAF	**Apollo 1 Command Pilot**	Mercury-Redstone 4, Gemini 3
Walter M. Schirra	USN	Apollo 7 CDR	Mercury-Atlas 8, Gemini 6A
Alan Shepard	USN	Apollo 14 CDR	Mercury-Redstone 3
From Astronaut Group 2			
Astronaut	**Service**	**Mission**	**Gemini Flights**
Neil A. Armstrong	ex-USN	Apollo 11 CDR	Gemini 8
Frank Borman	USAF	Apollo 8 CDR	Gemini 7
Charles "Pete" Conrad	USN	Apollo 12 CDR	Gemini 5, Gemini 11

James A. Lovell	USN	Apollo 8 CMP, Apollo 13 CDR	Gemini 7, Gemini 12
James A. McDivitt	USAF	Apollo 9 CDR	Gemini 4
Thomas P. Stafford	USAF	Apollo 10 CDR	Gemini 6A, Gemini 9A
Edward H. White II	USAF	**Apollo 1 Senior Pilot**	Gemini 4
John W. Young	USN	Apollo 10 CMP, Apollo 16 CDR	Gemini 3, Gemini 10
From Astronaut Group 3			
Astronaut	**Service**	**Mission**	**Gemini Flights**
Edwin "Buzz" Aldrin	USAF	Apollo 11 LMP	Gemini 12
William A. Anders	USAF	Apollo 8 LMP	
Alan L. Bean	USN	Apollo 12 LMP	
Eugene A. Cernan	USN	Apollo 10 LMP, Apollo 17 CDR	Gemini 9A
Roger B. Chaffee	USN	**Apollo 1 Pilot**	
Michael Collins	USAF	Apollo 11 CMP	Gemini 10
R. Walter Cunningham	ex-USMC	Apollo 7 LMP	
Donn F. Eisele	USAF	Apollo 7 CMP	
Richard F. Gordon, Jr.	USN	Apollo 12 CMP	Gemini 11
Russell L. "Rusty" Schweickart	ex-USAF	Apollo 9 LMP	
David R. Scott	USAF	Apollo 9 CMP, Apollo 15 CDR	Gemini 8

From Astronaut Group 4		
Astronaut	**Service**	**Mission**
Harrison H. Schmitt	Geologist	Apollo 17 LMP

From Astronaut Group 5		
Astronaut	**Service**	**Mission**
Charles M. Duke	USAF	Apollo 16 LMP
Ronald E. Evans	USAF	Apollo 17 CMP
Fred W. Haise	ex-USMC	Apollo 13 LMP
James B. Irwin	USAF	Apollo 15 LMP
T. Kenneth Mattingly	USN	Apollo 16 CMP
Edgar D. Mitchell	USN	Apollo 14 LMP
Stuart A. Roosa	USAF	Apollo 14 CMP
John L. Swigert	ex-USAF	Apollo 13 CMP
Alfred M. Worden	USAF	Apollo 15 CMP

Mission	CDR	Group	Mission #	CMP	Group	Mission #	LMP	Group	Mission #
Apollo 1	Grissom	1	(3)	White	2	(2)	Chaffee	3	(1)
Apollo 7	Schirra	1	3	Eisele	3	1	Cunningham	3	1
Apollo 8	Borman	2	2	Lovell	2	3	Anders	3	1
Apollo 9	McDivitt	2	2	Scott	3	2	Schweickart	3	1
Apollo 10	Stafford	2	3	Young	2	3	Cernan	3	2
Apollo 11	Armstrong	2	2	Collins	3	2	Aldrin	3	2
Apollo 12	Conrad	2	3	Gordon	3	2	Bean	3	1
Apollo 13	Lovell	2	4	Swigert	5	1	Haise	5	1
Apollo 14	Shepard	1	2	Roosa	5	1	Mitchell	5	1
Apollo 15	Scott	3	3	Worden	5	1	Irwin	5	1
Apollo 16	Young	2	4	Mattingly	5	1	Duke	5	1
Apollo 17	Cernan	3	3	Evans	5	1	Schmitt	4	1

Capsule Communicator (CAPCOM)

Mission rules specified that, in most circumstances, only one person in the Mission Control Center would communicate directly with the in-flight crew, and that this was to be another astronaut, who would be best able to understand the situation in the spacecraft and communicate with the crew in the clearest way. These individuals were designated *Capsule Communicators* or CAPCOMs, a term carried over from the Mercury and Gemini programs. They were usually chosen from the backup and support crews, and worked in shifts during long missions.

The periodic *beeps* heard during communications with the astronauts are known as Quindar tones.

Missions

Unmanned missions

Preparations for the Apollo program began long before the manned Apollo missions were flown. Test flights of the Saturn I booster began in October 1961 and lasted until September 1964. Three further Saturn I launches carried boilerplate models of the Apollo command/service module. Two pad abort tests of the launch escape system took place in 1963 and 1965 at the White Sands Missile Range. Three unmanned tests of Apollo components with the Saturn IB (Apollo-Saturn, or **AS**) were officially designated AS-201, AS-202, and AS-203.

The only unmanned missions to include "Apollo", rather than their serial number, as part of their name were Apollo 4, Apollo 5 and Apollo 6. The simple numbering was started at "4" due to the previous three Apollo-Saturn flights using the Saturn IB, nevertheless these next three unmanned flights kept their "AS" call signs as AS-501, AS-204, and AS-502, respectively. The "AS-20 series" continued to be reserved for Saturn IB flights, and the "AS-50" series designated Saturn V launches.

Apollo 4 was the first test flight of the Saturn V booster. Launched on November 9, 1967, Apollo 4 exemplified George Mueller's strategy of "all up" testing. Rather than being tested stage by stage, as most rockets were, the Saturn V would be flown for the first time as one unit. The mission was a highly successful one. Walter Cronkite covered the launch from a broadcast booth about 4 miles (6 km) from the launch site. The extreme noise and vibrations from the launch nearly shook the broadcast booth apart- ceiling tiles fell and windows shook. At one point, Cronkite was forced to dampen the booth's plate glass window to prevent it from shattering. This launch showed that additional protective measures were necessary to protect structures in the immediate vicinity. Future launches used a damping mechanism directly at the launchpad which proved effective in limiting the generated noise.

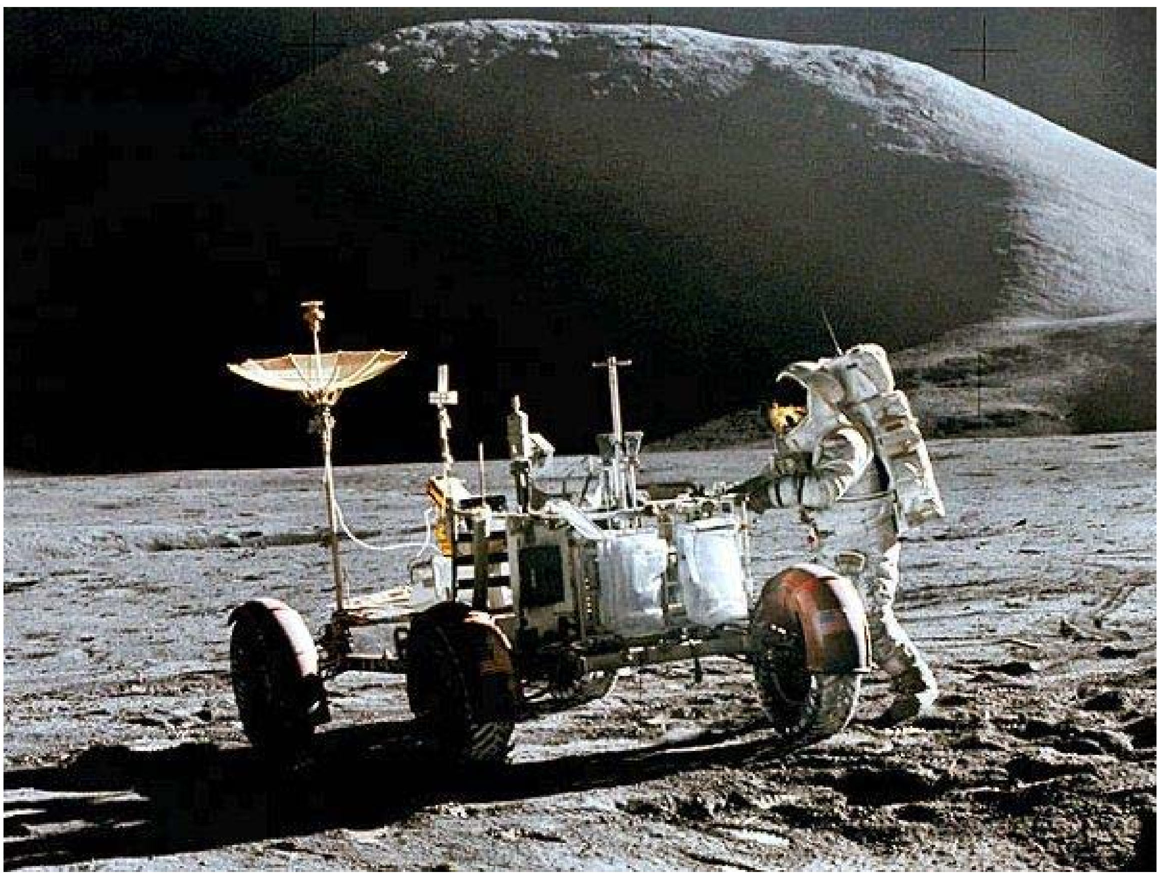
Apollo 5 was a Saturn IB flight which tested a legless, windowless version of the lunar module (LM) in Earth orbit. No Command and Service Module (CSM) was included. The critical LM engines were tested, including an in-flight test of the second stage engine in "abort mode," a test of an emergency procedure which would have been unnecessarily dangerous to test on a manned flight.

Apollo 6 was the last in the series of unmanned Apollo missions. It was launched on April 4, 1968, and landed back on Earth almost ten hours later at 21:57:21 UTC. It was a Saturn V flight intended to send a CSM and a "dummy" LM (Lunar Module Test Article) of the correct mass, all to the velocity needed to go to the moon, then, after 5 minutes, use the SPS (service module engine) to return the CM to Earth from a distance that would never be greater than 12,000 nautical miles. This 10 hour mission would fully test the Saturn V's ability to launch a full Apollo craft into trans-lunar orbit, and test re-entry from a simulated lunar return, including the correct re-entry velocity and angle of -6.5 degrees. The mission was only a partial success, due to vibrations and failure of fuel lines to several Saturn V engines, and in particular a failure of the third stage to re-ignite to send the craft from Earth orbit into a translunar injection orbit. Instead, somewhat as in Apollo 4, the SPS was used to raise the craft to a higher Earth orbit. The CM returned with a velocity midway between low Earth orbit and lunar return velocity. This mission was considered successful enough to attempt to successfully repeat it (minus the LM, but with an actual voyage into lunar orbit) as a manned version: Apollo 8.

Manned missions

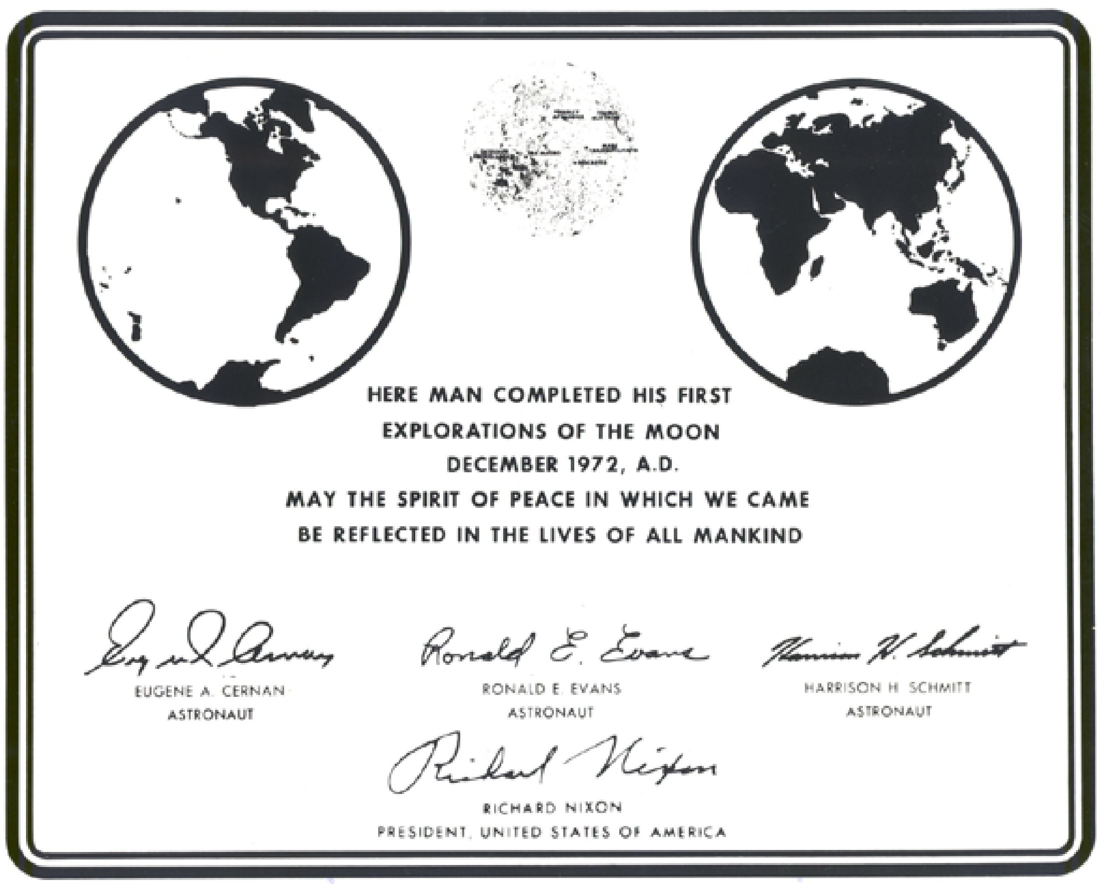
The manned missions carried three astronauts, designated as Commander, Command Module Pilot (CMP), and Lunar Module Pilot (LMP). Besides exercising all crew command decisions, the Commander was the primary pilot of both spacecraft (when present) and was first to exit the LM on the surface of the Moon. The CMP functioned as navigator, usually performed the initial docking with the LM, and remained in the Command/Service Module when his companions flew the LM. The LMP functioned as engineering officer, monitoring the systems of both spacecraft. On a landing mission, he accompanied the Commander on the lunar surface. On the last flight, the LMP was a professional geologist, Dr. Harrison Schmitt.

Apollo 7, launched on October 11, 1968, was the first manned mission in the program. It was an eleven-day Earth-orbital flight intended to test the Command Module, redesigned following the Apollo 1 fire. It was the first manned launch of the Saturn IB launch vehicle and the first three-man American space mission.



Jim Irwin near a Lunar Roving Vehicle used on Apollos 15–17

Between December 21, 1968 and May 18, 1969, NASA planned to launch three manned test / practice missions using the Saturn V launch vehicle and the complete spacecraft including the LM. But by the summer of 1968 it became clear to program managers that a fully functional LM would not be available for the Apollo 8 launch. Rather than waste the Saturn V on another simple Earth-orbiting mission, they chose to send the crew planned to make the second orbital LM test in Apollo 9, to orbit the Moon in the CSM on Apollo 8 during Christmas. The original idea for this switch was the brainchild of George Low, Manager of the Apollo Spacecraft Program Office. Although it has often been claimed that this change was made as a direct response to Soviet attempts to fly a piloted Zond spacecraft around the Moon, there is no evidence that this was the case. NASA officials were aware of the Soviet Zond flights, but the timing of the Zond missions does not correspond well with the extensive written record from NASA about the Apollo 8 decision. The Apollo 8 decision was primarily based upon the LM schedule, not fear of the Soviets beating the Americans to the Moon.



On the final Apollo mission, the Apollo 17 crew left this plaque as on all landings

This was followed by the first orbital manned LM flight on Apollo 9 (with the original Apollo 8 crew), and the lunar "dress rehearsal" Apollo 10 which took the LM to within 50,000 feet (15 km) of the surface, but did not land.

That's one small step for [a] man, one giant leap for mankind.

—Neil Armstrong

The next two flights (11 and 12) included successful Moon landings. The Apollo 13 mission was aborted before the landing attempt, but the crew returned safely to Earth. The four subsequent Apollo missions (14 through 17) included successful Moon landings. The last three of these were J-class missions that included the use of Lunar Rovers.

Apollo 17, launched December 7, 1972, was the last Apollo mission to the Moon. Mission commander Eugene Cernan was the last person to leave the Moon's surface. The crew returned safely to Earth on December 19, 1972.

Summary of missions

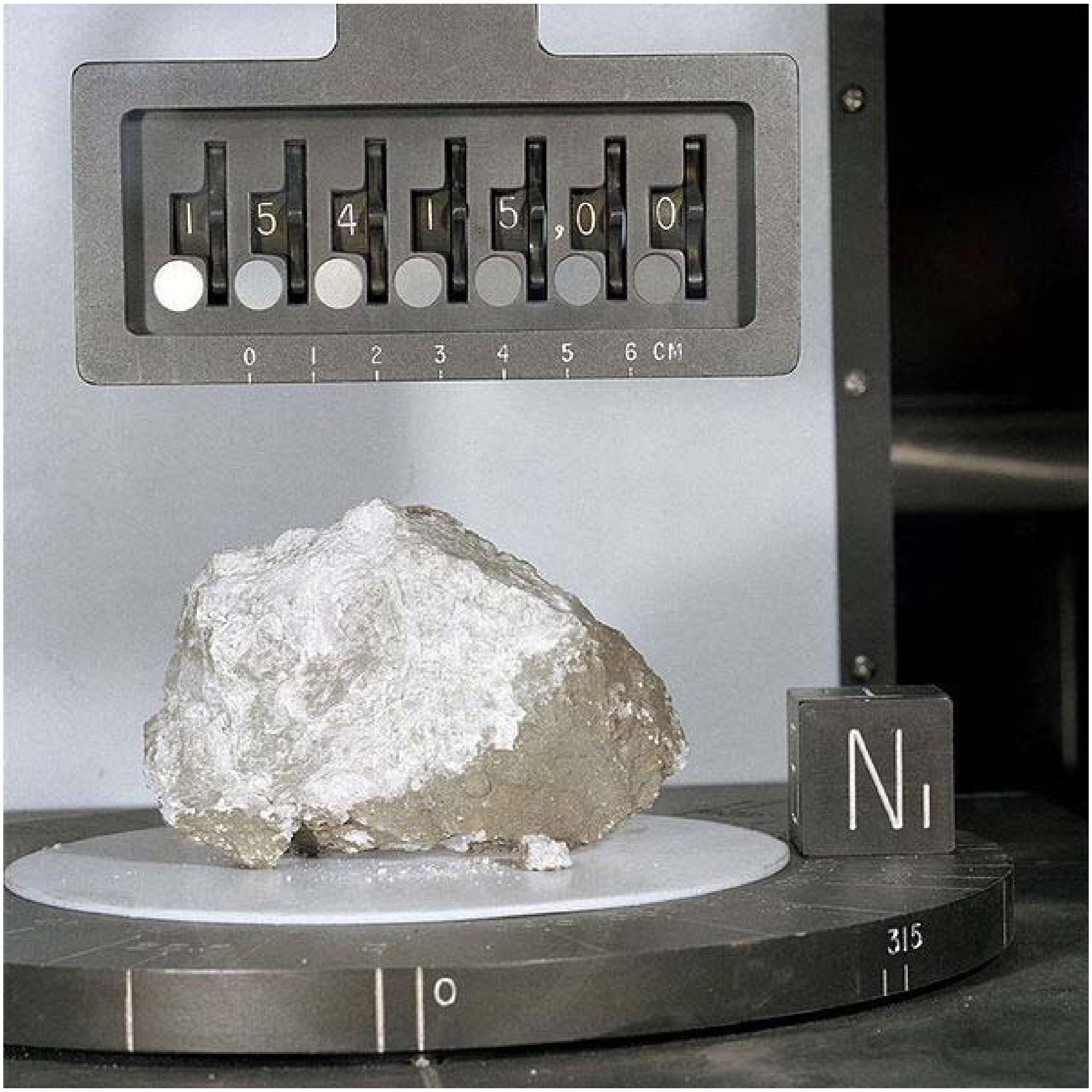
Mission	Launch vehicle	Crew	Launch date	Planned profile	Results
AS-201	Saturn 1B	Unmanned	February 26, 1966	Suborbital CSM test	First test flight of Saturn IB and Apollo Command and Service Modules; demonstrated heat shield; propellant pressure loss caused premature SM engine shutdown
AS-203	Saturn IB	Unmanned	July 5, 1966	Orbital S-IVB test	No Apollo spacecraft carried; successful test of liquid hydrogen fuel behavior to verify restartable S-IVB stage design for Saturn V. Additional testing designed to rupture the tank inadvertently destroyed the stage.
AS-202	Saturn IB	Unmanned	August 25, 1966	Suborbital CSM test	Longer duration to Pacific Ocean spashdown; CM heat shield tested to higher speed; successful SM firings

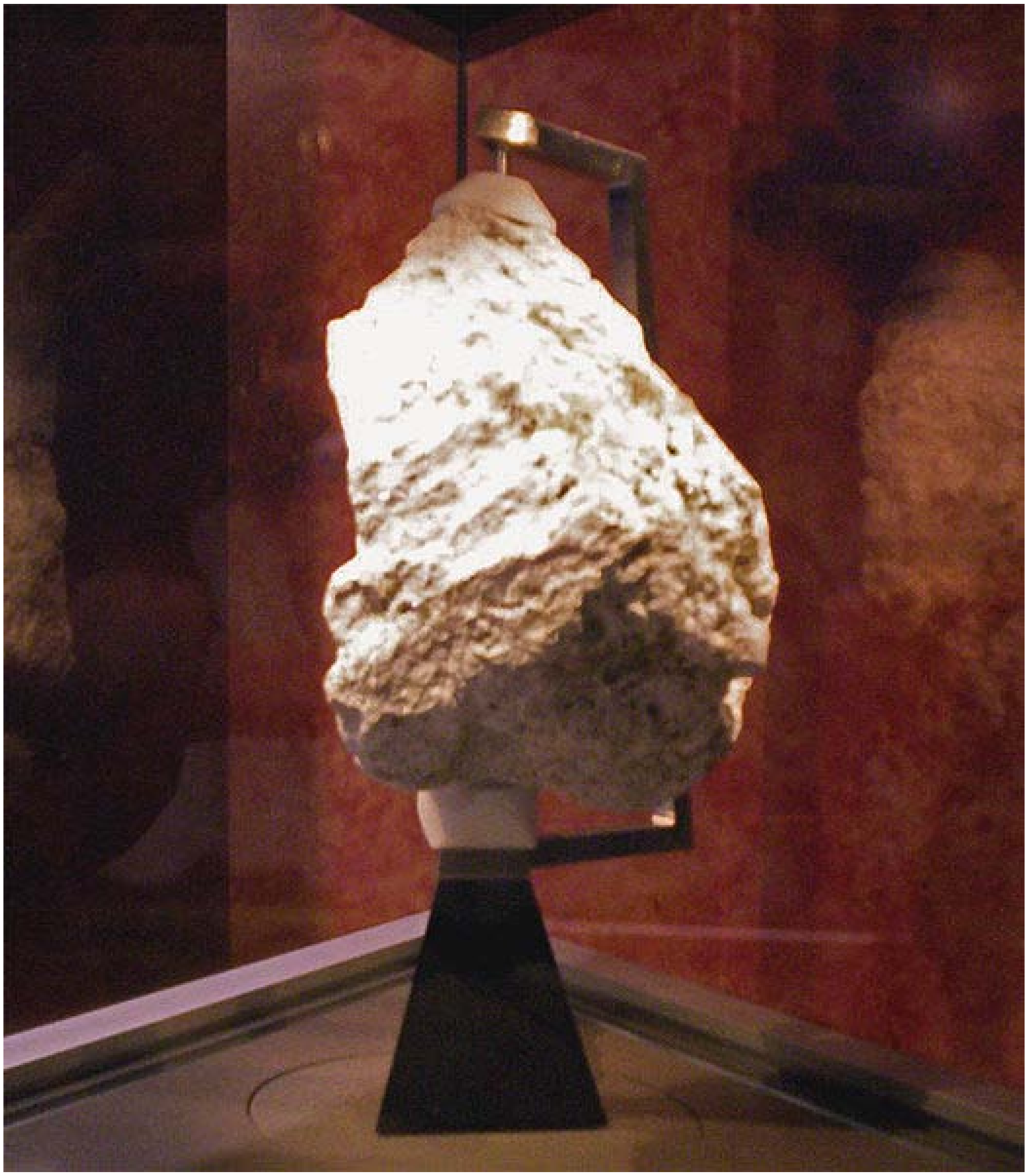
AS-204 (Apollo 1)	Saturn IB	Virgil I. "Gus" Grissom, Edward White, Roger B. Chaffee	None	Fourteen-day CSM orbital flight	Cabin fire broke out in pure oxygen atmosphere during launch rehearsal test on 27 January 1967, killing all three crewmen and destroying the CM.
Apollo 4	Saturn V	Unmanned	November 9, 1967	Highly elliptical orbital CSM test	Successfully demonstrated S-IVB third stage restart and tested CM heat shield at lunar re-entry speeds
Apollo 5	Saturn IB	Unmanned	January 22, 1968	Lunar Module test	Successfully fired descent engine and ascent engine; demonstrated "fire-in-the-hole" landing abort test. Used the Saturn IB originally slated for Apollo 1.
Apollo 6	Saturn V	Unmanned	April 4, 1968	CSM test: trans-lunar injection with direct abort to high-speed re-entry	Severe "pogo" vibrations caused two second-stage engines engines to shut down prematurely, and third stage restart to fail. SM engine used to achieved high-speed re-entry, though less than Apollo 4. NASA identified vibration fixes and declared Saturn V man-rated.
Apollo 7	Saturn IB	Walter M. "Wally" Schirra, Donn Eisele, Walter Cunningham	October 11, 1968	Eleven-day CSM orbital flight	Successful test of Block II CSM. First live television broadcast from a US space flight
Apollo 8	Saturn V	Frank Borman, Jim Lovell, William A.	December 21, 1968	Lunar orbit (CSM only)	First manned lunar flight, improvised because LM was not ready for first manned orbital test. Ten lunar orbits

		Anders			in twenty hours; first humans to see lunar far side and Earthrise with own eyes; Live television pictures broadcast to Earth
Apollo 9	Saturn V	James McDivitt, David Scott, Russell L. "Rusty" Schweickart	March 3, 1969	Earth orbit CSM / LM test	Ten days in Earth orbit, demonstrated LM propulsion, rendezvous and docking with CSM. EVA tested lunar Portable Life Support System (PLSS).
Apollo 10	Saturn V	Thomas P. Stafford, John W. Young, Eugene Cernan	May 18, 1969	"Dress rehearsal" for lunar landing	LM descended to 8.4 nautical miles (15.6 km) without landing
Apollo 11	Saturn V	Neil Armstrong, Michael Collins, Edwin E. "Buzz" Aldrin	July 16, 1969	First lunar landing	Sea of Tranquility; single EVA in direct vicinity of LM. Navigation errors and computer alarms overcome
Apollo 12	Saturn V	Charles "Pete" Conrad, Richard Gordon, Alan Bean	November 14, 1969	Lunar landing	Ocean of Storms; successful precision landing near Surveyor 3 probe; two EVAs, returned Surveyor parts to earth; first controlled LM ascent stage impact after jettison; first use of deployable S-band antenna; two lightning strikes after liftoff with brief loss of fuel cells and telemetry; lunar TV camera damaged by accidental exposure to sun.
Apollo 13	Saturn V	Jim Lovell, Jack Swigert, Fred Haise	April 11, 1970	Lunar landing	Planned Fra Mauro landing aborted after SM oxygen tank explosion on outward leg; LM used as crew "lifeboat" for safe return. First S-IVB stage impact on Moon as active seismic test.
Apollo 14	Saturn V	Alan B. Shepard,	January 31, 1971	Lunar landing	Successful landing at Fra Mauro site intended for

		Stuart Roosa, Edgar Mitchell			Apollo 13; mission overcame docking problems, faulty LM abort switch and delayed landing radar acquisition; first color video images from the lunar surface; first materials science experiments in space; two EVAs
Apollo 15	Saturn V	David Scott, Alfred Worden, James Irwin	July 26, 1971	Extended lunar landing	First "J series" mission with 3-day lunar stay and extensive geology investigations; first use of lunar rover (17.25 miles (27.8 km) driven); 1 lunar "standup" EVA, 3 lunar surface EVAs, plus deep space EVA on return to retrieve orbital camera film from SM.
Apollo 16	Saturn V	John W. Young, Ken Mattingly, Charles Duke	April 16, 1972	Extended lunar landing	Only landing in lunar highlands; malfunction in a backup CSM yaw gimbal servo loop delayed landing and reduced stay in lunar orbit; no ascent stage deorbit due to malfunction; 3 lunar EVAs plus deep space EVA
Apollo 17	Saturn V	Eugene Cernan, Ronald Evans, Harrison H. "Jack" Schmitt	December 7, 1972	Extended lunar landing	Last Apollo lunar landing; last (to date) human flight beyond low Earth orbit; only lunar mission with a scientist (geologist); 3 lunar EVAs plus deep space EVA
Planned Apollo 18, 19, and 20	Saturn V	Missions cancelled	Never launched	Extended lunar landings	Three more landings were planned; canceled to cut costs

Samples returned





The most famous of the Moon rocks recovered, the Genesis Rock, returned from Apollo 15.

Ferroan Anorthosite Moon rock, returned from Apollo 16.

The Apollo program returned 841.5 lb (381.7 kg) of rocks and other material from the Moon, much of which is stored at the Lunar Receiving Laboratory in Houston. The only sources of Moon rocks on Earth are those collected from the Apollo program, the former Soviet Union's Luna missions, and lunar meteorites.

The rocks collected from the Moon are extremely old compared to rocks found on Earth, as measured by radiometric dating techniques. They range in age from about 3.2 billion years old for the basaltic samples derived from the lunar mare, to about 4.6 billion years for samples derived from the highlands crust. As such, they represent samples from a very early period in the development of the Solar System that is largely missing from Earth. One important rock found during the Apollo Program was the Genesis Rock, retrieved by astronauts James Irwin and David Scott during the Apollo 15 mission. This rock, called anorthosite, is composed almost exclusively of the calcium-rich feldspar mineral anorthite, and is believed to be representative of the highland crust. A geochemical component called KREEP was discovered that has no known terrestrial counterpart. Together, KREEP and the anorthositic samples have been used to infer that the outer portion of the Moon was once completely molten.

Almost all the rocks show evidence for having been affected by impact processes. For instance, many samples appear to be pitted with micrometeoroid impact craters, something which is never seen on earth due to its thick atmosphere. Additionally, many show signs of being subjected to high pressure shock waves that are generated during impact events. Some of the returned samples are of impact melt, referring to materials that are melted near an impact crater. Finally, all samples returned from the Moon are highly brecciated as a result of being subjected to multiple impact events.

Analysis of composition of the lunar samples support the giant impact hypothesis, that the Moon was created through a "giant impact" of a large astronomical body with the Earth.

Program costs and cancellation

When President Kennedy first chartered the Moon landing program, a preliminary cost estimate of $7 billion was generated, but this proved an extremely unrealistic guess of what could not possibly be determined precisely, and James Webb used his administrator's judgement to change the estimate to $20 billion before giving it to Vice President Johnson. Webb's estimate shocked everyone at the time, but ultimately proved to be reasonably accurate. The final cost of project Apollo was reported to Congress as $25.4 billion in 1973.

In 2009, NASA held a symposium on project costs which presented an estimate of the Apollo program costs in 2005 dollars as roughly $170 billion. This included all research and development costs; the procurement of 15 Saturn V rockets, 16 Command/Service Modules, 12 Lunar Modules, plus program support and management costs; construction expenses for facilities and their upgrading, and costs for flight operations. This was based on a Congressional Budget Office report, *A Budgetary Analysis of NASA's New Vision for Space*, September 2004.

Canceled missions

Originally three additional lunar landing missions had been planned, as *Apollo 18* through *Apollo 20*. In light of the drastically shrinking NASA budget and the decision not to produce a second batch of Saturn Vs, these missions were canceled to make funds available for the development of the Space Shuttle, and to make their Apollo spacecraft and Saturn V launch vehicles available to the Skylab program. Only one of the remaining Saturn Vs was actually used to launch the Skylab orbital laboratory in 1973; the others became museum exhibits at the John F. Kennedy Space Center on Merritt Island, Florida, George C. Marshall Space Center in Huntsville, Alabama, Michoud Assembly Facility in New Orleans, Louisiana, and Lyndon B. Johnson Space Center in Houston, Texas.

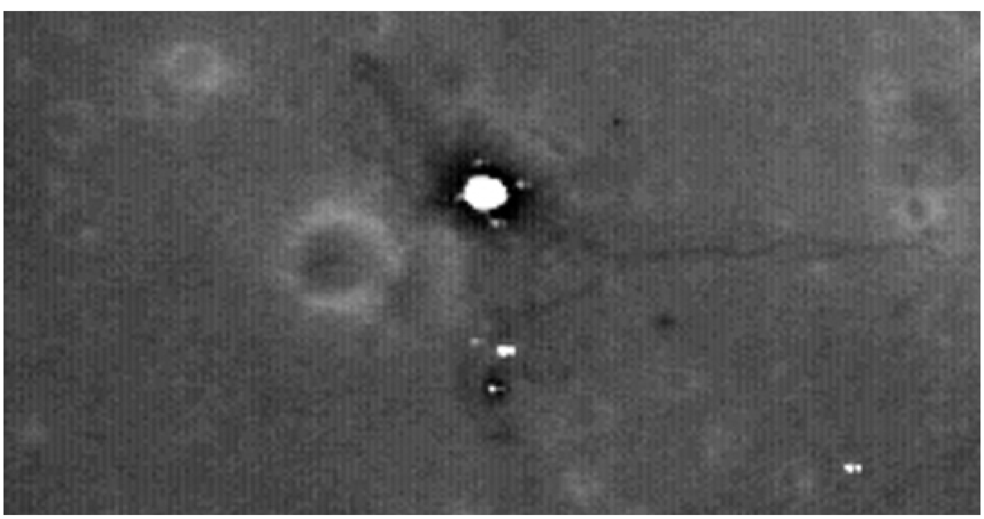
Apollo Applications Program

Following the success of the Apollo program, both NASA and its major contractors investigated several post-lunar applications for Apollo hardware. The Apollo Extension Series, later called the Apollo Applications Program, proposed up to 30 flights to Earth orbit. Many of these would use the space that the lunar module took up in the Saturn rocket to carry scientific equipment. Of all the plans, only two were implemented: the Skylab space station and the Apollo–Soyuz Test Project.

Skylab's fuselage was constructed from the second stage of a Saturn IB, and the station was equipped with the Apollo Telescope Mount, itself based on a lunar module. The station's three crews were ferried into orbit atop Saturn IBs, riding in CSMs; the station itself had been launched with a modified Saturn V. Skylab's last crew departed the station on February 8, 1974, and the station itself re-entered the atmosphere in 1979, by which time it had become the oldest operational Apollo-Saturn component.

The Apollo-Soyuz Test Project involved a docking in Earth orbit between a CSM and a Soviet Soyuz spacecraft from July 15 to July 24, 1975. NASA's next manned mission would not be until STS-1 in 1981.

Recent observations



"There the [Apollo 11] lunar module sits, parked just where it landed 40 years ago, as if it still really were 40 years ago and all the time since merely imaginary." *–The New York Times*

In 2008, Japan Aerospace Exploration Agency's SELENE probe observed evidence of the halo surrounding the Apollo 15 lunar module blast crater while orbiting above the lunar surface. In 2009, NASA's robotic Lunar Reconnaissance Orbiter, while orbiting 50 kilometres (31 mi) above the moon, photographed the remnants of the Apollo program left on the lunar surface, and photographed each site where manned Apollo flights landed.

In a November 16, 2009 editorial, *The New York Times* opined that: "[T]here's something terribly wistful about these photographs of the Apollo landing sites. The detail is such that if Neil Armstrong were walking there now, we could make him out, make out his footsteps even, like the astronaut footpath clearly visible in the photos of the Apollo 14 site. Perhaps the wistfulness is caused by the sense of simple grandeur in those Apollo missions. Perhaps, too, it's a reminder of the risk we all felt after the Eagle had landed — the possibility that it might be unable to lift off again and the astronauts would be stranded on the Moon. But it may also be that a photograph like this one is as close as we're able to come to looking directly back into the human past."

Proposed future lunar landing missions, such as the Google Lunar X Prize, intend to record close-up images of the Apollo Lunar Modules and other artificial objects on the surface.

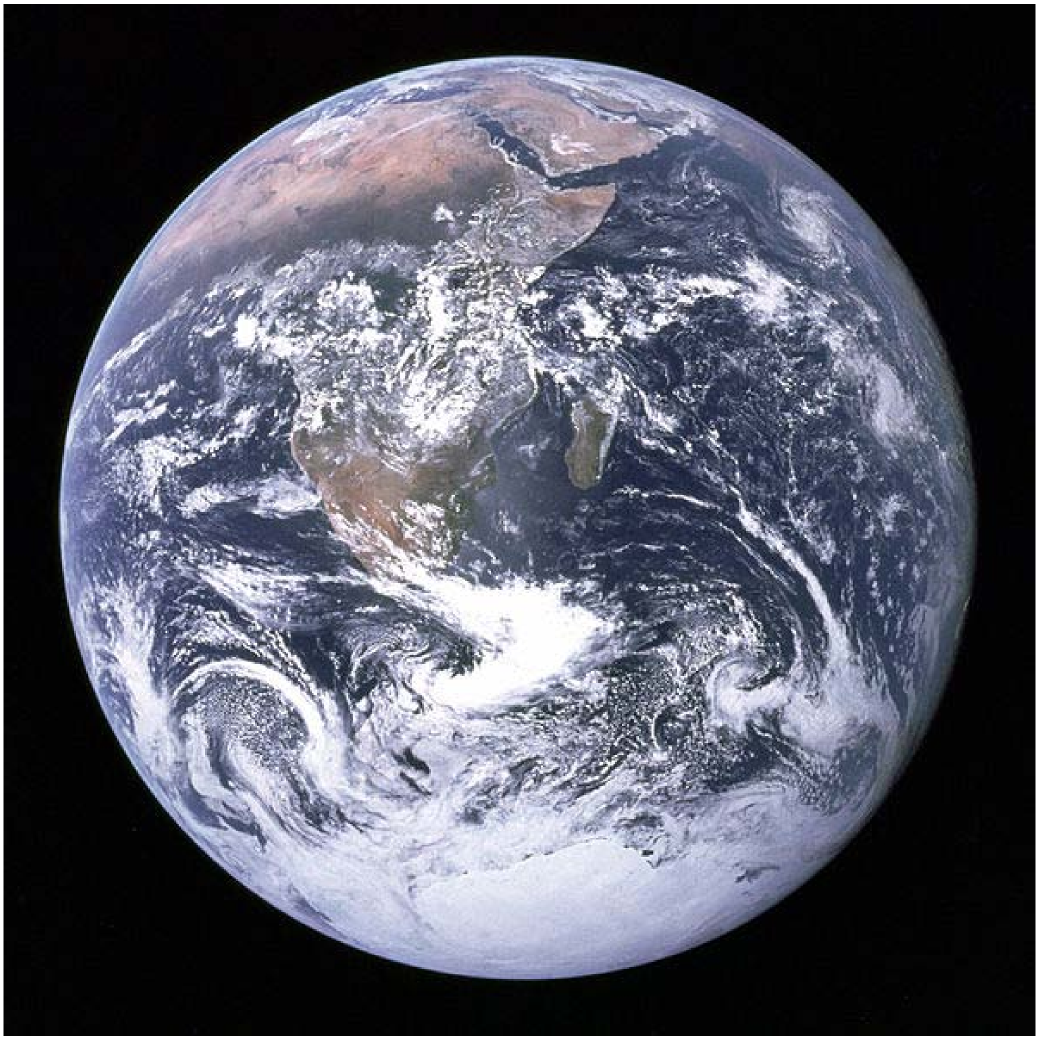
Legacy

Science and engineering

The Apollo program, specifically the lunar landings, has been called the greatest technological achievement in human history. The program stimulated many areas of technology. The flight computer design used in both the lunar and command modules was, along with the Minuteman Missile System, the driving force behind early research into integrated circuits. The fuel cell developed for this program was the first practical fuel cell. Computer-controlled machining (CNC) was pioneered in fabricating Apollo structural components.

Cultural impact

"Everything that I ever knew - my life, my loved ones, the Navy - everything, the whole world was behind my thumb." –James Lovell



"We went to explore the Moon, and in fact discovered the Earth." –Eugene Cernan

The crew of Apollo 8, the first manned spacecraft to orbit the Moon, sent televised pictures of the Earth and the Moon back to Earth (left), and read from the creation story in the Biblical book of Genesis, on Christmas Eve, 1968, This was believed to be the most widely-watched television broadcast until that time. The mission and Christmas provided an inspiring end to 1968, which had been a bad year for the U.S., marked by Vietnam War protests, race riots, and the assassinations of civil rights leader Martin Luther King and Senator Robert Kennedy.

An estimated one-fifth of the population of the world watched the live transmission of the first Apollo moonwalk.

One legacy of the Apollo program is the now-common view of Earth as a fragile, small planet, captured in photographs taken by the astronauts during the lunar missions. The most famous, taken by the Apollo 17 astronauts, is The Blue Marble (right). These photographs have also motivated some people toward environmentalism.

Many astronauts and cosmonauts have commented on the profound effects that seeing Earth from space has had on them; the 24 astronauts who traveled to the Moon are the only humans to have observed Earth from beyond low Earth orbit, and have traveled farther from Earth than anyone else to date.

Apollo 11 broadcast data restoration project

As part of Apollo 11's 40th anniversary in 2009, NASA spearheaded an effort to digitally restore the existing videotapes of the mission's live televised moonwalk. After a three-year exhaustive search for missing tapes of the original video of the Apollo 11 moonwalk, NASA concluded the data tapes had more than likely been accidentally erased.

We're all saddened that they're not there. We all wish we had 20-20 hindsight. I don't think anyone in the NASA organization did anything wrong, I think it slipped through the cracks, and nobody's happy about it.
—Dick Nafzger, TV Specialist, NASA Goddard Space Flight Center

The Moon landing data was recorded by a special Apollo TV camera which recorded in a format incompatible with broadcast TV. This resulted in lunar footage that had to be converted for the live television broadcast and stored on magnetic telemetry tapes. During the following years, a magnetic tape shortage prompted NASA to remove massive numbers of magnetic tapes from the National Archives and Records Administration to be recorded over with newer satellite data. Stan Lebar, who designed and built the lunar camera at Westinghouse Electric Corporation, also worked with Nafzger to try to locate the missing tapes.

So I don't believe that the tapes exist today at all. It was a hard thing to accept. But there was just an overwhelming amount of evidence that led us to believe that they just don't exist anymore. And you have to accept reality.
—Stan Lebar, Lunar Camera Designer, Westinghouse Electric Corporation

With a budget of $230,000, the surviving original lunar broadcast data from Apollo 11 was compiled by Nafzger and assigned to Lowry Digital for restoration. The video was processed to remove random noise and camera shake without destroying historical legitimacy. The images were from tapes in Australia, the CBS News archive, and kinescope recordings made at Johnson Space Center. The restored video, remaining in black and white, contains conservative digital enhancements and did not include sound quality improvements.

Chapter 11

Space Shuttle Program

The maiden flight of Space Shuttle *Columbia* on April 12, 1981. This was one of only two missions that had a painted external tank.

NASA's **Space Shuttle**, officially called **Space Transportation System** (**STS**), is the United States government's current manned launch vehicle. The winged Space Shuttle orbiter is launched vertically, usually carrying five to seven astronauts (although eight have been carried) and up to 50,000 lb (22 700 kg) of payload into low earth orbit. When its mission is complete, the shuttle can independently move itself out of orbit using its

Maneuvering System (it orients itself appropriately and fires its main OMS engines, thus slowing it down) and re-enter the Earth's atmosphere. During descent and landing the orbiter acts as a re-entry vehicle and a glider, using its OMS system and flight surfaces to make adjustments.

The shuttle is the only winged manned spacecraft to achieve orbit and land, and the only reusable space vehicle that has ever made multiple flights into orbit. Its missions involve carrying large payloads to various orbits (including segments to be added to the International Space Station), providing crew rotation for the International Space Station, and performing service missions. The orbiter has also recovered satellites and other payloads from orbit and return them to Earth, but its use in this capacity was rare. However, the shuttle has previously been used to return large payloads from the ISS to Earth, as the Russian Soyuz spacecraft has limited capacity for return payloads. Each vehicle was designed with a projected lifespan of 100 launches, or 10 years' operational life.

The program started in the late 1960s and has dominated NASA's manned operations since the mid-1970s. According to the Vision for Space Exploration, use of the space shuttle was to be focused on completing assembly of the ISS by 2010, after which it will be retired. NASA planned to replace the shuttle with the Orion spacecraft, but budget cuts have placed full development of the Orion craft in doubt.

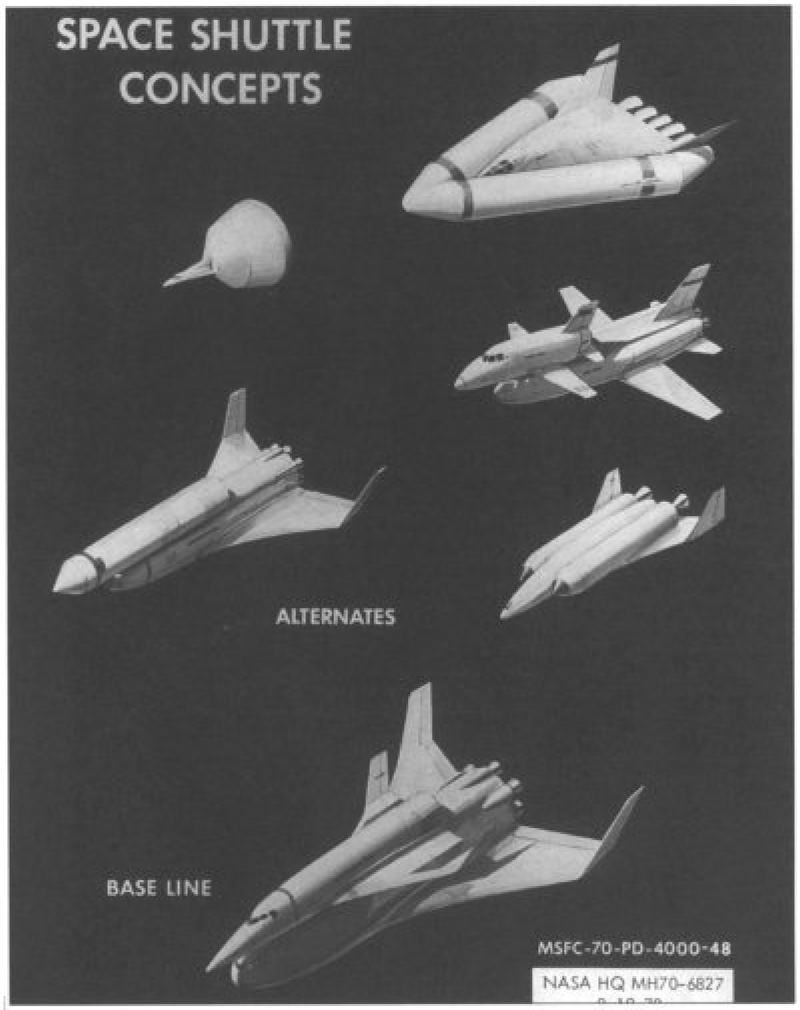
Conception (1960s-1970s)

Before the Apollo 11 moon landing in 1969, NASA began early studies of space shuttle designs. In 1969 President Richard Nixon formed the Space Task Group, chaired by vice president Spiro T. Agnew. This group evaluated the shuttle studies to date, and recommended a national space strategy including building a space shuttle. The goal, as presented by NASA to Congress, was to provide a much less-expensive means of access to space that would be used by NASA, the Department of Defense, and other commercial and scientific users.

Development

During early shuttle development there was great debate about the optimal shuttle design that best balanced capability, development cost and operating cost. Ultimately the current design was chosen, using a reusable winged orbiter, reusable solid rocket boosters, and an expendable external tank.

The shuttle program was formally launched on January 5, 1972, when President Nixon announced that NASA would proceed with the development of a reusable space shuttle system. The final design was less costly to build and less technically ambitious than earlier fully reusable designs. The initial design parameters included a larger external fuel tank, which would have been carried to orbit, where it could be used as a section of a space station, but this idea was killed due to budgetary and political considerations.



Early U.S. space shuttle concepts

The prime contractor for the program was North American Aviation (later Rockwell International, now Boeing), the same company responsible for building the Apollo Command/Service Module. The contractor for the Space Shuttle Solid Rocket Boosters was Morton Thiokol (now part of Alliant Techsystems), for the external tank, Martin Marietta (now Lockheed Martin), and for the Space shuttle main engines, Rocketdyne (now Pratt & Whitney Rocketdyne, part of United Technologies).

The first orbiter was originally planned to be named *Constitution*, but a massive write-in campaign from fans of the *Star Trek* television series convinced the White House to change the name to *Enterprise*. Amid great fanfare, the *Enterprise* (designated OV-101) was rolled out on September 17, 1976, and later conducted a successful series of glide-approach and landing tests that were the first real validation of the design.

The first fully functional orbiter was the *Columbia* (designated OV-102), built in Palmdale, California. It was delivered to Kennedy Space Center on March 25, 1979, and was first launched on April 12, 1981—the 20th anniversary of Yuri Gagarin's space flight—with a crew of two. *Challenger* (OV-099) was delivered to KSC in July 1982, *Discovery* (OV-103) in November 1983, and *Atlantis* (OV-104) in April 1985. *Challenger* was originally built and used as a Structural Test Article (STA-099) but was converted to a complete shuttle when this was found to be less expensive than converting *Enterprise* from its Approach and Landing Test configuration, according to NASA. *Challenger* was destroyed during ascent due to O-Ring failure on the right solid rocket booster (SRB) on January 28, 1986, with the loss of all seven astronauts on board. *Endeavour* (OV-105) was built to replace *Challenger* (using structural spare parts originally intended for the other orbiters) and delivered in May 1991; it was first launched a year later. Seventeen years after *Challenger*, *Columbia* broke up on reentry, killing all seven crew members, on February 1, 2003, and it has not been replaced. Out of the five fully functional shuttle orbiters built, three remain. *Enterprise*, which was used for atmospheric test flights but not intended for orbital flight, had many parts taken out for use on the other orbiters. It was later visually restored and is on display at the National Air and Space Museum's Steven F. Udvar-Hazy Center. (NASA also maintains warehoused extensive catalogs of recovered pieces from the two destroyed orbiters.)

Shuttle applications

Space Shuttle Program commemorative emblem

Space shuttle applications have included:

- Crew rotation and servicing of Mir and the International Space Station (ISS)
- Manned servicing missions, such as to the Hubble Space Telescope (HST)
- Manned experiments in Low Earth orbit (LEO)
- Carried to LEO:
- Components for the construction of the ISS
    - Supplies in Spacehab modules or Multi-Purpose Logistics Modules
- Carried satellites with a booster, the Payload Assist Module (PAM-D) or the Inertial Upper Stage (IUS), to the point where the booster sends the satellite to:
    - A higher Earth orbit; these have included:
        - Chandra X-ray Observatory
        - Many TDRS satellites
        - Two DSCS-III (Defense Satellite Communications System) communications satellites in one mission
        - A Defense Support Program satellite
    - An interplanetary orbit; these have included:
        - Magellan probe
        - Galileo spacecraft
        - Ulysses probe

Flight statistics

Shuttle	Flights	Flight days	Orbits	Longest flight	First flight		Most recent flight		Mir/ISS docking
					STS	Date	STS	Date	
Columbia †	28	300d 17h 46m 42s	4,808	17d 15h 53m 18s	STS-1	Apr 12, 1981	STS-107 †	Jan 16, 2003	0 / 0
Challenger †	10	62d 07h 56m 15s	995	08d 05h 23m 33s	STS-6	Apr 04, 1983	STS-51-L †	Jan 28, 1986	0 / 0
Discovery	38	351d 17h 50m 41s	5,628	15d 02h 48m 08s	STS-41-D	Aug 30, 1984	STS-131	Apr 05, 2010	1 / 11
Atlantis	32	293d 18h 29m 37s	4,648	13d 20h 12m 44s	STS-51-J	Oct 03, 1985	STS-132	May 14, 2010	7 / 11
Endeavour	24	280d 09h 39m 44s	4,429	16d 15h 08m 48s	STS-49	May 07, 1992	STS-130	Feb 08, 2010	1 / 10
Total	**132**	**1289d 09h 52m 48s**	**20,022**						**9 / 32**

† No longer in service (destroyed)

Disasters (1986, 2003)

Challenger disintegrated 1 minute 13 seconds after liftoff in 1986

Two shuttles have been destroyed in 130 missions, both with the loss of crew (14 astronauts total):

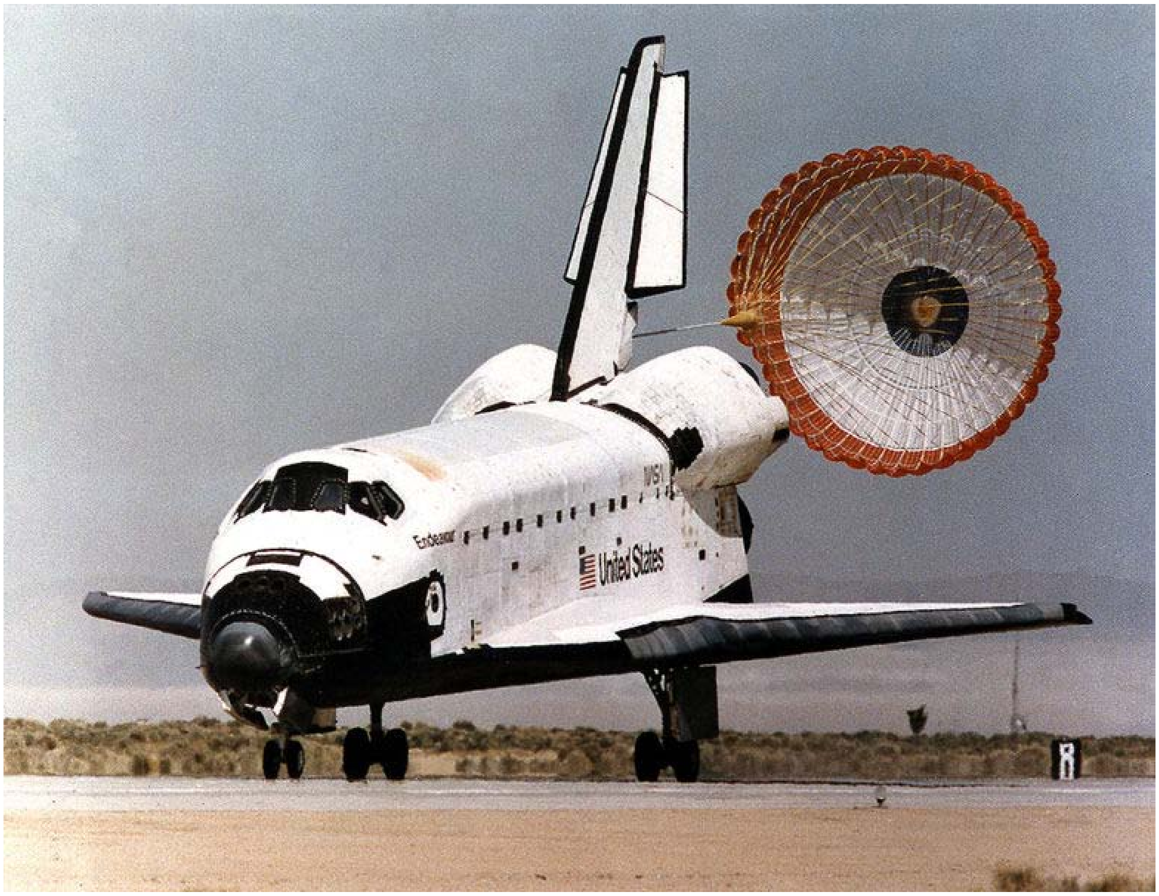
- *Challenger* — lost 73 seconds after liftoff, STS-51-L, January 28, 1986
- *Columbia* — lost approximately 16 minutes before its expected landing, STS-107, February 1, 2003

This gives a 2 percent death rate per astronaut-flight, and an average failure rate of 1 in every 65 missions. The original disaster potential, though disaster is not defined as fatal or non-fatal, was estimated during shuttle development at one every 75 missions. 87 successful missions were flown between STS-51-L and STS-107.

Status

Astronaut crews have performed vital servicing tasks on Hubble through four servicing missions since December 1993 in order to extend operating life with the replacement of aging hardware and enhancing scientific capability through the installation of advanced science instruments.

Space Shuttle Atlantis takes flight on the STS-27 mission on December 2, 1988. The Shuttle takes about 8.5 minutes to accelerate to a speed of over 27,000 km/h (17000 mph) and achieve orbit.



A drag chute is deployed by Space Shuttle Endeavour as it completes a mission of almost 17 days in space on Runway 22 at Edwards Air Force Base in southern California. Landing occurred at 1:46 p.m. (EST), March 18, 1995.

From September 2005 until early 2008, the manager of the space shuttle program was Wayne Hale. Hale then became NASA's deputy associate administrator for strategic partnerships. John Shannon, who had been Hale's deputy since November 2005, succeeded him as the Space Shuttle Program Manager.

After the Space Shuttle *Columbia* disaster in 2003, the International Space Station operated on a skeleton crew of two for more than two years and was serviced primarily by Russian spacecraft. While the "Return to Flight" mission STS-114 in 2005 was successful, a similar piece of foam from a different portion of the tank was shed. Although the debris did not strike the orbiter, the program was grounded once again for this reason.

The second "Return to Flight" mission, STS-121 launched on July 4, 2006, at 2:37 p.m. (EDT). Two previous launches were scrubbed because of lingering thunderstorms and high winds around the launch pad, and the launch took place despite objections from its chief engineer and safety head. A five-inch (13 cm) crack in the foam insulation of the external tank gave cause for concern; however, the Mission Management Team gave the go for launch. This mission increased the ISS crew to three. *Discovery* touched down successfully on July 17, 2006 at 9:14 a.m. (EDT) on Runway 15 at Kennedy Space Center.

Following the success of STS-121, all subsequent missions have been completed without major foam problems, and the construction of ISS is nearing completion. (During the STS-118 mission in August 2007, the orbiter was again struck by a foam fragment on liftoff, but this was a very small damage compared to the damage sustained to Columbia.)

The Columbia Accident Investigation Board, in its report, noted the reduced risk to the crew when a shuttle flies to the International Space Station (ISS), as the station can be used as a safe haven for the crew awaiting rescue in the event that damage to the shuttle orbiter on ascent makes it unsafe for re-entry. The board recommended that for the remaining flights, the shuttle always orbit with the station. Prior to Return to Flight, NASA Administrator Sean O'Keefe declared that all future flights of the shuttle would go to the ISS, precluding the possibility of executing the final Hubble Space Telescope servicing mission which had been scheduled before the Columbia accident, despite the fact that millions of dollars worth of upgrade equipment for Hubble were ready and waiting in NASA warehouses. Many dissenters, including astronauts, asked NASA management to reconsider allowing the mission, but initially the director stood firm. On October 31, 2006, NASA announced approval of the launch of the space shuttle, Atlantis, the fifth and final shuttle servicing mission to the Hubble Space Telescope, scheduled for August 28, 2008. However SM4/STS-125 eventually launched in May 2009.

Retirement

The shuttle program is scheduled for mandatory retirement in 2011, in accord with the directives President George W. Bush issued in the Vision for Space Exploration. The shuttle's planned successor was to be Project Constellation with its Ares I and Ares V launch vehicles and the Orion Spacecraft; however, in early 2010 the Obama administration asked Congress to instead endorse a scaled-back plan with heavy reliance on the private sector.

NASA originally planned to make the Hubble a Smithsonian museum display, but decided to keep it in space until a successor is launched.

In an internal e-mail apparently sent August 18, 2008 to NASA managers and leaked to the press (published September 6, 2008 in the *Orlando Sentinel*), NASA Administrator Michael Griffin stated his belief that the Bush administration had made no viable plan for U.S. crews to participate in the International Space Station beyond 2011, and that OMB and OSTP are actually seeking its demise. The email appeared to suggest that Griffin believed the only reasonable solution was to extend the operation of the shuttle beyond 2010, but noted that Executive Policy (i.e., the White House) is firm that there will be no extension of the shuttle retirement date, and thus no US capability to launch crews into orbit until the Ares I/Orion system becomes operational in 2014 at the very earliest. He appeared to indicate that he did not see purchase of Russian launches for NASA crews as politically viable following the 2008 South Ossetia war, and hoped the new US administration will resolve the issue in 2009 by extending shuttle operations beyond 2010. However, according to an article by former Space Shuttle program Director Wayne Hale on his official NASA blog, the space shuttle program, in preparation for the 2010 shutdown, has already terminated many specialty parts and materials contracts, many with small mom-and-pop companies whose only customer may have been the shuttle program and who closed shop and retired upon receiving their termination letters; as a result, it would be difficult and expensive at this point to extend the shuttle program, and there would be a lag of at least a year (without flights) before exhausted exotic parts and supplies could be replaced. The loss of talent from dismissed employees is another obstacle to program extension.

On September 7, 2008, NASA released a statement regarding the leaked email, in which Griffin said:

"The leaked internal email fails to provide the contextual framework for my remarks, and my support for the administration's policies. Administration policy is to retire the space shuttle in 2010 and purchase crew transport from Russia until Ares and Orion are available. The administration continues to support our request for an INKSNA exemption. Administration policy continues to be that we will take no action to preclude continued operation of the International Space Station past 2016. I strongly support these administration policies, as do OSTP and OMB."
—Michael D. Griffin,

A $2.5 billion spending provision allowing NASA to fly the space shuttle beyond its then-scheduled retirement in 2010 passed the Congress in April 2009, although neither NASA nor the White House requested the one-year extension.

NASA Authorization Act of 2008

U.S. Representative Dave Weldon introduced H.R. 4837, known as the SPACE Act. This legislation would have kept the shuttle flying past 2010 at a reduced rate until the Orion spacecraft would have been ready to replace it. It would also have allowed the Alpha Magnetic Spectrometer to be launched to the ISS, which the schedule at the time did not allow.

On October 15, 2008, President Bush signed the NASA Authorization Act of 2008, giving NASA funding for one additional mission to "deliver science experiments to the station". The act allowed for an additional space shuttle flight, STS-134, to the ISS to install the Alpha Magnetic Spectrometer, which was previously canceled.

Budget

Space Shuttle *Discovery* as it approaches the International Space Station during STS-114 on July 28, 2005.

The total cost of the shuttle program has been $145 billion as of early 2005, and is estimated to be $174 billion when the shuttle retires in early 2011. NASA's budget for 2005 allocated 30%, or $5 billion, to space shuttle operations; this was decreased in 2006 to a request of $4.3 billion.

Per-launch costs can be measured by dividing the total cost over the life of the program (including buildings, facilities, training, salaries, etc.) by the number of launches. With 115 missions (as of 6 August 2006), and a total cost of $150 billion ($145 billion as of early 2005 + $5 billion for 2005, this gives approximately $1.3 billion per launch. Another method is to calculate the incremental (or marginal) cost differential to add or subtract one flight — just the immediate resources expended/saved/involved in that one flight. This is about $60 million U. S. dollars.

Early cost estimates of $118 per pound ($260/kg) of payload were based on marginal or incremental launch costs, and based on 1972 dollars and assuming a 65,000 pound (30 000 kg) payload capacity. Correcting for inflation, this equates to roughly $36 million incremental per launch costs; today's actual incremental per launch costs of $60 million are about two thirds more than this.

Assets and transition plan

The Space Shuttle Program occupies over 654 facilities, uses over 1.2 million line items of equipment and employs over 5,000. The total value of equipment is over $12 billion. Shuttle related facilities represent over a quarter of NASA's inventory. There are over 1,200 active suppliers to the program throughout the United States. NASA's transition plan has the program operating through 2010 with a transition and retirement phase lasting through 2015. During this time the Ares I and Orion as well as the Altair Lunar Lander would be under development.

Criticism

The space shuttle program has been criticized for failing to achieve its promised cost and utility goals, as well as design, cost, management, and safety issues.

After both the *Challenger* disaster and the *Columbia* disaster, high profile boards convened to investigate the accidents with both committees returning praise and serious critiques to the program and NASA management. One of the most famous of these criticisms came from Nobel Prize winner Richard Feynman.

Other STS program vehicles

Crawler-transporter #2 ("Franz") in a December 2004 road test after track shoe replacement.

STS Program mate/de-mate facility for STS Orbiter and STS Shuttle Carrier Aircraft. (Space Shuttle Atlantis in 1991)

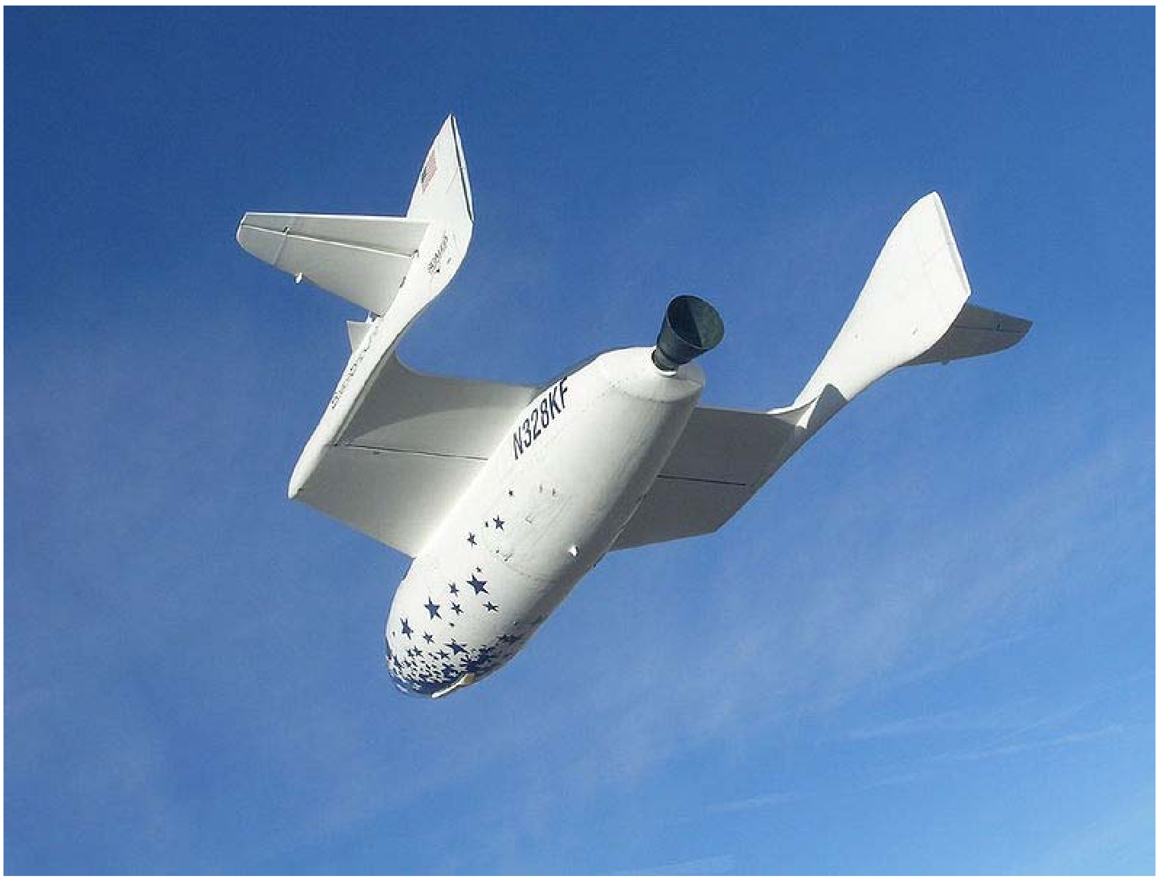
Many other vehicles are used in support of the Space Shuttle program, mainly terrestrial transportation vehicles.

- The Crawler-Transporter carries the Mobile Launcher Platform and the space shuttle from the Vehicle Assembly Building at Launch Complex 39 to Pad A.
- The Shuttle Carrier Aircraft are two modified Boeing 747s. Either can fly an orbiter from alternative landing sites back to the Kennedy Space Center.
- A 36-wheeled transport trailer, the Orbiter Transfer System, originally built for the U.S. Air Force's launch facility at Vandenberg Air Force Base in California (since then converted for Delta IV rockets) that would transport the orbiter from the landing facility to the launch pad, which allowed both "stacking" and launch without utilizing a separate VAB-style building and crawler-transporter roadway. Prior to the closing of the Vandenberg facility, orbiters were transported from the OPF to the VAB on its undercarriage, only to be raised when the orbiter was being lifted for attachment to the SRB/ET stack. The trailer allows the transportation of the orbiter from the OPF to either the SCA-747 "Mate-Demate" stand or the VAB without placing any additional stress on the undercarriage.

- The Crew Transport Vehicle (CTV), a modified airport jet bridge, is used to assist astronauts to egress from the orbiter after landing. Upon entering the CTV, astronauts can take off their launch and re-entry suits then proceed to chairs and beds for medical checks before being transported back to the crew quarters in the Operations and Checkout Building.
- The Astrovan is used to transport astronauts from the crew quarters in the Operations and Checkout Building to the launch pad on launch day. It is also used to transport astronauts back again from the Crew Transport Vehicle at the Shuttle Landing Facility.

Chapter 12

Virgin Galactic Tier One



Tier One is Scaled Composites' program of suborbital human spaceflight using the reusable spacecraft SpaceShipOne and its launcher White Knight. The craft was designed by Burt Rutan, and the project is funded 20 million US Dollars by Paul Allen. In 2004 it made the first privately funded human spaceflight and won the 10 million US Dollars Ansari X Prize for the first non-governmental reusable manned spacecraft.

The objective of the project is to develop technology for low-cost routine access to space. Tier One is not itself intended to carry paying passengers, but it is envisioned that there will be commercial spinoffs, initially in space tourism. The company Mojave Aerospace Ventures was formed to manage commercial exploitation of the technology. A deal with

Virgin Galactic could see routine space tourism, using a spacecraft based on Tier One technology, starting as soon as 2011.

Design

The design concept is to air launch a three-person piloted spacecraft which climbs to slightly above 100 km (62 mi) altitude using a hybrid rocket motor and then glides to the ground and lands horizontally. Scaled Composites lists the following components of the program:

- launch aircraft (White Knight)
- three-seater human-rated spacecraft (SpaceShipOne)
- hybrid rocket propulsion system
- mobile propulsion test facility
- flight simulator
- inertial-nav flight director
- mobile mission control center
- spacecraft systems
- pilot training program
- flight test program

Spacecraft

Tier One's spacecraft, Scaled Composites model **316**, known as **SpaceShipOne**, is a spaceplane designed to:

- carry three humans (one of them a pilot) in a sea-level pressurized cabin
- be propelled by rocket from an altitude of 15 km (9.3 mi) to in excess of 100 km (62 mi)
- reenter atmosphere and shed kinetic energy in an aerodynamically stable configuration
- glide transonically and subsonically
- land horizontally on a standard runway

The fuselage is cigar-shaped, with an overall diameter of about 1.52 m (5 ft 0 in). The main structure is of a graphite/epoxy composite material. From front to back, it contains the crew cabin, oxidizer tank, fuel casing, and rocket nozzle. The craft has short, wide wings, with a span of 5 m (16 ft) and a chord of 3 m (9.8 ft). There are large vertical tailbooms mounted on the end of each wing, with horizontal stabilisers protruding from the tailbooms. It has gear for horizontal landings.

The overall mass of the fully-fueled craft is 3,600 kg (7,900 lb), of which 2,700 kg (6,000 lb) is taken by the fully loaded rocket motor. Empty mass of the spacecraft is 1,200 kg (2,600 lb), including the 300 kg (660 lb) empty motor casing.

Originally the nozzle protruded from the back, but this turned out to be aerodynamically disadvantageous. In June 2004, between flights 14P and 15P, a fairing was added, smoothly extending the fuselage shape to meet the flared end of the nozzle. On flight 15P the new fairing overheated, due to being black on the inside and facing a hot, black nozzle. The fairing softened, and the lower part crumpled inwards during boost. Following that flight the interior of the fairing was painted white, and some small stiffening ribs were added.

The craft has a single unsteerable and unthrottleable hybrid rocket motor, a cold gas reaction control system, and aerodynamic control surfaces. All can be controlled manually.

The reaction control system is the only way to control spacecraft attitude outside the atmosphere. It consists of three sets of thrusters: there are thrusters at each wingtip to control roll, at the top and bottom of the nose to control pitch, and at the sides of the fuselage to control yaw. All thrusters have redundant backups, so there are twelve thrusters in all.

The aerodynamic control surfaces are designed to operate in two distinct flight regimes, subsonic and supersonic. The supersonic flight regime is of primary interest during the boost phase of a flight, and the subsonic mode when gliding. There are separate upper and lower rudders, and elevons. These are controlled using aviation-style stick and pedals. In supersonic mode the trim tabs are controlled electrically, whereas the subsonic mode uses mechanical cable-and-rod linkage.

The wings can be pneumatically tilted forwards into an aerodynamically-stable high-drag "feathered" shape. This removes most of the need to actively control attitude during the early part of reentry: Scaled Composites refer to this as "care-free reentry". One of the early test flights actually performed re-entry inverted, demonstrating the flexibility and inherent stability of Burt Rutan's "shuttlecock" design.

This feathered reentry mode is inherently far safer than the behaviour at similar speeds of the only comparable craft previously built, the Space Shuttle. The Shuttle undergoes enormous aerodynamic stresses and must be precisely steered in order to remain in a stable glide. (Although this is an interesting comparison of behaviour, it is not an entirely fair comparison of design concepts: the Shuttle starts reentry at much higher speed than SpaceShipOne, and so has some very different requirements.)

An early design called for a permanently shuttlecock-like shape, with a ring of feather-like stabilising fins. This would have made the spacecraft incapable of landing independently, requiring mid-air retrieval. This was deemed too risky, and the hybrid final design manages to incorporate the feathering capability into a craft that can land in a conventional manner. The tiltable rear sections of the wings and the tailbooms are collectively referred to as "the feather".

The landing gear consists of two widely-separated main wheels and a nose skid. These are deployed using springs, assisted by gravity. Once deployed, they cannot be retracted inflight.

The spacecraft is incapable of independent takeoff from the ground. It requires a launch aircraft to carry it to launch altitude for an air launch.

The parts of the craft that experience the greatest heating, such as the leading edges of the wings, have about 6.5 kg (14 lb) of ablative thermal protection material applied. The main ingredient of this material was accidentally leaked to *Air and Space*. If it flew with no thermal protection, the spacecraft would survive reentry but would be damaged.

There is an acknowledged "known deficiency" with the spacecraft's aerodynamic design that makes it susceptible to roll excursions. This has been seen on SpaceShipOne flight 15P where wind shear caused a large roll immediately after ignition, and SpaceShipOne flight 16P where circumstances not yet fully understood caused multiple rapid rolls. This flaw is not considered dangerous, but in both of these flights led to the achievement of a much lower altitude than expected. The details of the flaw are not public.

Navigation

The core of the spacecraft avionics is the **System Navigation Unit** (**SNU**). Together with the **Flight Director Display** (**FDD**), it comprises the **Flight Navigation Unit**. The unit was developed jointly by Fundamental Technology Systems and Scaled Composites.

The SNU is a GPS-based inertial navigation system, which processes spacecraft sensor data and subsystem health data. It downlinks telemetry data by radio to mission control.

The FDD display data from the SNU on a colour LCD. It has several distinct display modes for different phases of flight, including the boost phase, coast, reentry, and gliding. The FDD is particularly important to the pilot during the boost and coast phase in order to "turn the corner" and null rates caused by asymmetric thrust. A mix of commercial and bespoke software is used in the FDD.

Cabin

The spacecraft cabin, designed to hold three humans, is shaped as a short cylinder, diameter 1.52 m (5 ft 0 in), with a pointed forward end. The pilot sits towards the front, and two passengers can be seated behind.

The cabin is pressurized, maintaining a sea level breathable atmosphere. Oxygen is introduced to the cabin from a bottle, and carbon dioxide and water vapor are removed by absorbers. The occupants do not wear spacesuits or breathing masks, because the cabin has been designed to maintain pressure in the face of faults: all windows and seals are doubled.

The cabin has sixteen round double-pane windows, positioned to provide a view of the horizon at all stages of flight. The windows are small compared to the gaps between them, but there are sufficiently many for human occupants to patch together a moderately good view.

The nose section can be removed, and there is also a hatch below the rear windows on the left side. Crew ingress and egress is possible by either route.

Launch aircraft

Tier One's launch aircraft, Scaled Composites model **318**, known as **White Knight**, is designed to take off and land horizontally and attain an altitude of about 15 km (9.3 mi), all while carrying the Tier One spacecraft in a parasite aircraft configuration. Its propulsion is by twin turbojets: afterburning J-85-GE-5 engines, rated at 15.6 kN (3,500 lb_f) of thrust each.

It has the same cabin, avionics, and trim system as SpaceShipOne. This means it can flight-qualify almost all components of SpaceShipOne. It also has a high thrust-to-weight ratio and large speed brakes. These features combined allow it to be used as a high-fidelity moving platform flight simulator for SpaceShipOne. White Knight is also equipped with a trim system which (when activated) causes it to have the same glide profile as SpaceShipOne; this allows the pilots to practice for landing SpaceShipOne. The same pilots fly White Knight as fly SpaceShipOne.

The aircraft's distinctive shape features long, thin wings, in a flattened "W" shape, with a wingspan of 25 m (82 ft), dual tailplanes, and four wheels (front and rear at each side). The rear wheels retract, but the front ones, which are steerable, are permanently deployed, with small fairings, referred to as "spats", in front. Another way to look at the overall shape is as two conventional planes, with very thin fuselages, side-by-side and joined together at their wingtips, with the cockpit and engines mounted at the point of joining.

Although White Knight was developed for certain roles in the Tier One program, it is a very capable aircraft in its own right. Scaled Composites describe it as a "high-altitude research aircraft".

Hybrid rocket motor

Tier One uses a hybrid rocket motor supplied by SpaceDev, with solid hydroxyl-terminated polybutadiene (HTPB, or rubber) fuel and liquid nitrous oxide oxidiser. It generates 88 kN (20,000 lb_f) of thrust, and can burn for about 87 s (1.45 min).

The physical layout of the engine is novel. The oxidiser tank is a primary structural component, and is the only part of the engine that is structurally connected to the spacecraft: the tank is in fact an integral part of the spacecraft fuselage. The tank is a short cylinder of diameter approximately 1.52 m (5 ft 0 in), with domed ends, and is the forwardmost part of the engine. The fuel casing is a narrow cylinder cantilevered to the tank, pointing backwards. The cantilevered design means that a variety of motor sizes can be accommodated without changing the interface or other components. The nozzle is a simple extension of the fuel casing; the casing and nozzle are actually a single component, referred to as the **CTN** (**c**ase, **t**hroat, and **n**ozzle). Burt Rutan has applied for a patent on this engine configuration.

There is considerable use of composite materials in the engine design. The oxidiser tank consists of a composite liner with graphite/epoxy over-wrap and titanium interface flanges. The CTN uses a high-temperature composite insulator with a graphite/epoxy structure. Incorporating the solid fuel (and hence the main part of the engine) and the ablative nozzle into this single bonded component minimizes the possible leak paths.

The oxidiser tank and CTN are bolted together at the main valve bulkhead, which is integrated into the tank. There are O-rings at the interface to prevent leakage; this is the main potential leak path in the engine. The ignition system, main control valve, and injector are mounted on the valve bulkhead, inside the tank. Slosh baffles are also mounted on this bulkhead. Because the oxidiser is stored under pressure, no pump is required.

The tank liner and the fuel casing are built in-house by Scaled Composites. The tank over-wrap is supplied by Thiokol. The ablative nozzle is supplied by AAE Aerospace. The oxidiser fill, vent, and dump system is supplied by Environmental Aeroscience Corporation. The remaining components — the ignition system, main control valve, injector, tank bulkheads, electronic controls, and solid fuel casting — are supplied by SpaceDev.

The CTN must be replaced between firings. This is the only part of the craft, other than the fuel and oxidiser themselves, that must be replaced.

The solid fuel is cast with four holes. This has the disadvantage that it is possible for chunks of fuel between the holes to become detached during a burn and obstruct the flow of oxidiser and exhaust. Such situations tend to rapidly self-correct.

The oxidiser tank is filled and vented through its forward bulkhead, on the opposite side of the tank from the fuel and the rest of the engine. This improves safety. It is filled to a pressure of 4.8 MPa (700 psi) at room temperature.

The nozzle has an expansion ratio of 25:1, which is optimised for the upper part of the atmosphere. A different nozzle, with an expansion ratio of 10:1, is used for test firing on the ground. The nozzles are black on the outside, but for aerodynamic testing, red dummy nozzles are used instead.

The rocket is not throttleable. Once lit, the burn can be aborted, but the power output cannot otherwise be controlled. The thrust in fact varies, for two reasons. Firstly, as the pressure in the oxidiser tank decreases, the flow rate reduces, reducing thrust. Secondly, in the late stages of a burn the oxidiser tank contains a mixture of liquid and gaseous oxidiser, and the power output of the engine varies greatly depending on whether it's using liquid or gaseous oxidiser at a particular moment. (The liquid, being far denser, allows a greater burn rate.)

Both the fuel and oxidiser can be stored without special precautions, and they do not burn when brought together without a significant source of heat. This makes the rocket far safer than conventional liquid or solid rockets. It is also relatively non-polluting: the combustion products are water vapor, carbon dioxide, hydrogen, nitrogen, and some carbon monoxide.

The engine was upgraded in September 2004, between flights 15P and 16P. The upgrade increased the oxidiser tank size, to provide greater thrust in the early part of the burn, allow a longer burn, and delay the onset of the variable thrust phase at the end of the burn. Prior to the upgrade the engine generated 76 kN (17,000 lb_f) of thrust and could burn for 76 s (1.27 min). After the upgrade it was capable of 88 kN (20,000 lb_f) thrust and an 87 s (1.45 min) burn.

Flight profile

SpaceShipOne takes off from the ground, attached to White Knight in a parasite configuration, and under White Knight's power. The combination of SpaceShipOne and White Knight can take off, land, and fly under jet power to high altitude. A captive carry flight is one where the two craft land together without launching SpaceShipOne; this is one of the main abort modes available.

For launch, the combined craft flies to an altitude of around 14 km (8.7 mi), which takes about an hour. SpaceShipOne is then drop-released, and briefly glides unpowered. Rocket ignition may take place immediately, or may be delayed. If the rocket is never lit then SpaceShipOne can glide down to the ground. This is another major abort mode, in addition to being flown deliberately in glide tests.

The rocket engine is ignited while the spacecraft is gliding. Once under power, it is raised into a 65° climb, which is further steepened in the higher part of the trajectory. The maximum possible acceleration is about 4 *g*.

By the end of the burn the craft is flying upwards at some multiple of the speed of sound, up to about 900 m/s (3,000 ft/s) and Mach 3.5, and it continues to coast upwards unpowered (ie ballistically). If the burn was long enough then it will exceed an altitude of 100 km (62 mi), at which height the atmosphere presents no appreciable resistance, and the craft experiences free fall for a few minutes.

While at apogee the wings are reconfigured into high-drag mode. As the craft falls back it achieves high speeds comparable to those achieved on the way up; when it subsequently reenters the atmosphere it decelerates violently, up to about 5 *g*. At some altitude between

10 km (6.2 mi) and 20 km (12 mi) it reconfigures into low-drag glider mode, and glides down to a landing in about 20 minutes.

White Knight takes longer to descend, and typically lands a few minutes after SpaceShipOne.

Mission control

In addition to an office-based mission control, Tier One has a mobile mission control center. This is relatively small, built into a large road-going truck. It bears the Scaled Composites logo, but no other overt indication of its link to Tier One. The vehicle performs a combination of support functions:

- telemetry monitoring and recording
- telecommunications
- auxiliary environment control for White Knight and SpaceShipOne

This control center is used to support both rocket motor ground tests and all flight tests of White Knight and SpaceShipOne. Its primary function is to monitor and record test data, and to this end it is equipped with computers and radio communication gear. SpaceShipOne's avionics displays are duplicated in mission control. Telemetry data is received on a **Data Reduction System** (**DRS**), which automatically directs radio antennas to point at the craft being monitored. The telemetry system has a range of about 280 km (170 mi).

The control center is equipped to communicate with Scaled Composites' offices, as well as the aircraft and spacecraft.

The control center maintains a temperature-controlled atmosphere for its staff, and can be hooked up to provide temperature control for the White Knight and SpaceShipOne cabins. The physical structure of mission control also provides easier access to the White Knight cabin.

Nitrous oxide delivery

Unlike the solid fuel, the nitrous oxide oxidiser is handled as a bulk commodity and pumped into the spacecraft's oxidiser tank in the field. Tier One therefore has a mobile delivery system for nitrous oxide, which they call **MONODS** (**mo**bile **n**itrous **o**xide **d**elivery **s**ystem).

MONODS is built on an open trailer, which can be carried by road in conventional manner. It consists principally of a 6.5 m^3 (230 cu ft) tank, a temperature control unit, and a generator to power the temperature control unit. The nitrous oxide is stored at room temperature, at a pressure of 4.8 MPa (700 psi).

MONODS is refilled from a commercial supplier, which uses 50 m^3 (1,800 cu ft) tankers and delivers the nitrous oxide at about −17 °C (1.4 °F) and 2 MPa (290 psi). MONODS heats the nitrous oxide to room temperature, increasing its pressure.

Propulsion testing

Tier One has a mobile thrust test stand, known as the **Test Stand Trailer** (**TST**). The advantage of making it mobile is that all the mounting and instrumentation work can be done in the hangar, so that at the test site all that needs to be done is to fill the oxidiser tank (from MONODS) and conduct the firing.

The test stand replicates the essential structural components of the spacecraft. It has an oxidiser tank and associated fittings identical to the one used in flight. This means that the motor test also automatically performs appropriate vibration, stress, and heat tests of the spacecraft structure. The crew cabin, however, is not replicated.

For ground-based thrust tests, a rocket nozzle with an expansion ratio of 10:1 is used, differing from the 25:1 nozzle used at altitude during actual flight.

The test stand is instrumented to record not only thrust but also side force and temperature and strain experienced by components. Data is recorded on a computer in a bunker at the test site. The data acquisition computer is remotely controlled from mission control.

Flight simulator

The SpaceShipOne flight simulator consists of a simulator program and a cockpit.

The flight simulator program aims to accurately simulate SpaceShipOne's behaviour under any circumstances and in all phases of flight. Rather than having a model of SpaceShipOne's overall flight behaviour, it uses computational fluid dynamics to model the air around the craft. It calculates the aerodynamic and other forces operating on the craft, taking into account the positions of its control surfaces. This simulation is based on the computer modelling that was used during the design process and refined using data from flight tests. This yields a highly accurate image of craft behaviour, even in unanticipated modes of flight. (This is one of the first modern aircraft to be designed without wind tunnel testing.)

The cockpit replica is on a static base, and so cannot accurately reproduce the equilibrioceptive and accelerative aspects of flight. However, White Knight is equipped to operate as a high-fidelity moving-base simulator. The simulator cockpit is an accurate copy of the SpaceShipOne cabin, including its avionics. It is the system of pilot plus avionics, not just the pilot, that is being simulated to. The flight simulator program drives the sensor inputs that are used by the avionics, and also drives twelve display computers which use commercial graphics software to generate high-resolution images of the outside view for the pilot. These views appear on eleven monitors and one projector screen. Stick force feedback is not simulated in real time.

Ground-based flight simulation is not only used for pilot training. It is also used to train ground crew, develop procedures, and test the avionics software and hardware.

History and status

According to Scaled Composites, the concept for the program originated in April 1996, preliminary development began in 1999, and full development began in April 2001. It was initially kept secret, even after White Knight first flew on August 1, 2002. The program was announced to the public on April 18, 2003, when the program was ready to flight-test SpaceShipOne. Its first flight test, SpaceShipOne flight 01C, took place on May 20, 2003.

After months of glide tests, the first powered flight, SpaceShipOne flight 11P, was made on December 17, 2003. Further powered tests followed, reaching increasing altitudes, culminating on June 21, 2004 with the first privately funded human spaceflight, SpaceShipOne flight 15P. Ansari X Prize competitive flights followed. SpaceShipOne flight 16P on September 29, 2004 and SpaceShipOne flight 17P on October 4, 2004 were successful competitive flights, winning the X Prize.

The program will continue making test flights, to develop the technology further, in support of the development of successor spacecraft such as the Virgin SpaceShip. The program has ruled out carrying scientific payloads, despite several requests.