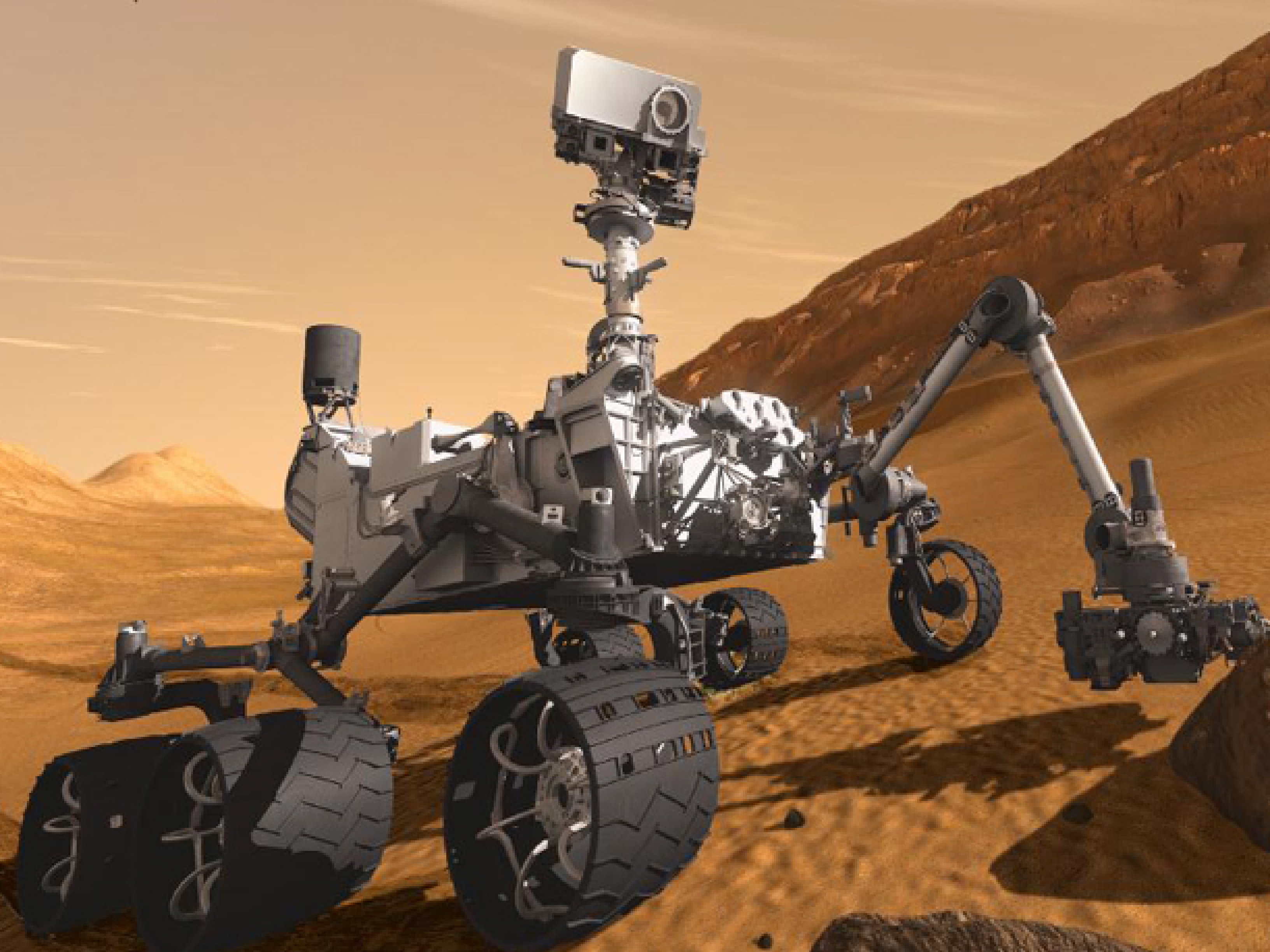
Complete Handbook of

Solar System and Space Exploration



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Chapter- 1

Exploration of Mercury and Venus

Exploration of Mercury

MESSENGER image of Mercury

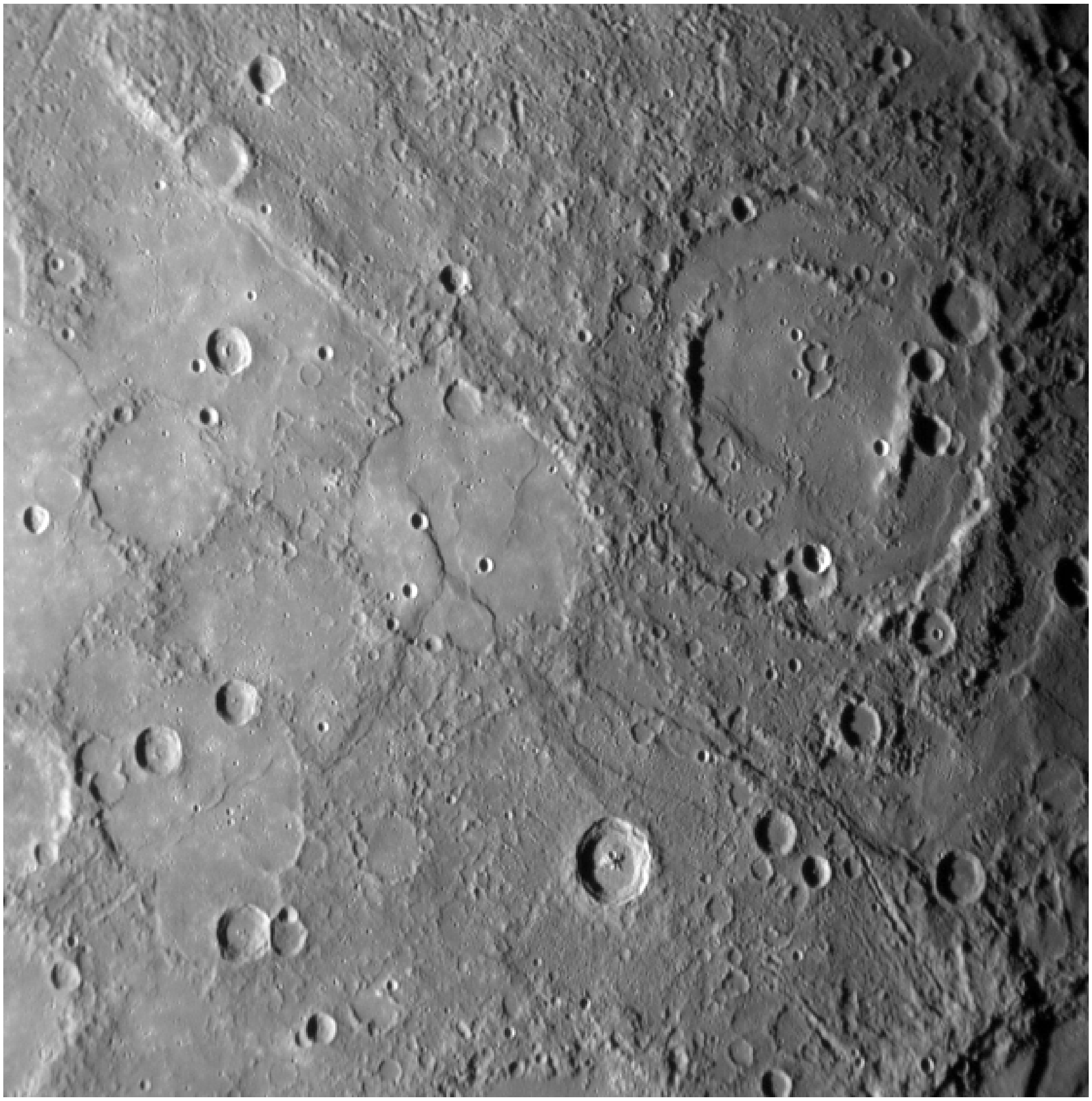
The **exploration of Mercury** has taken only a minor role in the space interests of the world. It is the least explored inner planet. As of 2008, the Mariner 10 and MESSENGER missions have been the only missions that have made close observations of Mercury. MESSENGER made a fly-by of Mercury on 14 January 2008, to further investigate the observations made by Mariner 10 in 1975. A third mission to Mercury, BepiColombo, is to include two probes. BepiColombo is a joint mission between Japan and the European Space Agency. MESSENGER and BepiColombo are intended to gather complementary data to help scientists understand many of the mysteries discovered by Mariner 10's flybys.

Compared to other planets, Mercury is difficult to explore. The increased speed required to reach it is relatively high, and due to the proximity to the Sun, orbits around it are rather unstable.

Interest in Mercury

Mercury has not been a primary focus of many space programs because the planet has had little to offer. Since the planet is so close to the Sun and spins on its own axis very slowly its surface temperature varies from 427 °C (801 °F) to -173 °C (-279 °F). There is discussion of the possibility of terraforming Mercury and inhabiting the poles of the planet, but this possibility lies far in the future, being significantly less practical than terraforming Mars. The current interest in Mercury is derived from the unexpected observations of Mariner 10. Before Mariner 10, it was thought that the planet simply revolved around the sun in a highly elliptical orbit. The planet had been observed through ground based telescopes, and scientists felt that they were able to draw a great many inferences from such observations. Mariner 10 provided data that contradicted many of these.

Another reason why so few missions have targeted Mercury is that it is very difficult to obtain a satellite orbit around the planet on account of its proximity to the Sun. This causes the Sun's gravitational field to pull on any satellite that would be set into Mercury's orbit. Furthermore, spacecraft naturally accelerate as they approach the greater gravitational pull of the Sun, but must slow down in order to orbit Mercury, so this entails considerable fuel requirements. This is different with planets beyond Earth's orbit where the satellite works against the pull of the Sun. Mercury's lack of an atmosphere poses further challenges because a probe attempting to land on Mercury would not be able to aerobrake or use a parachute type device. Thus it requires a great amount of energy to reach and observe the planet.



A MESSENGER image from 18,000 km showing a region about 500 km across

Mariner 10

Mariner 10 probe

Mariner 10 was a probe, whose primary objective was to observe the atmosphere, surface, and physical characteristics of Mercury and Venus. It was a low-cost mission completed for under $98 million. Mariner 10 was launched at 21:45 PST on November 2, 1973 from Cape Kennedy. Since Mercury is so close to the Sun it was too difficult to incorporate an orbit around Mercury in the route so Mariner 10 orbited the Sun. In order to reach its destination, the satellite was accelerated with the gravity field of Venus. It then passed close to Mercury on March 29, 1974, as it flew towards the Sun. This was the first observation made of Mercury at close range. After the encounter Mariner 10 was in an orbit around the Sun such that for every one of its orbits Mercury made two, and the spacecraft and the planet would be able to meet again. This allowed the probe to pass by Mercury two additional times before completing the mission; these encounters were made on September 21, 1974 and March 16, 1975. However, since the same side of Mercury was illuminated during each of the flybys, at the conclusion of the mission Mariner 10 had only photographed 45% of its surface. The mission was terminated by simply stopping contact with Mariner 10 on March 24, 1975. This was forced by a loss of fuel.

The close observations collected two important sets of data. The probe detected Mercury's magnetic field, which is very similar to Earth's. This was a surprise to scientists, because Mercury spins so slowly on its axis. Secondly, visual data was provided, which showed the high number of craters on the surface of the planet. The visual data also allowed scientists to determine that Mercury had "not experienced significant crustal modification". This also added to the mystery of the magnetic field, as it was previously believed that the magnetic fields are caused by a molten dynamo effect, but since there was little crustal modification this undermined that idea. The visual data also allowed scientists to investigate the composition and age of the planet.

MESSENGER

MESSENGER is a probe launched by NASA that is currently en route to Mercury. MESSENGER stands for *MErcury Surface, Space ENvironment, GEochemistry, and Ranging*. It was launched from Cape Canaveral on August 3, 2004 after a two-day delay due to bad weather. To correct the speed of the satellite it undertook gravitational slingshot flybys of planets several times. It passed by the Earth in February 2005 and then Venus in October 2006 and in October 2007. The total travel time before entering orbit is about six and a half years. Before entering orbit in 2011, the probe made three passes of Mercury. The first two flybys took place on January 14 and October 6, 2008. There was a third encounter on September 29, 2009. During these flybys, enough data was collected to produce images of over 95% of Mercury's surface. MESSENGER uses a "chemical bi-propellant system both to reach Mercury and brake into orbit". MESSENGER's scheduled orbital insertion takes place on March 18, 2011. The mission is scheduled to end sometime in 2012, when there will no longer be enough fuel to maintain the probe's orbit.

The information collected by MESSENGER will be used to try to answer six questions about Mercury:

1. Why is the planet so dense?
2. What is Mercury's geologic history?
3. What is the structure of Mercury's core?
4. What is the nature of Mercury's magnetic field?
5. What are the unusual materials at Mercury's poles?
6. What volatiles are important on Mercury?"

BepiColombo

This mission to Mercury is to include two satellites: the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). Each orbiter has a distinct purpose: the MPO is to take images of Mercury, and the MMO is to study the magnetosphere. The European Space Agency and Japan are working in conjunction on BepiColombo and will each provide one of the orbiters. The ESA will provide MPO, while Japan will provide MMO. The BepiColombo was designed with 12 specific objectives:

1. What can we learn from Mercury about the composition of the solar nebula and the formation of the planetary system?
2. Why is Mercury's normalized density markedly higher than that of all other terrestrial planets, as well as the Moon?
3. Is the core of Mercury liquid or solid?
4. Is Mercury tectonically active today?
5. Why does such a small planet possess an intrinsic magnetic field, while Venus, Mars and the Moon do not have any?
6. Why do spectroscopic observations not reveal the presence of any iron, while this element is supposedly the major constituent of Mercury?
7. Do the permanently shadowed craters of the polar regions contain sulfur or water ice?
8. What are the production mechanisms of the exosphere?
9. In the absence of any ionosphere, how does the magnetic field interact with the solar wind?
10. Is Mercury's magnetised environment characterized by features reminiscent of the aurorae, radiation belts and magnetospheric substorms observed on Earth?
11. Since the advance of Mercury's perihelion was explained in terms of space-time curvature, can we take advantage of the proximity of the Sun to test general relativity with improved accuracy?

Like Mariner 10 and MESSENGER, BepiColombo will use gravity slingshots from Venus and Earth. BepiColombo will use Solar Electric Propulsion and then also use similar manoeuvres at the Moon, Venus, and Mercury. These techniques will slow the orbiters as they approach Mercury. It is essential to avoid using fuel to slow the orbiters as they get closer to the Sun to minimize the gravitational influence of the Sun.

BepiColombo is set for launch in August 2013. It is scheduled to enter orbit around Mercury in August of 2019. It will then gather data for one, or possibly two years.

Comparison of MESSENGER and BepiColombo

BepiColombo was designed to complement the findings of MESSENGER and is equipped with far more measuring equipment than MESSENGER. BepiColombo is being sent to obtain a larger range of data. The orbit patterns of BepiColombo and MESSENGER are significantly different.

The MPO will have a circular orbit much closer to Mercury. The reason for this orbit is that the MPO will be taking photos of Mercury, and the close orbit will aid picture quality. On the other hand, the MMO and MESSENGER will take largely elliptical orbits. This is because of the stability of the orbit and the lower amount of fuel required to obtain and maintain the orbit. Another reason for the different orbits of MMO and

MESSENGER is to provide complementary data. The data of the two combined satellites will provide more accurate measurements.

These constitute the major differences in the two missions. It is notable that some of the questions that BepiColombo is seeking answers for are very similar to those of MESSENGER. The inexplicably strong magnetic field, for example, is of interest to both missions. A more detailed discussion of differences is provided by *An international program for Mercury exploration: synergy of MESSENGER and BepiColombo*.

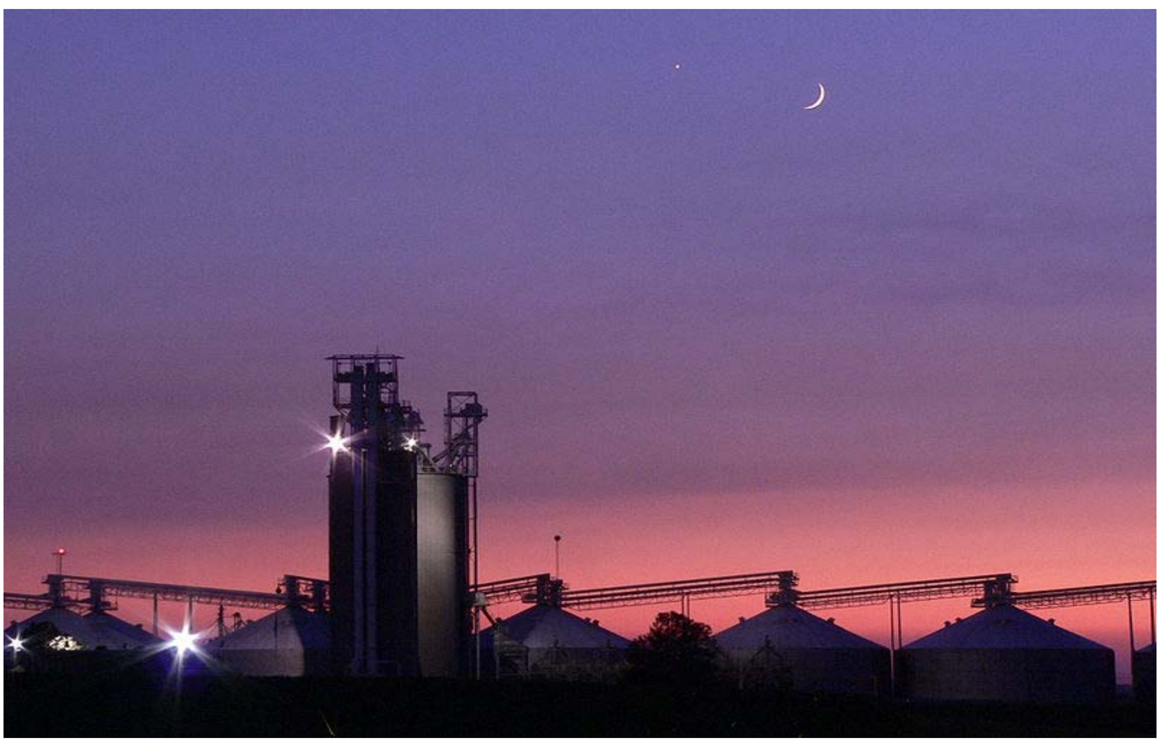
Observation and Exploration of Venus

Venus in real color as it would appear to the naked eye

Observations of the planet Venus were first made by Babylonian astronomers around 1600 BC and have continued into the present. The Maya also kept records of the movements of Venus and attached special importance to the planet. In 1610, Galileo Galilei was the first person to observe Venus through a telescope, and discovered that it appears to undergo phases, supporting the heliocentric model of planetary motions. Important later observations centered around rare transits of Venus, in which the planet passes across the face of the Sun as seen from Earth. During one transit in 1761, Mikhail Lomonosov discovered that Venus has an atmosphere, and another transit in the 19th century allowed astronomers to calculate the distance from Earth to the Sun. In the early 1960s, astronomers studied Venus by making radar and microwave observations from Earth, which suggested Venus has a surface temperature of several hundred kelvins.

The **exploration of Venus** by space probes began shortly after the Space Age, starting with the Soviet probe *Venera 1* in 1961. The first successful Venus probe was NASA's *Mariner 2*, which flew by the planet and confirmed its high surface temperatures. In 1966, *Venera 3* became the first spacecraft to reach the surface of another planet when it crash-landed on Venus. Its successor *Venera 4* succeeded in returning data during its descent, reporting that the atmosphere of Venus was 95% carbon dioxide and the surface pressure around 100 times greater than on Earth. *Venera 7* made the first successful soft landing in 1970. In 1975, *Venera 9* and *10* were the first spacecraft to enter an orbit around Venus, each also dispatching a lander to the surface. They were followed by several other NASA and Soviet orbiter/lander missions during the late 1970s and 1980s, including *Veneras 11* through *16*, *Pioneer Venus*, and *Vega*. However, there have been fewer Venus missions since the collapse of the Soviet Union. Between 1990 and 1994, NASA's *Magellan* orbiter mapped 98% of the surface using radar. The European Space Agency's *Venus Express* arrived in orbit around the planet in 2006, and is currently studying its atmosphere and surface characteristics.

Historical observations



Venus as a brilliant "Evening Star" next to crescent moon

Asia

One of the oldest surviving astronomical documents, from the Babylonian library of Ashurbanipal around 1600 BC, is a 21-year record of the appearances of Venus (which the early Babylonians called *Nindaranna*).

The ancient Sumerians and Babylonians called Venus *Dil-bat* or *Dil-i-pat*; in Akkadia it was the special star of the mother-god *Ishtar*; and in Chinese it is *Jīn-xīng* (金星), the planet of the metal element. In India, Venus is called *Shukra Graha* ("the planet Shukra") which is named after a powerful saint Shukra. The word *Shukra* is also associated with semen, or generation.

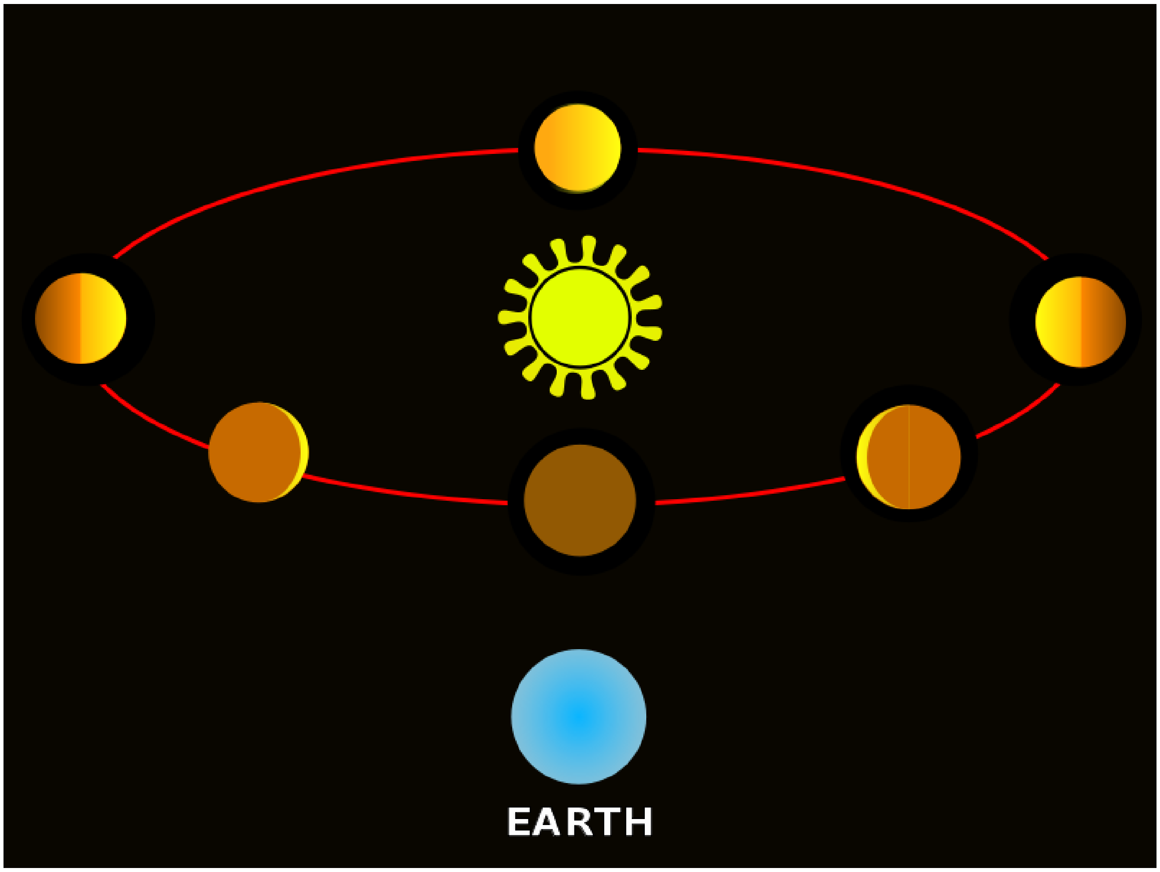
Maya

Venus was considered the most important celestial body observed by the Maya, who called it *Chak ek*, "the Great Star". The Mayans monitored the movements of Venus closely and observed it in daytime. The positions of Venus and other planets were thought to influence life on Earth, so Maya and other ancient Mesoamerican cultures timed wars and other important events based on their observations. In the Dresden Codex, the Maya included an almanac showing Venus's full cycle, in five sets of 584 days each (approximately eight years), after which the patterns repeated (since Venus has a synodic period of 583.92 days).

Greeks

Early Greeks thought that the evening and morning appearances of Venus represented two different objects, calling it *Hesperus* when it appeared in the western evening sky and *Phosphorus* when it appeared in the eastern morning sky. They eventually came to recognize that both objects were the same planet; Pythagoras is credited with this realization.

Phases



Phases of Venus

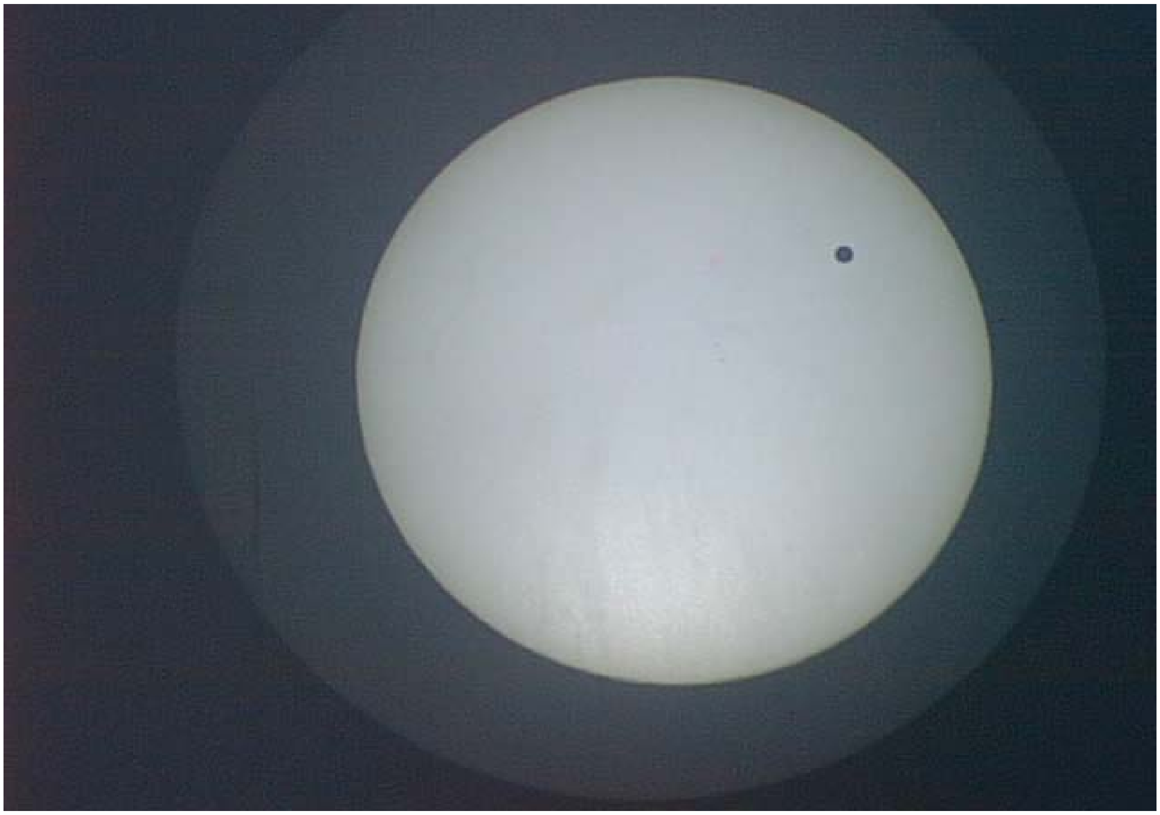
Because its orbit takes it between the Earth and the Sun, Venus as seen from Earth exhibits visible phases in much the same manner as the Earth's Moon. Galileo Galilei was the first person to observe the phases of Venus in December 1610, an observation which supported Copernicus's then contentious heliocentric description of the solar system. He also noted changes in the size of Venus's visible diameter when it was in different phases, suggesting that it was farther from Earth when it was full and nearer when it was a crescent. This observation strongly supported the heliocentric model. Venus (and also Mercury) is not visible from Earth when it is full, since at that time it is at superior conjunction, rising and setting concomitantly with the Sun and hence lost in the Sun's glare.

Venus is brightest when approximately 25% of its disk is illuminated; this typically occurs 37 days both before (in the evening sky) and after (in the morning sky), its inferior conjunction. Its greatest elongations occur approximately 70 days before and after inferior conjunction, at which time it is half full; between these two intervals Venus is actually visible in broad daylight, if the observer knows specifically where to look for it. The planet's period of retrograde motion is 20 days on either side of the inferior conjunction. In fact, through a telescope Venus at greatest elongation appears less than half full due to Schröter's effect first noticed in 1793 and shown in 1996 as due to its thick atmosphere.

Venus in daylight at 5 p.m. in the southern hemisphere - December 2005

On rare occasions, Venus can actually be seen in both the morning (before sunrise) and evening (after sunset) on the same day. This scenario arises when Venus is at its maximum separation from the ecliptic and concomitantly at inferior conjunction; then one hemisphere (Northern or Southern) will be able to see it at both times. This opportunity presented itself most recently for Northern Hemisphere observers within a few days on either side of March 29, 2001, and for those in the Southern Hemisphere, on and around August 19, 1999. These respective events repeat themselves every eight years pursuant to the planet's synodic cycle.

Transit and early terrestrial observations



Venus's 2004 transit across the Sun

Transits of Venus, when the planet crosses directly between the Earth and the Sun's visible disc, are rare astronomical events. The first time such a transit was observed was on December 4, 1639 by Jeremiah Horrocks and William Crabtree. A transit in 1761 observed by Mikhail Lomonosov provided the first evidence that Venus had an atmosphere, and the 19th-century observations of parallax during its transits allowed the distance between the Earth and Sun to be accurately calculated for the first time. Transits can only occur either in early June or early December, these being the points at which Venus crosses the ecliptic (the orbital plane of the Earth), and occur in pairs at eight-year intervals, with each such pair more than a century apart. The previous pair of transits of Venus occurred in 1874 and 1882, and the current pair is in 2004 and 2012.

In the 19th century, many observers stated that Venus had a period of rotation of roughly 24 hours. Italian astronomer Giovanni Schiaparelli was the first to predict a significantly slower rotation, proposing that Venus was tidally locked with the Sun (as he had also proposed for Mercury). While not actually true for either body, this was still a reasonably accurate estimate. The near-resonance between its rotation and its closest approach to Earth helped to create this impression, as Venus always seemed to be facing the same direction when it was in the best location for observations to be made. The rotation rate of Venus was first measured during the 1961 conjunction, observed by radar from a 26 m antenna at Goldstone, California, the Jodrell Bank Radio Observatory in the UK, and the Soviet deep space facility in Eupatoria, Crimea. Accuracy was refined at each subsequent conjunction, primarily from measurements made from Goldstone and Eupatoria. The fact that rotation was retrograde was not confirmed until 1964.

Before radio observations in the 1960s, many believed that Venus contained a lush, Earth-like environment. This was due to the planet's size and orbital radius, which suggested a fairly Earth-like situation as well as to the thick layer of clouds which prevented the surface from being seen. Among the speculations on Venus were that it had a jungle-like environment or that it had oceans of either petroleum or carbonated water. However, microwave observations by C. Mayer *et al.*, indicated a high-temperature source (600 K). Strangely, millimetre-band observations made by A. D. Kuzmin indicated much lower temperatures. Two competing theories explained the unusual radio spectrum, one suggesting the high temperatures originated in the ionosphere, and another suggesting a hot planetary surface.

Terrestrial radar mapping

After the Moon, Venus was the second object in the solar system to be explored by radar from the Earth. The first studies were carried out in 1961 at NASA's Goldstone Observatory, part of the Deep Space Network. At successive inferior conjunctions, Venus was observed both by Goldstone and the National Astronomy and Ionosphere Center in Arecibo. The studies carried out were similar to the earlier measurement of transits of the meridian, which had revealed in 1963 that the rotation of Venus was retrograde (it rotates in the opposite direction to that in which it orbits the Sun). The radar observations also allowed astronomers to determine that the rotation period of Venus was 243.1 days, and that its axis of rotation was almost perpendicular to its orbital plane. It was also established that the radius of the planet was 6,052 kilometres (3,761 mi), some 70 kilometres (43 mi) less than the best previous figure obtained with terrestrial telescopes.

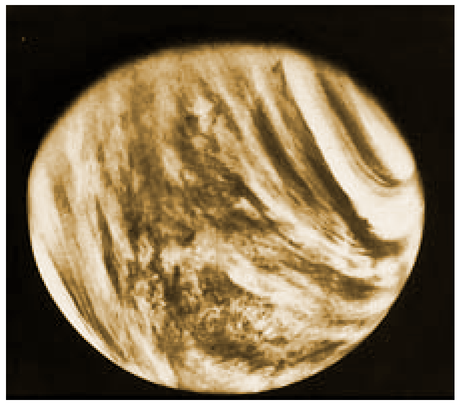
Interest in the geological characteristics of Venus was stimulated by the refinement of imaging techniques between 1970 and 1985. Early radar observations suggested merely that the surface of Venus was more compacted than the dusty surface of the Moon. The first radar images taken from the Earth showed very bright (radar-reflective) highlands christened Alpha Regio, Beta Regio, and Maxwell Montes; improvements in radar techniques later achieved an image resolution of 1–2 kilometres.

Observation by spacecraft

There have been numerous unmanned missions to Venus. Ten Soviet probes have achieved a soft landing on the surface, with up to 110 minutes of communication from the surface, all without return. Launch windows occur every 19 months, and from 1962 to 1985, every window was utilized to launch reconnaissance probes.

Early flybys

On February 12, 1961, the Soviet spacecraft *Venera 1* was the first probe launched to another planet. An overheated orientation sensor caused it to malfunction, but *Venera 1* was first to combine all the necessary features of an interplanetary spacecraft: solar panels, parabolic telemetry antenna, 3-axis stabilization, course-correction engine, and the first launch from parking orbit.



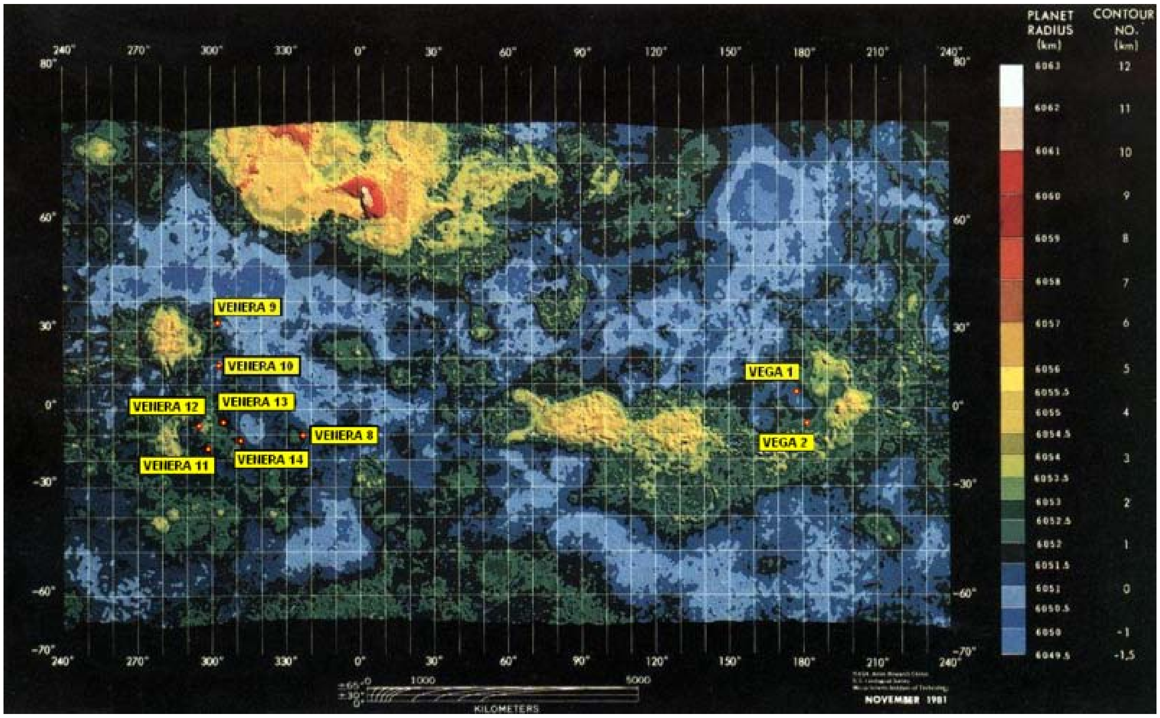
Global view of Venus in ultraviolet light done by Mariner 10

The first successful Venus probe was the American *Mariner 2* spacecraft, which flew past Venus in 1962. A modified *Ranger* Moon probe, it established that Venus has practically no intrinsic magnetic field and measured the planet's temperature range as 490 to 590 K.

The Soviet Union launched the *Zond 1* probe to Venus in 1964, but it malfunctioned sometime after its May 16 telemetry session.

During another American flyby in 1967, *Mariner 5* measured the strength of Venus's magnetic field. In 1974, *Mariner 10* swung by Venus on its way to Mercury and took ultraviolet photographs of the clouds, revealing the extraordinarily high wind speeds in the Venusian atmosphere.

Early landings



Location of Soviet Venus landers

On March 1, 1966 the *Venera 3* Soviet space probe crash-landed on Venus, becoming the first spacecraft to reach the surface of another planet. Its sister craft *Venera 2* had failed due to overheating shortly before completing its flyby mission.

The descent capsule of *Venera 4* entered the atmosphere of Venus on October 18, 1967, making it the first probe to return direct measurements from another planet's atmosphere. The capsule measured temperature, pressure, density and performed 11 automatic chemical experiments to analyze the atmosphere. It discovered that the atmosphere of Venus was 95% carbon dioxide, and in combination with radio occultation data from the *Mariner 5* probe, showed that surface pressures were far greater than expected (75 to 100 atmospheres).

These results were verified and refined by the *Venera 5* and *Venera 6* in May 1969. But thus far, none of these missions had reached the surface while still transmitting. *Venera 4*'s battery ran out while still slowly floating through the massive atmosphere, and *Venera 5* and *6* were crushed by high pressure 18 km (60,000 ft) above the surface.

The first successful landing on Venus was by *Venera 7* on December 15, 1970. It remained in contact with Earth for 23 minutes, relaying surface temperatures of 455 °C to 475 °C (855 °F to 885 °F). *Venera 8* landed on July 22, 1972. In addition to pressure and temperature profiles, a photometer showed that the clouds of Venus formed a layer, ending over 22 miles above the surface. A gamma ray spectrometer analyzed the chemical composition of the crust.

Lander/orbiter pairs

Venera 9 and 10

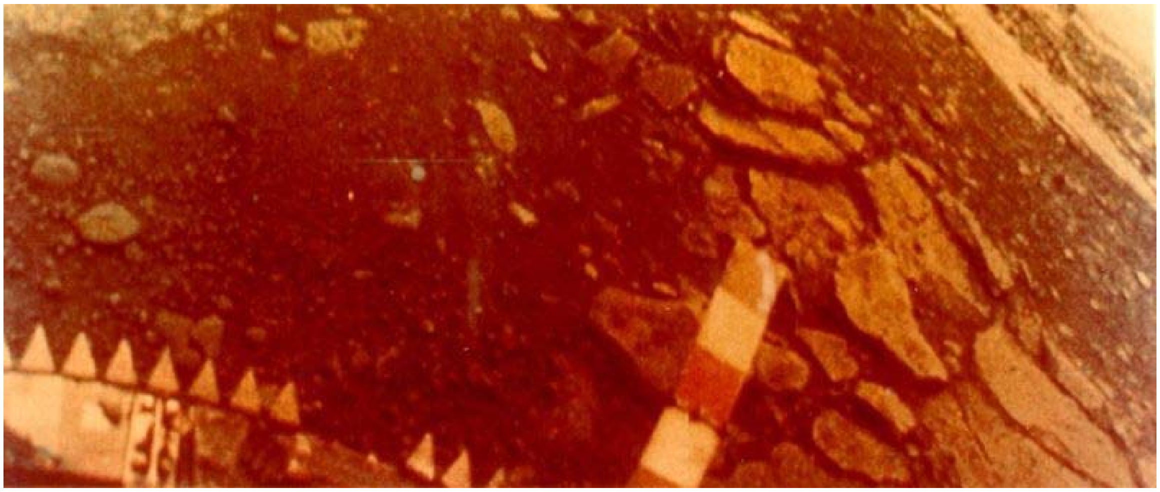
The Soviet probe *Venera 9* entered orbit on October 22, 1975, becoming the first artificial satellite of Venus. A battery of cameras and spectrometers returned information about the planet's clouds, ionosphere and magnetosphere, as well as performing bi-static radar measurements of the surface. The 660 kg (1,455 lb) descent vehicle separated from *Venera 9* and landed, taking the first pictures of the surface and analyzing the crust with a gamma ray spectrometer and a densitometer. During descent, pressure, temperature and photometric measurements were made, as well as backscattering and multi-angle scattering (nephelometer) measurements of cloud density. It was discovered that the clouds of Venus are formed in three distinct layers. On October 25, *Venera 10* arrived and carried out a similar program of study.

Pioneer Venus

In 1978, NASA sent two *Pioneer* spacecraft to Venus. The *Pioneer* mission consisted of two components, launched separately: an orbiter and a multiprobe. The *Pioneer Venus Multiprobe* carried one large and three small atmospheric probes. The large probe was released on November 16, 1978 and the three small probes on November 20. All four probes entered the Venusian atmosphere on December 9, followed by the delivery vehicle. Although not expected to survive the descent through the atmosphere, one probe continued to operate for 45 minutes after reaching the surface. The *Pioneer Venus Orbiter* was inserted into an elliptical orbit around Venus on December 4, 1978. It carried 17 experiments and operated until the fuel used to maintain its orbit was exhausted and atmospheric entry destroyed the spacecraft in August 1992.

Further Soviet missions

Also in 1978, *Venera 11* and *Venera 12* flew past Venus, dropping descent vehicles on December 21 and December 25 respectively. The landers carried colour cameras and a soil drill and analyzer, which unfortunately malfunctioned. Each lander made measurements with a nephelometer, mass spectrometer, gas chromatograph, and a cloud-droplet chemical analyzer using X-ray fluorescence that unexpectedly discovered a large proportion of chlorine in the clouds, in addition to sulfur. Strong lightning activity was also detected.



Color image of the Venusian surface taken by Venera 13

In 1981, the Soviet *Venera 13* sent the first colour image of Venus's surface and analysed the X-ray fluorescence of an excavated soil sample. The probe operated for a record 127 minutes on the planet's hostile surface. Also in 1981, the *Venera 14* lander detected possible seismic activity in the planet's crust.

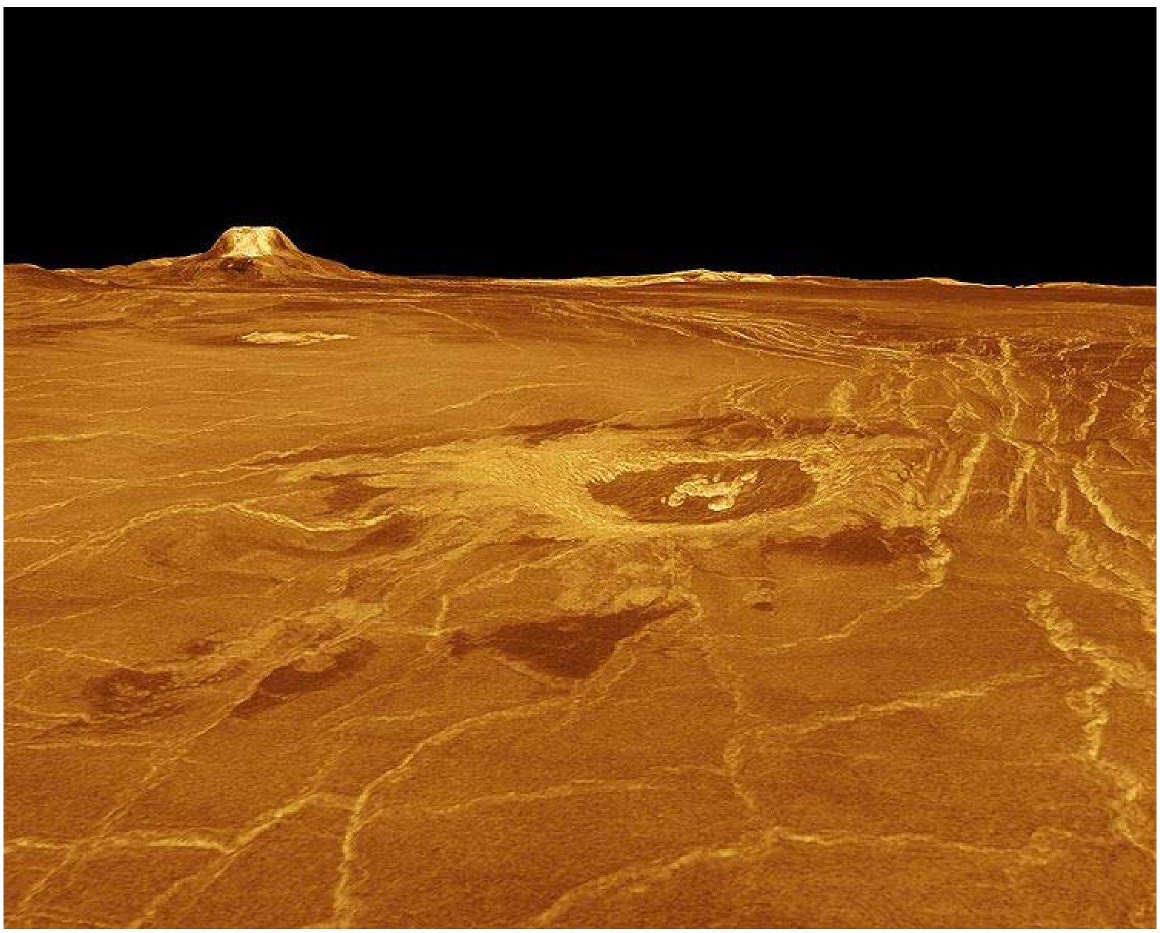
In December 1984, during the apparition of Halley's Comet, the Soviet Union launched the two *Vega* probes to Venus. *Vega 1* and *Vega 2* encountered Venus in June 1985, each deploying a lander and an instrumented helium balloon. The balloon-borne aerostat probes floated at about 53 km altitude for 46 and 60 hours respectively, traveling about 1/3 of the way around the planet and allowing scientists to study the dynamics of the most active part of Venus's atmosphere. These measured wind speed, temperature, pressure and cloud density. More turbulence and convection activity than expected was discovered, including occasional plunges of 1 to 3 km in downdrafts.

The landing vehicles carried experiments focusing on cloud aerosol composition and structure. Each carried an ultraviolet absorption spectrometer, aerosol particle-size analyzers, and devices for collecting aerosol material and analyzing it with a mass spectrometer, a gas chromatograph, and an X-ray fluorescence spectrometer. The upper two layers of the clouds were found to be sulfuric acid droplets, but the lower layer is probably composed of phosphoric acid solution. The crust of Venus was analyzed with the soil drill experiment and a gamma ray spectrometer. As the landers carried no cameras on board, no images were returned from the surface. They would be the last probes to land on Venus for decades. The *Vega* spacecraft continued to rendezvous with Halley's Comet nine months later, bringing an additional 14 instruments and cameras for that mission.

Orbiters

Venera 15 and 16

In October 1983, *Venera 15* and *Venera 16* entered polar orbits around Venus. The images had a 1–2 kilometre (0.6–1.2 mile) resolution, comparable to those obtained by the best Earth radars. *Venera 15* analyzed and mapped the upper atmosphere with an infrared Fourier spectrometer. From November 11 to July 10, both satellites mapped the northern third of the planet with synthetic aperture radar. These results provided the first detailed understanding of the surface geology of Venus, including the discovery of unusual massive shield volcanoes such as coronae and arachnoids. Venus had no evidence of plate tectonics, unless the northern third of the planet happened to be a single plate. The altimetry data obtained by the Venera missions had a resolution four times better than *Pioneer'*s.



A portion of western Eistla Regio displayed in a three-dimensional perspective view acquired by the Magellan probe.

Magellan

On August 10, 1990, the US *Magellan* probe, named after the explorer Ferdinand Magellan, arrived at its orbit around the planet and started a mission of detailed radar mapping at a frequency of 2.38 GHz. Whereas previous probes had created low-resolution radar maps of continent-sized formations, *Magellan* mapped 98% of the surface with a resolution of approximately 100 m. The resulting maps were comparable to visible-light photographs of other planets, and are still the most detailed in existence. *Magellan* greatly improved scientific understanding of the geology of Venus: the probe found no signs of plate tectonics, but the scarcity of impact craters suggested the surface was relatively young, and there were lava channels thousands of kilometers long. After a four-year mission, *Magellan*, as planned, plunged into the atmosphere on October 11, 1994, and partly vaporized; some sections are thought to have hit the planet's surface.

Venus Express

Venus Express is a mission prepared by the European Space Agency to study the atmosphere and surface characteristics of Venus from orbit. The design is based on ESA's *Mars Express* and *Rosetta* missions. The probe's main objective is the long-term observation of the Venusian atmosphere, which it is hoped will also contribute to an understanding of Earth's atmosphere and climate. It will also make global maps of Venusian surface temperatures, and attempt to observe signs of life on Earth from a distance.

Venus Express successfully assumed a polar orbit on April 11, 2006 and has been continuously sending back science data. The mission was originally planned to last for two Venusian years (about 500 Earth days), but has been extended to the end of 2012. Some of the first results emerging from *Venus Express* include evidence of past oceans, the discovery of a huge double atmospheric vortex at the south pole, and the detection of hydroxyl in the atmosphere.

Akatsuki

Akatsuki was launched on May 20, 2010, by JAXA, and will enter Venusian orbit in December 2010. The probe will image the surface in ultraviolet, infrared, microwaves, and radio, and look for evidence of lightning and volcanism on the planet.

Recent flybys

Several space probes *en route* to other destinations have used flybys of Venus to increase their speed via the gravitational slingshot method. These include the *Galileo* mission to Jupiter and the *Cassini–Huygens* mission to Saturn (two flybys). Rather curiously, during *Cassini'*s examination of the radio frequency emissions of Venus with its radio and plasma wave science instrument during both the 1998 and 1999 flybys, it reported no high-frequency radio waves (0.125 to 16 MHz), which are commonly associated with lightning. This was in direct opposition to the findings of the Soviet *Venera* missions 20 years earlier. It was postulated that perhaps if Venus did have lightning, it might be some type of low-frequency electrical activity, due to the fact that radio signals cannot penetrate the ionosphere at frequencies below about 1 megahertz. At the University of Iowa, Donald Gurnett's examination of Venus's radio emissions by the *Galileo* spacecraft during its flyby in 1990 were interpreted at the time to be indicative of lightning. However the *Galileo* probe was over 60 times further from Venus than *Cassini* was during its flyby, making its observations substantially less significant. The mystery as to whether or not Venus does in fact have lightning in its atmosphere was not solved until 2007, when the scientific journal *Nature* published a series of papers giving the initial findings of *Venus Express*. It confirmed the presence of lightning on Venus and that it is more common on Venus than it is on Earth.

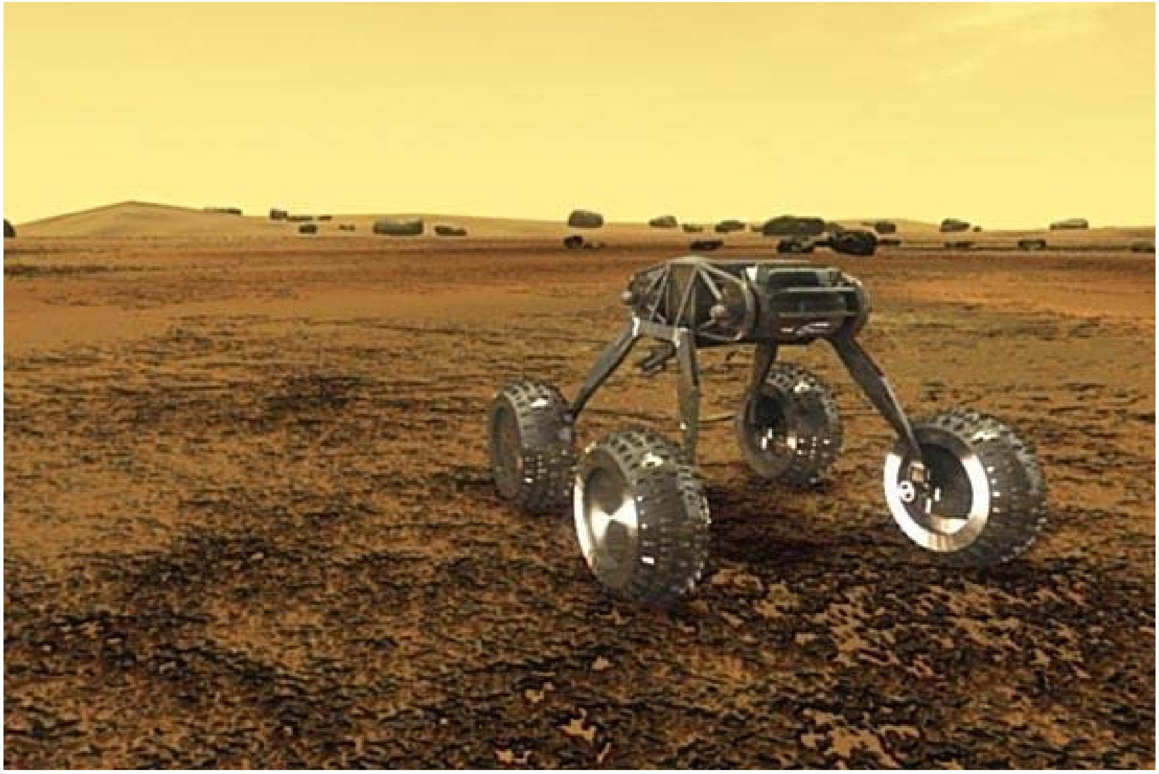
MESSENGER passed by Venus twice on its way to Mercury. The first time, it flew by on October 24, 2006, passing 3000 km from Venus. As Earth was on the other side of the Sun, no data was recorded. The second flyby was on July 6, 2007, where the spacecraft passed only 325 km from the cloudtops.

Future missions

Future flybys *en route* to other destinations include the *BepiColombo* mission to Mercury, and the *Solar Probe+* mission to the solar corona.

NASA has proposed the *Venus In-Situ Explorer* (*VISE*), to be launched in 2013. It would land and perform experiments on the surface of Venus, including taking a core sample and measuring its composition. ESA has proposed the *Venus Entry Probe* to be launched around the same time.

Also, the *Venera-D* spacecraft has been proposed by Roscosmos. It would be launched around 2016, and its prime purpose is to map Venus's surface using more powerful radar than *Magellan*. The mission would also include a lander capable of surviving for a long duration on the surface.



Artist's impression of a Stirling cooled Venus Rover

Proposals

To overcome the severely inhospitable surface conditions, a team led by Geoffrey Landis of NASA's Glenn Research Center in Ohio has proposed a Venus Rover mission that includes a tough surface rover in communication with a solar-powered aircraft. The aircraft would carry the mission's sensitive electronics in the relatively mild temperatures of Venus' upper atmosphere. Another more recent rover design proposal by Landis uses a Stirling cooler powered by a nuclear power source to keep an electronics package at a relatively comfortable 200°C (392°F)

Landis also makes a case for Venus as a target for human colonization. At 50 km above the surface, the temperature range is 0-50°C, the air pressure drops to 1 atmosphere, the gravity is 0.9 that of Earth, and the resources for life are plentiful.

Chapter- 2

Earth Observation Satellite and Exploration of Moon

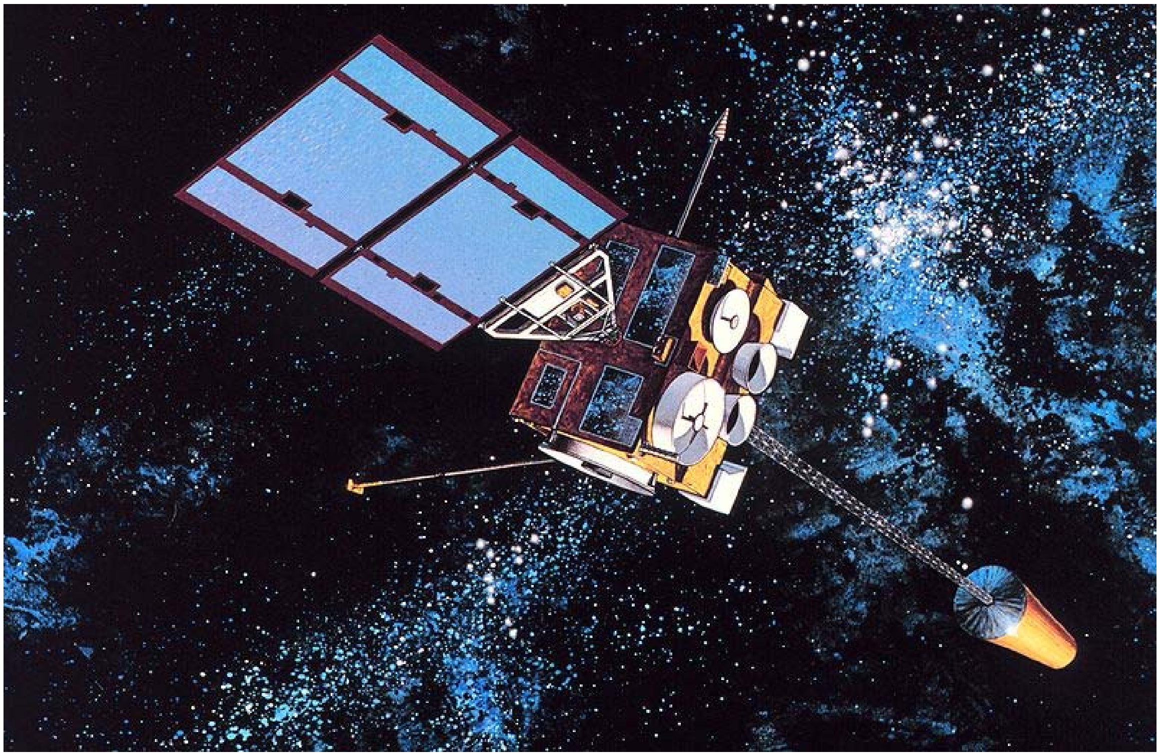
Earth Observation Satellite

The "marble" Earth picture taken by Apollo 17

An Earth observation satellite, ERS 2

Earth observation satellites are satellites specifically designed to observe Earth from orbit, similar to reconnaissance satellites but intended for non-military uses such as environmental monitoring, meteorology, map making etc. Geostationary satellites hover over the same spot, providing continuous monitoring to a portion of the Earth's surface. Polar orbiting satellites provide global coverage, but only twice per day at any given spot.

Weather



GOES-8, a United States weather satellite

A weather satellite is a type of satellite that is primarily used to monitor the weather and climate of the Earth. These meteorological satellites, however, more than clouds and cloud systems. City lights, fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, energy flows, etc., are other types of environmental information collected using weather satellites.

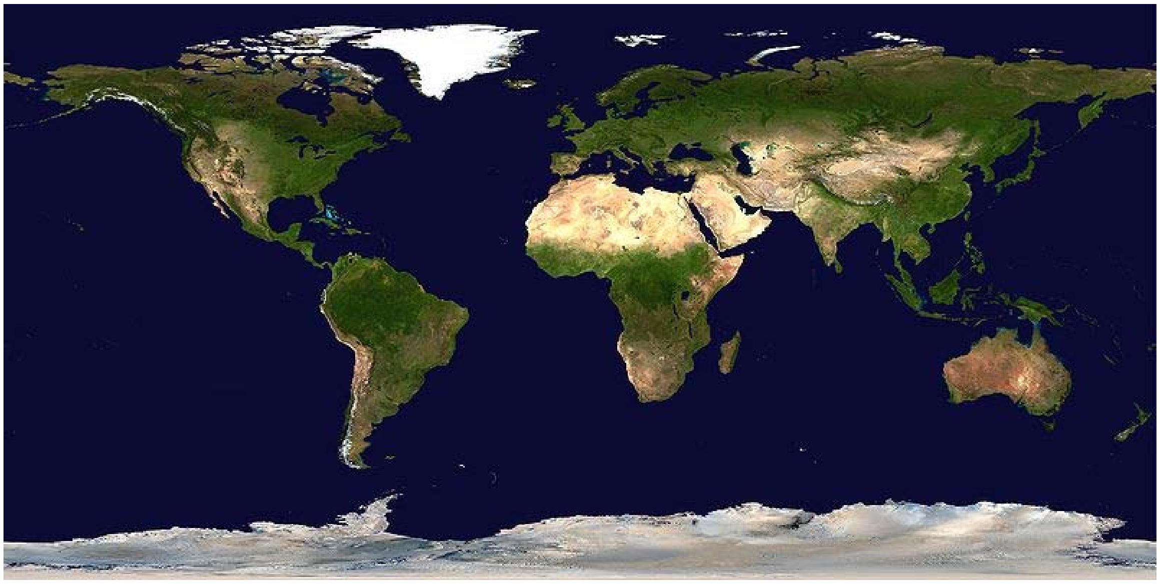
Weather satellite images helped in monitoring the volcanic ash cloud from Mount St. Helens and activity from other volcanoes such as Mount Etna. Smoke from fires in the western United States such as Colorado and Utah have also been monitored.

El Niño and its effects on weather are monitored daily from satellite images. The Antarctic ozone hole is mapped from weather satellite data. Collectively, weather satellites flown by the U.S., Europe, India, China, Russia, and Japan provide nearly continuous observations for a global weather watch. used via visible light and infrared rays of the electromagnetic spectrum.

Environmental monitoring

Other environmental satellites can assist environmental monitoring by detecting changes in the Earth's vegetation, sea state, ocean color, and ice fields. By monitoring vegetation changes over time, droughts can be monitored by comparing the current vegetation state to its long term average. For example, the 2002 oil spill off the northwest coast of Spain was watched carefully by the European ENVISAT, which, though not a weather satellite, flies an instrument (ASAR) which can see changes in the sea surface.

Mapping



A composite satellite image of the earth, showing its entire surface, both land and ocean, in Plate carrée projection.

Terrain can be mapped from space with the use of satellites, such as RADARSAT-1 and TerraSAR-X.

Exploration of Moon

Apollo 16 astronaut John Young

Apollo 12 lunar module *Intrepid* prepares to descend towards the surface of the Moon. *NASA photo.*

The physical **exploration of the Moon** began when Luna 2, a space probe launched by the Soviet Union, made an impact on the surface of the Moon on September 14, 1959. Prior to that the only available means of exploration had been observation. The invention of the optical telescope brought about the first leap in the quality of lunar observations. Galileo Galilei is generally credited as the first person to use a telescope for astronomical purposes; having made his own telescope in 1609, the mountains and craters on the lunar surface were among his first observations using it.

In 1969, NASA's Project Apollo first successfully landed people on the Moon. They placed scientific experiments there and returned rocks and data that suggested the Moon is of a similar composition to the Earth.

Early history

In Mesopotamia, Babylonian astronomers by the early first millennium BC had discovered a repeating 18-year cycle of lunar eclipses. They had also known by this time that 19 solar years is about equal to 235 lunar months. In the 2nd century BC, Seleucus of Seleucia correctly theorized that tides were caused by the Moon, although he believed that the interaction was mediated by the Earth's atmosphere. According to Strabo (1.1.9), Seleucus was the first to state that the tides are due to the attraction of the Moon, and that the height of the tides depends on the Moon's position relative to the Sun.

By the mid-first millennium BC, Indian astronomers described the Moon's monthly elongation in the *Aitareya Brāhmana*. By 499 AD, the Indian astronomer Aryabhata mentioned in his *Aryabhatiya* that reflected sunlight is the cause behind the shining of the moon.

Among the first in the Western world to offer a scientific explanation for the Moon was the Greek philosopher Anaxagoras (d. 428 BC), who reasoned that the Sun and Moon were both giant spherical rocks, and that the latter reflected the light of the former. His atheistic view of the heavens was one cause for his imprisonment and eventual exile. In Aristotle's (384–322 BC) description of the universe, the Moon marked the boundary between the spheres of the mutable elements (earth, water, air and fire), and the imperishable stars of aether. This separation was held to be part of Aristotelian physics for many centuries after. In the philosophy of Aristotle, the heavens, starting at the Moon, were the realm of perfection, the sublunary region was the realm of change and corruption, and any resemblance between these regions was strictly ruled out. Aristotle himself suggested that the Moon partook perhaps of some contamination from the realm of corruption. In his little book *On the Face in the Moon's Orb*, Plutarch expressed rather different views on the relationship between the Moon and Earth. He suggested that the Moon had deep recesses in which the light of the Sun did not reach and that the spots are nothing but the shadows of rivers or deep chasms. He also entertained the possibility that the Moon was inhabited. It had been suggested already in antiquity that the Moon was a perfect mirror and that its markings were reflections of earthly features, but this explanation was easily dismissed because the face of the Moon never changes as it moves about the Earth. The explanation that finally became standard was that there were variations of "density" in the Moon that caused this otherwise perfectly spherical body to appear the way it does. The perfection of the Moon, and therefore the heavens, was thus preserved. Aristarchus went a step further and computed the distance from Earth, together with its size, obtaining a value of 20 times the Earth radius for the distance (the real value is 60; the Earth radius was roughly known since Eratosthenes).

During the Warring States of China, astronomer Shi Shen (fl. 4th century BC) gave instructions for predicting solar and lunar eclipses based on the relative positions of the Moon and Sun. Although the Chinese of the Han Dynasty (202 BC–202 AD) believed the Moon to be energy equated to *qi*, their 'radiating influence' theory recognized that the light of the Moon was merely a reflection of the Sun (mentioned by Anaxagoras above). This was supported by mainstream thinkers such as Jing Fang (78–37 BC) and Zhang

Heng (78–139 AD), but it was also opposed by the influential philosopher Wang Chong (27–97 AD). Jing Fang noted the sphericity of the Moon, while Zhang Heng accurately described a lunar eclipse and solar eclipse. These assertions were supported by Shen Kuo (1031–1095) of the Song Dynasty (960–1279) who created an allegory equating the waxing and waning of the Moon to a round ball of reflective silver that, when doused with white powder and viewed from the side, would appear to be a crescent. He also noted that the reason for the Sun and Moon not eclipsing every time their paths met was because of a small obliquity in their orbital paths.

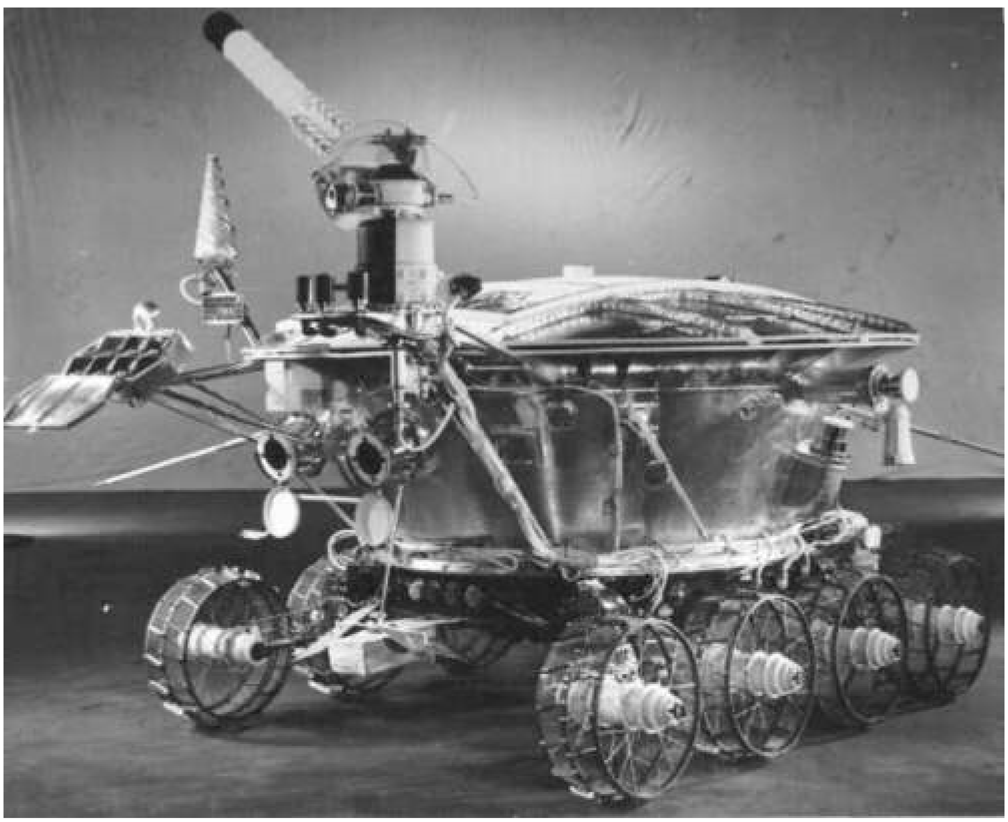
Habash al-Hasib al-Marwazi, a Persian astronomer, conducted various observations at the Al-Shammisiyyah observatory in Baghdad between 825 and 835 AD. Using these observations, he estimated the Moon's diameter as 3,037 km (equivalent to 1,519 km radius) and its distance from the Earth as 215,209 miles, which come close to the currently accepted values. In 1021, the Islamic physicist, Alhazen, accurately explained the Moon illusion in the *Book of Optics*, which stated that judging the distance of an object depends on there being an uninterrupted sequence of intervening bodies between the object and the observer. With the Moon, there are no intervening objects, therefore since the size of an object depends on its observed distance, which is in this case inaccurate, the Moon appears larger on the horizon. Through Alhazen's work, the Moon illusion gradually came to be accepted as a psychological phenomenon. He also investigated moonlight, which he proved through experimentation that it originates from sunlight and correctly concluded that it "emits light from those portions of its surface which the sun's light strikes."

By the Middle Ages, before the invention of the telescope, an increasing number of people began to recognise the Moon as a sphere, though many believed that it was "perfectly smooth". In 1609, Galileo Galilei drew one of the first telescopic drawings of the Moon in his book *Sidereus Nuncius* and noted that it was not smooth but had mountains and craters. Later in the 17th century, Giovanni Battista Riccioli and Francesco Maria Grimaldi drew a map of the Moon and gave many craters the names they still have today. On maps, the dark parts of the Moon's surface were called *maria* (singular *mare*) or seas, and the light parts were called *terrae* or continents.

The medieval followers of Aristotle, in the Islamic world and then in Christian Europe, tried to make sense of the lunar spots in Aristotelian terms. Thomas Harriot, as well as Galilei, drew the first telescopic representation of the Moon and observed it for several years. His drawings, however, remained unpublished. The first map of the Moon was made by the Belgian cosmographer and astronomer Michael Florent van Langren in 1645. Two years later a much more influential effort was published by Johannes Hevelius. In 1647 Hevelius published *Selenographia*, the first treatise entirely devoted to the Moon. Hevelius's nomenclature, although used in Protestant countries until the eighteenth century, was replaced by the system published in 1651 by the Jesuit astronomer Giovanni Battista Riccioli, who gave the large naked-eye spots the names of seas and the telescopic spots (now called craters) the name of philosophers and astronomers. In 1753 the Croatian Jesuit and astronomer Roger Joseph Boscovich discovered the absence of atmosphere on the Moon. In 1824 Franz von Gruithuisen explained the formation of craters as a result of meteorite strikes.

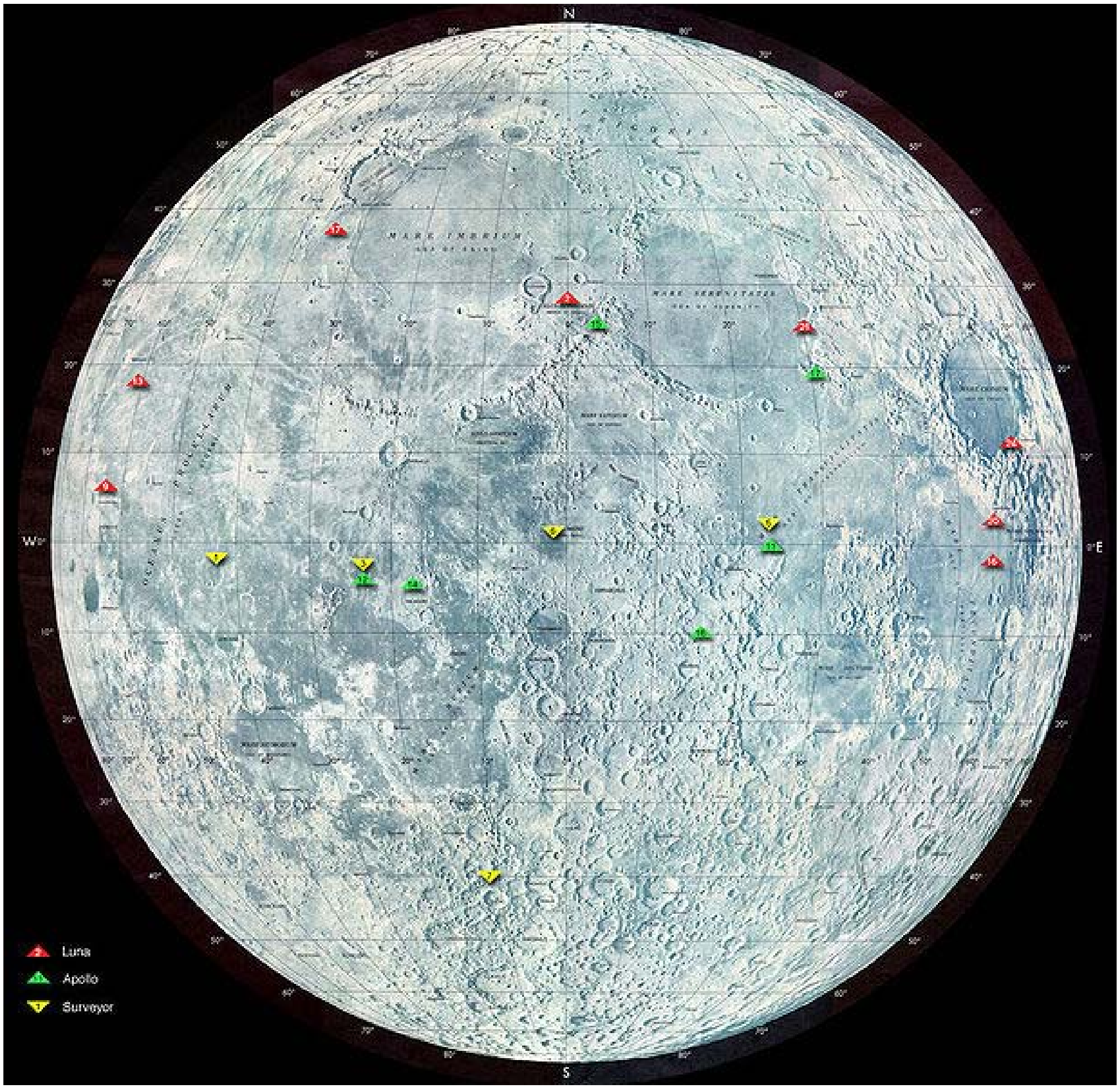
The possibility that the Moon contains vegetation and is inhabited by selenites was seriously considered by major astronomers even into the first decades of the 19th century. The contrast between the brighter highlands and darker maria create the patterns seen by different cultures as the Man in the Moon, the rabbit and the buffalo, among others. In 1835, the Great Moon Hoax fooled some people into thinking that there were exotic animals living on the Moon. Almost at the same time however (during 1834–1836), Wilhelm Beer and Johann Heinrich Mädler were publishing their four-volume *Mappa Selenographica* and the book *Der Mond* in 1837, which firmly established the conclusion that the Moon has no bodies of water nor any appreciable atmosphere.

Space race

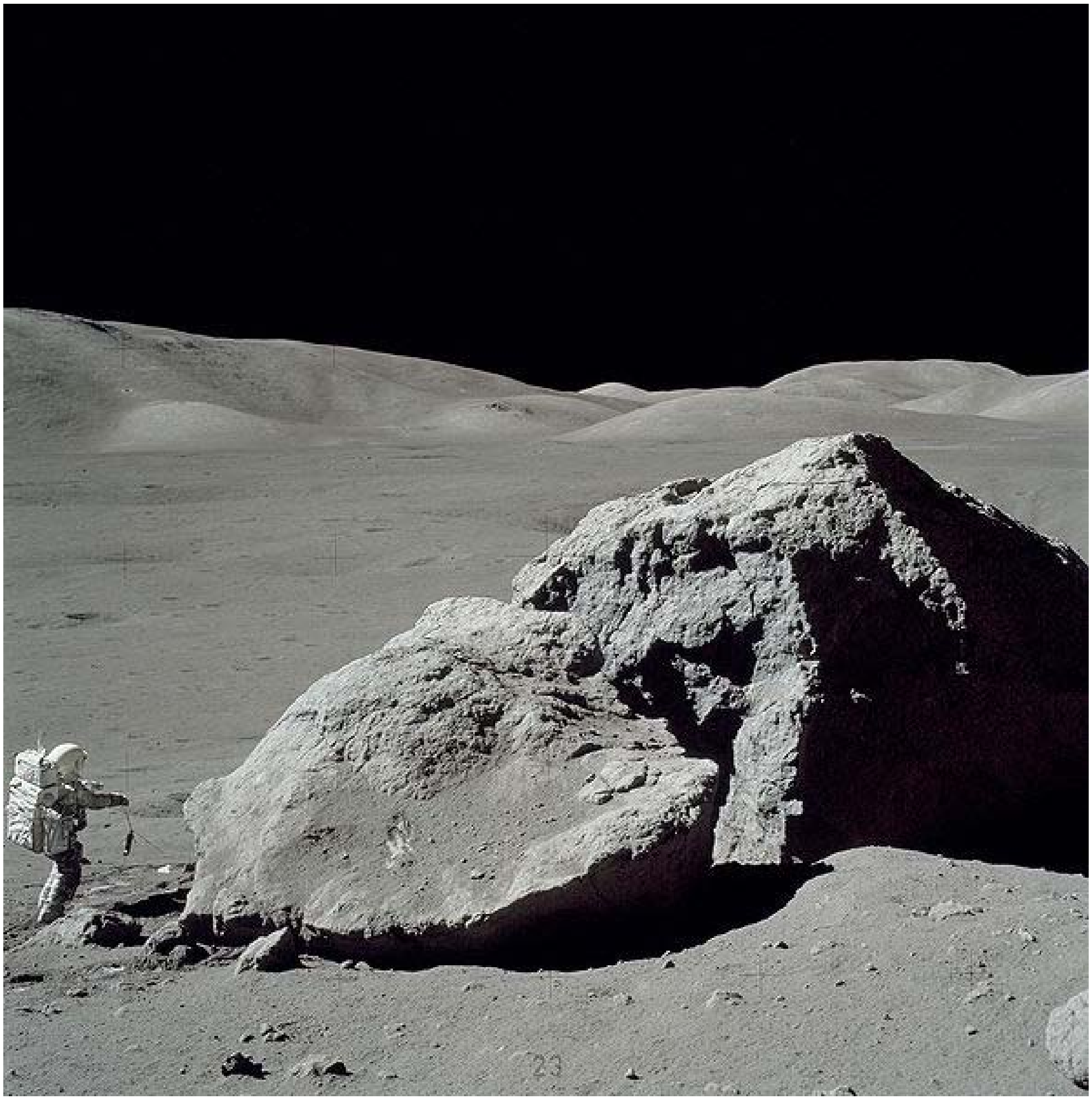


Lunokhod 1

The Cold War-inspired space race between the Soviet Union and the United States of America accelerated with a focus on the Moon. This included many scientifically important firsts, such as the first photographs of the then-unseen far side of the Moon in 1959 by the Soviet Union, and culminated with the landing of the first humans on the Moon in 1969, widely seen around the world as one of the pivotal events of the 20th century, and indeed of human history in general.



Landing map of Apollo, Surveyor and Luna missions



Apollo 17 astronaut Harrison Schmitt standing next to a boulder at Taurus-Littrow during the third EVA (extravehicular activity). *NASA photo.*

The first man-made object to reach the Moon was the unmanned Soviet probe Luna 2, which made a hard landing on September 14, 1959, at 21:02:24 Z. The far side of the Moon was first photographed on October 7, 1959 by the Soviet probe Luna 3. In an effort to compete with these Soviet successes, U.S. President John F. Kennedy proposed the national goal of landing a man on the Moon. Speaking to a Joint Session of Congress on May 25, 1961, he said

"First, 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 for the long-range exploration of space."

The Soviets nonetheless remained in the lead for some time. Luna 9 was the first probe to soft land on the Moon and transmit pictures from the Lunar surface on February 3, 1966. It was proven that a lunar lander would not sink into a thick layer of dust, as had been feared. The first artificial satellite of the Moon was the Soviet probe Luna 10 (launched March 31, 1966). One of the main impediments to human exploration of the Moon was development of adequate heat shield technology to permit atmospheric re-entry without completely burning up a manned spacecraft. The U.S. gained early supremacy in this field through NASA research in thermogravimetric experiments in hypersonic wind tunnels.

On December 24, 1968, the crew of Apollo 8, Frank Borman, James Lovell and William Anders, became the first human beings to enter lunar orbit and see the far side of the Moon with their own eyes. Humans first landed on the Moon on July 20, 1969. The first man to walk on the lunar surface was Neil Armstrong, commander of the U.S. mission *Apollo 11*. The first robot lunar rover to land on the Moon was the Soviet vessel Lunokhod 1 on November 17, 1970 as part of the Lunokhod program. To date, the last man to stand on the Moon was Eugene Cernan, who as part of the mission Apollo 17 walked on the Moon in December 1972.

Moon rock samples were brought back to Earth by three Luna missions (Luna 16, 20, and 24) and the Apollo missions 11 through 17 (excepting Apollo 13, which aborted its planned lunar landing).

From the mid-1960s to the mid-1970s there were 65 Moon landings (with 10 in 1971 alone), but after Luna 24 in 1976 they suddenly stopped. The Soviet Union started focusing on Venus and space stations and the U.S. on Mars and beyond.

Recent exploration

In 1990 Japan visited the Moon with the Hiten spacecraft, becoming the third country to place an object in orbit around the Moon. The spacecraft released the Hagoromo probe into lunar orbit, but the transmitter failed, thereby preventing further scientific use of the mission. In September 2007, Japan launched the SELENE spacecraft, with the objectives "to obtain scientific data of the lunar origin and evolution and to develop the technology for the future lunar exploration", according to the JAXA official website.

NASA launched the Clementine mission in 1994, and Lunar Prospector in 1998.

The European Space Agency launched a small, low-cost lunar orbital probe called SMART 1 on September 27, 2003. SMART 1's primary goal was to take three-dimensional X-ray and infrared imagery of the lunar surface. SMART 1 entered lunar orbit on November 15, 2004 and continued to make observations until September 3, 2006, when it was intentionally crashed into the lunar surface in order to study the impact plume.

The People's Republic of China has begun the Chang'e program for exploring the Moon and is investigating the prospect of lunar mining, specifically looking for the isotope helium-3 for use as an energy source on Earth. China launched the Chang'e 1 robotic lunar orbiter on October 24, 2007. Originally planned for a one-year mission, the Chang'e 1 mission was very successful and ended up being extended for another four months. On March 1, 2009, Chang'e 1 was intentionally impacted on the lunar surface completing the 16 month mission.

On October 1, 2010, China launched the Chang'e 2 lunar orbiter.

India's national space agency, Indian Space Research Organization (ISRO), launched Chandrayaan-1, an unmanned lunar orbiter, on October 22, 2008. The lunar probe was originally intended to orbit the Moon for two years, with scientific objectives to prepare a three-dimensional atlas of the near and far side of the Moon and to conduct a chemical and mineralogical mapping of the lunar surface. The unmanned Moon Impact Probe landed on the Moon at 15:04 GMT on November 14, 2008 making India the fourth country to touch down on the lunar surface. Among its many achievements was the discovery of the widespread presence of water molecules in lunar soil.

NASA launched a preliminary unmanned mission, the Lunar Reconnaissance Orbiter, on June 18, 2009. LRO will take high resolution imagery of the Moon's surface and carries the Lunar Crater Observation and Sensing Satellite (LCROSS), which will investigate the possible existence of water in Cabeus crater.

Future plans

The planned NASA Lunar Reconnaissance Orbiter

On January 14, 2004, US President George W. Bush announced the Vision for Space Exploration, a plan leading to new manned lunar missions by 2020. NASA's plan to accomplish that goal was announced on March 19, 2005, and was promptly dubbed "Apollo 2.0" by critics.

China plans to land the rover Chang'e 3 on the Moon in 2013, and to conduct a sample return mission in 2017.

India expects to launch another indigenous lunar mission by 2013 which would place a motorized rover on the surface of the Moon.

Japanese Aerospace Exploration Agency (JAXA) plans a manned lunar landing around 2020 that would lead to a manned lunar base by 2030; however, there is no budget yet for this project. This is highly unlikely to happen.

Russia also announced to resume its previously frozen project Luna-Glob, an unmanned lander and orbiter, which is slated to launch in 2012.

Germany also announced in March 2007 that it will launch a national lunar orbiter, LEO in 2012. however the mission was cancelled due to budgetary constraints.

In August 2007, NASA stated that all future missions and explorations of the Moon will be done entirely using the metric system. This was done to improve cooperation with space agencies of other countries which already use the metric system.

The European Space Agency has also announced its intention to send a manned mission to the Moon, as part of the Aurora programme. In September 2010 the agency introduces a "Lunar lander" programme with a target of autonomous mission to the moon in 2018.

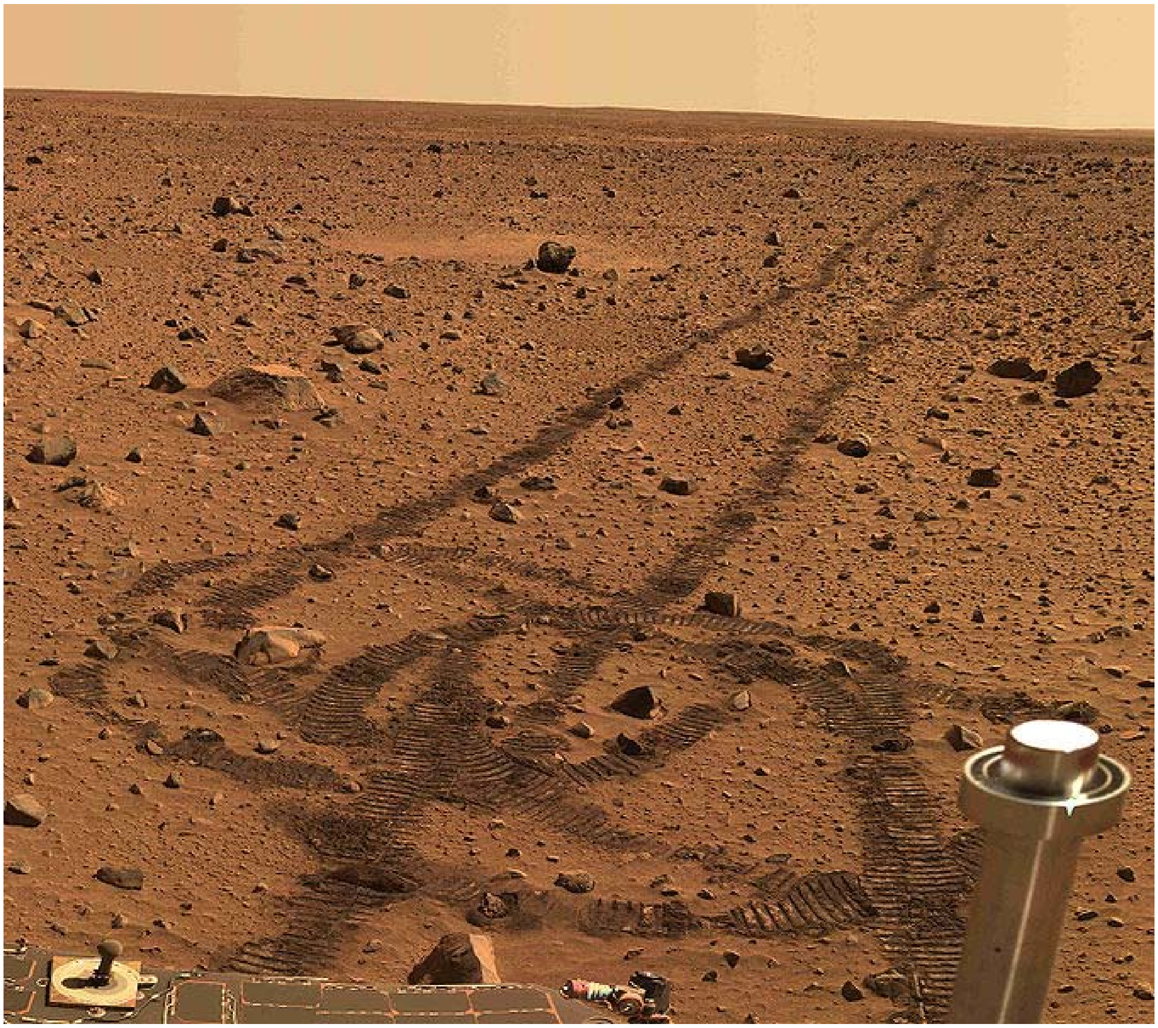
On September 13, 2007, the X Prize Foundation, in concert with Google, Inc., announced the Google Lunar X Prize. This contest requires competitors "to land a privately funded robotic rover on the Moon that is capable of completing several mission objectives, including roaming the lunar surface for at least 500 meters and sending video, images and data back to the Earth."

Chapter- 3

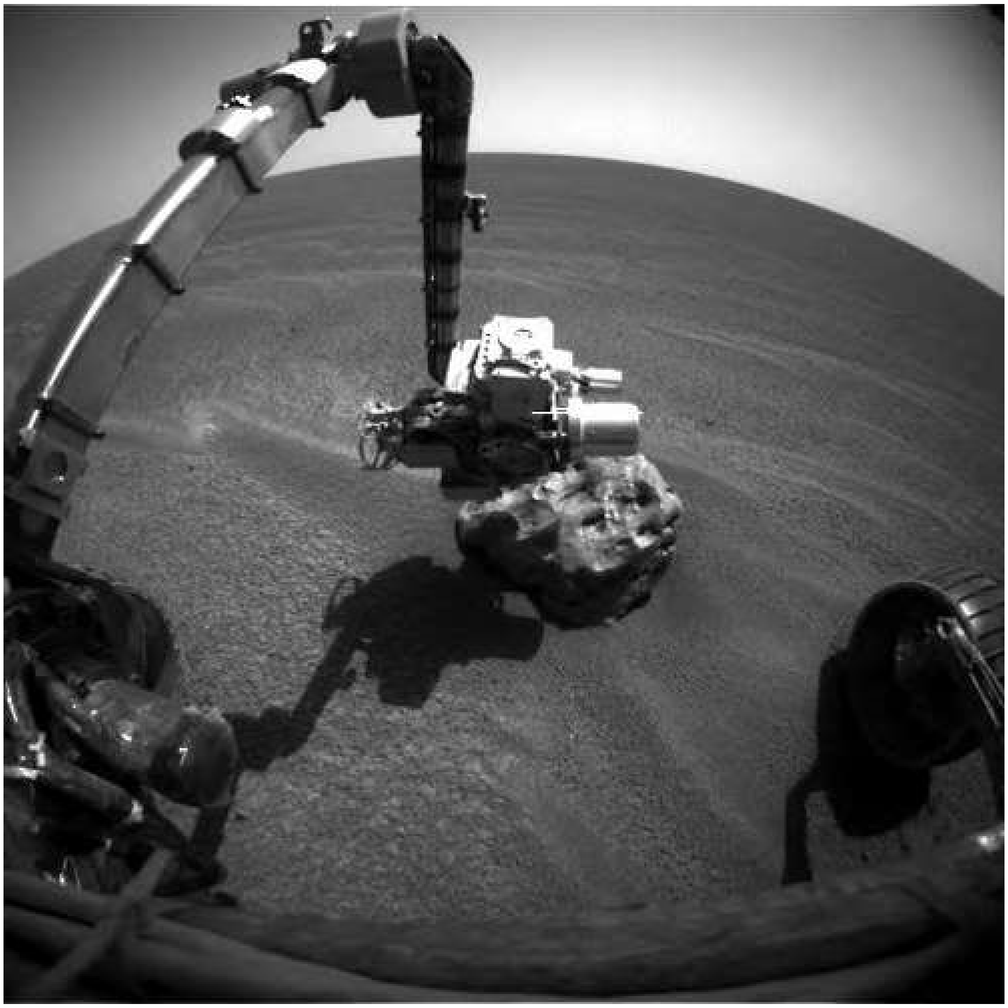
Exploration of Mars

Mars as seen by the HST

Computer-generated image of Spirit Mars Exploration Rover which touched down in Gusev Crater in 2004.



Real image from Mars, part of a panorama taken by the Spirit rover in 2004



Heat Shield Rock (Meridiani Planum) is examined by Opportunity rover (MER-B) in 2005

The **exploration of Mars** has been an important part of the space exploration programs of the Soviet Union, the United States, Europe, and Japan. Dozens of robotic spacecraft, including orbiters, landers, and rovers, have been launched toward Mars since the 1960s. These missions were aimed at gathering data about current conditions and answering questions about the history of Mars as well as a preparation for a possible human mission to Mars. The questions raised by the scientific community are expected to not only give a better appreciation of the red planet but also yield further insight into the past, and possible future, of Earth.

The exploration of Mars has come at a considerable financial cost with roughly two-thirds of all spacecraft destined for Mars failing before completing their missions, with some failing before they even begin. Such a high failure rate can be attributed to the complexity and large number of variables involved in an interplanetary journey, and has led researchers to jokingly speak of *The Great Galactic Ghoul* which subsists on a diet of Mars probes. This phenomenon is also informally known as the *Mars Curse*. As of

January 2010, there are two functioning pieces of equipment on the surface of Mars beaming signals back to Earth: the Spirit rover and the Opportunity rover.

In October 2009, an agreement was signed between United states' space agency, NASA, and Europe's space agency, ESA in order to increase cooperation and expand collective capabilities, resources and expertise to continue the exploration of Mars; this agreement is named the Mars Joint Exploration Initiative (MEJI).

The planet Mars

Mars has long been the subject of human fascination. Early telescopic observations revealed color changes on the surface which were originally attributed to seasonal vegetation as well as apparent linear features which were ascribed to intelligent design. These early and erroneous interpretations led to widespread public interest in Mars. Further telescopic observations found Mars' two moons - Phobos and Deimos, the polar ice caps and the feature now known as Olympus Mons, the solar system's tallest mountain. These discoveries piqued further interest in the study and exploration of the red planet. Mars is a rocky planet, like Earth, that formed around the same time, yet with only half the diameter of Earth, and a far thinner atmosphere, it has a cold and desert-like surface. It is notable, however, that although the planet has only one quarter of the *surface area* of the Earth, it has about the same *land area*, since only one quarter of the surface area of the Earth is land.

Launch windows

In order to understand the history of the robotic exploration of Mars it is important to note that minimum-energy launch windows occur at intervals of approximately 2.135 years, i.e. 780 days (the planet's synodic period with respect to Earth). This is a consequence of the Hohmann transfer orbit for minimum-energy interplanetary transfer. The slight inclination and eccentricity of Mars' orbit relative to Earth's orbit means that the minimum energy launch date differs from that implied by the synodic period slightly. Launch window width is subject to vehicle constraints but are typically on the order of one month wide. The windows for recent/future years were/will be centred on the following dates:

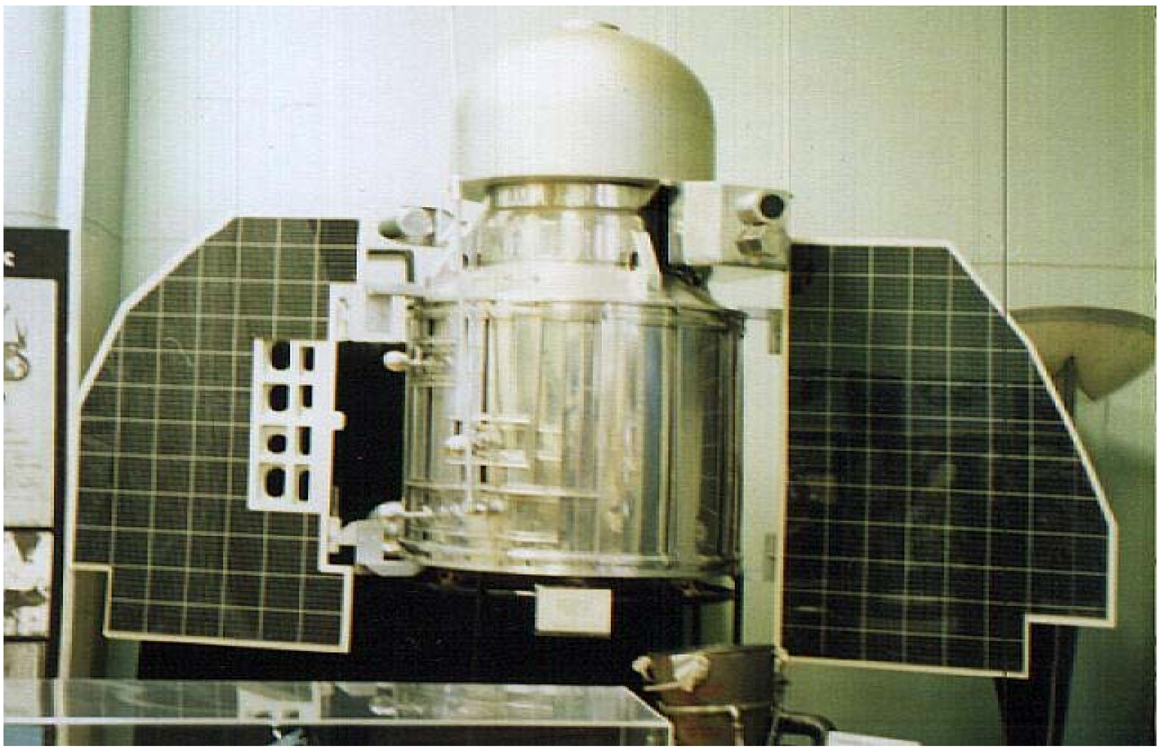
- 18 November 1996 (MJD 50405)
- 22 January 1999 (MJD 51200)
- 19 April 2001 (MJD 52018)
- 5 June 2003 (MJD 52795)
- 10 August 2005 (MJD 53592)
- 21 September 2007 (MJD 54364)
- 15 October 2009 (MJD 55119)
- 7 November 2011 (MJD 55872)
- 2 January 2014 (MJD 56659)

Minimum energy inbound (Mars to Earth) launch windows also occur at similar intervals.

In addition to these minimum-energy trajectories, which occur when the planets are aligned so that the Earth to Mars transfer trajectory goes halfway around the Sun, an alternate trajectory which has been proposed goes first inward toward Venus orbit, and then outward, resulting in a longer trajectory which goes about 360 degrees around the Sun ("opposition-class trajectory").

Early flyby probes and orbiters

Early Soviet missions



Marsnik spacecraft

The Marsnik program was the first Soviet unmanned spacecraft interplanetary exploration program, which consisted of two flyby probes launched towards Mars in October 1960, Marsnik 1 and 2 dubbed Mars 1960A and Mars 1960B (also known as *Korabl 4* and *Korabl 5* respectively). After launch, the third stage pumps on both Marsnik launchers were unable to develop enough thrust to commence ignition, so Earth parking orbit was not achieved. The spacecraft reached an altitude of 120 km before reentry.

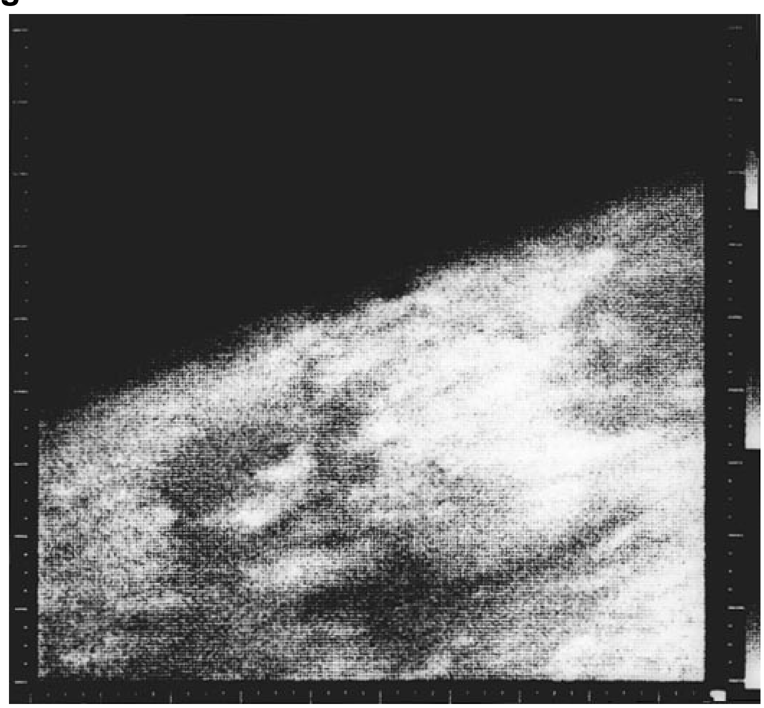
Mars 1962A was a Mars fly-by mission, launched on October 24, 1962 and Mars 1962B a lander mission, launched in late December of the same year both failed from either breaking up as they were going into Earth orbit or having the upper stage explode in orbit during the burn to put the spacecraft into the Mars trajectory.

Mars 1 (1962 Beta Nu 1) an automatic interplanetary station launched to Mars on November 1, 1962 was the first probe of the Soviet Mars probe program. Mars 1 was intended to fly by the planet at a distance of about 11,000 km and take images of the surface as well as send back data on cosmic radiation, micrometeoroid impacts and Mars' magnetic field, radiation environment, atmospheric structure, and possible organic compounds. Sixty-one radio transmissions were held, initially at two day intervals and later at 5 days in which a large amount of interplanetary data was collected. On 21 March 1963, when the spacecraft was at a distance of 106,760,000 km from Earth, on its way to Mars, communications ceased, due to failure of the spacecraft's antenna orientation system.

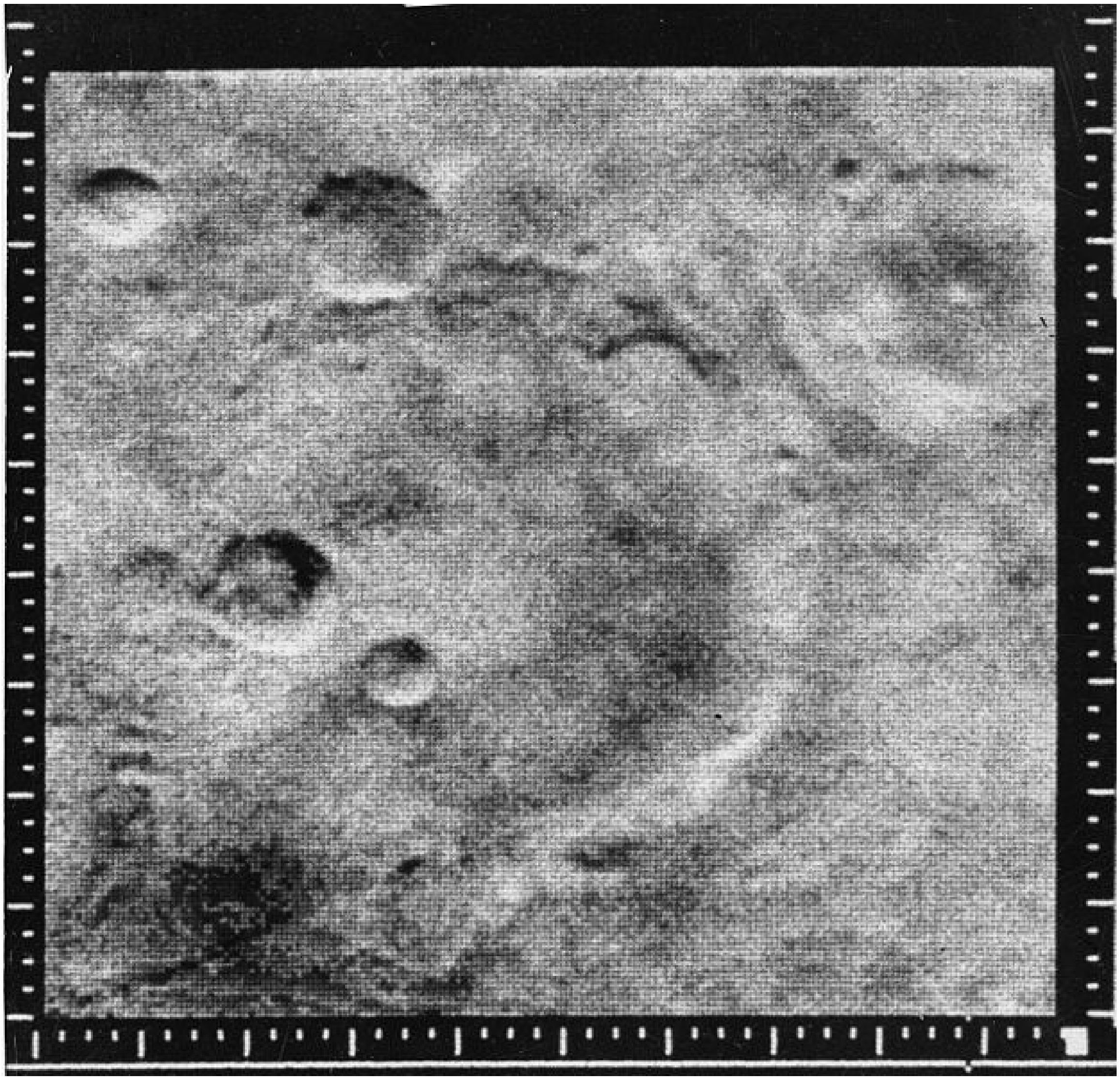
In 1964, both Soviet probe launches, of Zond 1964A on June 4, and Zond 2 on November 30, (part of the Zond program), resulted in failures. Zond 1964A had a failure at launch, while communication was lost with Zond 2 en route to Mars after a mid-course maneuver, in early May 1965.

The USSR intended to have the first artificial satellite of Mars beating the planned American Mariner 8 and Mariner 9 martian orbiters. But on May 5, 1971 Cosmos 419 (Mars 1971C), a heavy probe of the Soviet Mars program M-71, failed on launch. This spacecraft was designed as an orbiter only, while the second and third probes of project M-71, Mars 2 and Mars 3, were multi-aimed combinations of orbiter and lander.

Mariner program



The first close-up images taken of Mars in 1965 from Mariner 4 show an area about 330 km across by 1200 km from limb to bottom of frame.



Mariner Crater, as seen by Mariner 4. The location is Phaethontis quadrangle.

In 1964, NASA's Jet Propulsion Laboratory made two attempts at reaching Mars. Mariner 3 and Mariner 4 were identical spacecraft designed to carry out the first flybys of Mars. Mariner 3 was launched on November 5, 1964, but the shroud encasing the spacecraft atop its rocket failed to open properly, and it failed to reach Mars. Three weeks later, on November 28, 1964, Mariner 4 was launched successfully on a 7½-month voyage to the red planet.

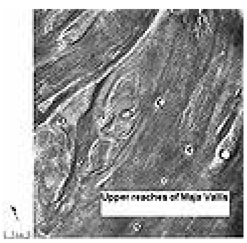
Mariner 4 flew past Mars on July 14, 1965, providing the first close-up photographs of another planet. The pictures, gradually played back to Earth from a small tape recorder on the probe, showed lunar-type impact craters.

NASA continued the Mariner program with another pair of Mars flyby probes, Mariner 6 and 7, at the next launch window. These probes reached the planet in 1969. During the following launch window the Mariner program again suffered the loss of one of a pair of probes. Mariner 9 successfully entered orbit about Mars, the first spacecraft ever to do so, after the launch time failure of its sister ship, Mariner 8. When Mariner 9 reached Mars, it and two Soviet orbiters found that a planet-wide dust storm was in progress. The mission controllers used the time spent waiting for the storm to clear to have the probe rendezvous with, and photograph, Phobos. When the storm cleared sufficiently for Mars' surface to be photographed by Mariner 9, the pictures returned represented a substantial advance over previous missions. These pictures were the first to offer evidence that liquid water might at one time have flowed on the planetary surface.

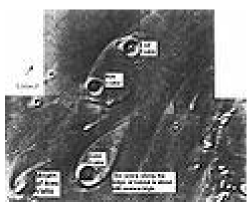
Viking program

The Viking Orbiters caused a revolution in our ideas about water on Mars. Huge river valleys were found in many areas. They showed that floods of water broke through dams, carved deep valleys, eroded grooves into bedrock, and traveled thousands of kilometers. Areas of branched streams, in the southern hemisphere, suggested that rain once fell.

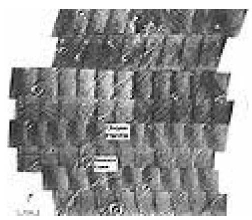
The images below, some of the best from the Viking Orbiters, are mosaics of many small, high resolution images.



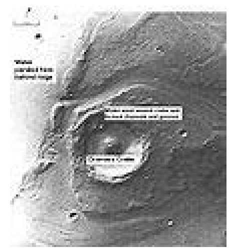
Streamlined Islands seen by Viking showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.



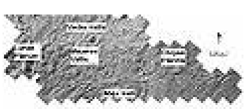
Tear-drop shaped islands caused by flood waters from Maja Valles, as seen by Viking Orbiter. Image is located in Oxia Palus quadrangle. The islands are formed in the ejecta of Lod Crater, Bok Crater, and Gold Crater.



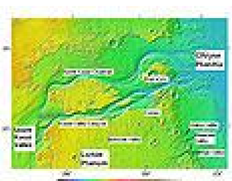
Scour Patterns, located in Lunae Palus quadrangle, were produced by flowing water from Maja Vallis, which lies just to the left of this mosaic. Detail of flow around Dromore Crater is shown on the next image.



Great amounts of water were required to carry out the erosion shown in this Viking image. Image is located in Lunae Palus quadrangle. The erosion shaped the ejecta around Dromore Crater.

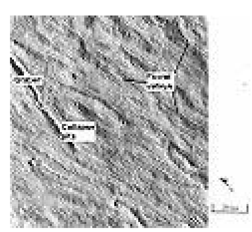


Waters from Vedra Vallis, Maumee Vallis, and Maja Vallis went from



Area around Northern Kasei Valles,

The ejecta from



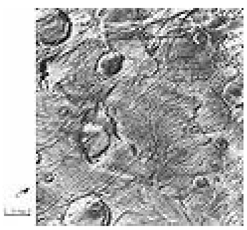
This view of the flank

Lunae Planum on the left, to Chryse Planitia on the right. Image is located in Lunae Palus quadrangle and was taken by Viking Orbiter.

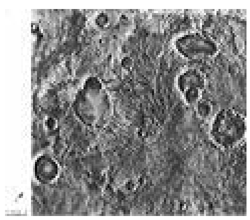
showing relationships among Kasei Valles, Bahram Vallis, Vedra Vallis, Maumee Vallis, and Maja Valles. Map location is in Lunae Palus quadrangle and includes parts of Lunae Planum and Chryse Planitia.

Arandas Crater acts like mud. It moves around small craters (indicated by arrows), instead of just falling down on them. Craters like this suggest that large amounts of frozen water were melted when the impact crater was produced. Image is located in Mare Acidalium quadrangle and was taken by Viking Orbiter.

of Alba Patera shows several chnnels/troughs. Some channels are associated with lava flows; others are probably caused by running water. A large trough or graben turns into a line of collapse pits. Image is located in Arcadia quadrangle and was taken by Viking Orbiter.



Branched channels in Thaumasia quadrangle, as seen by Viking Orbiter. Networks of channels like this are strong evidence for rain on Mars in the past.

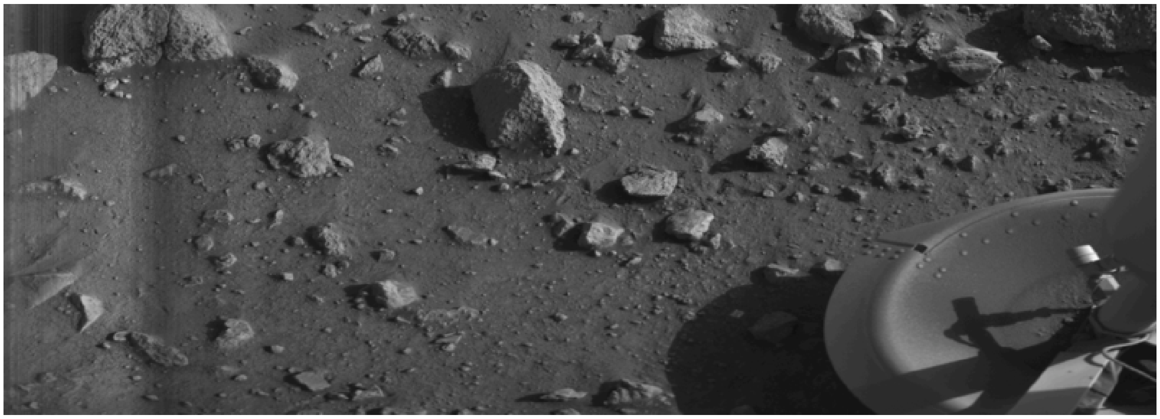


The branched channels seen by Viking from orbit strongly suggested that it rained on Mars in the past. Image is located in Margaritifer Sinus quadrangle.

Ravi Vallis, as seen by Viking Orbiter. Ravi Vallis was probably formed when catastrophic floods came out of the ground to the right (chaotic terrain). Image located in Margaritifer Sinus quadrangle.

Surface missions

The following is a map of landings on Mars.



The first image transmitted by the Viking 1 Lander from the surface of Mars, showing the craft's footpad.

The Soviet Union intended to beat the USA by sending landers first in the Mars probe program M-69 in 1969, but both probes of the new heavy 5-ton design, Mars 1969A and Mars 1969B, failed at launch.

The first probes to impact and land on Mars were the Soviet Union's Mars 2 and Mars 3, as part of the Mars probe program M-71 in 1971. Each carried a lander. The Mars 2 lander crashed; Mars 3 was the first successful lander but stopped transmitting data and images from the surface after 22 seconds of operation.

Mars 6 and Mars 7 landers on the next Soviet Mars probe program M-73 failed their missions; the first impacted on the surface while the second missed the planet.

The first landers to successfully accomplish their missions were the American Viking 1 and Viking 2.

Mars Curse

The high failure rate of missions launched from Earth attempting to explore Mars has become informally known as the "Mars Curse". The "Galactic Ghoul" is a fictional space monster that consumes Mars probes, a term coined in 1997 by Time Magazine journalist Donald Neff.

Of 38 launches from Earth in an attempt to reach the planet, only 19 succeeded, a success rate of 50%. Twelve of the missions included attempts to land on the surface, but only seven transmitted data after landing.

The majority of the failed missions occurred in the early years of space exploration and were part of the Soviet and later Russian Mars probe program that suffered several technical difficulties, other than the largely successful Venera program for the exploration of Venus.

Modern missions have an improved success rate; however, the challenge, complexity and length of the missions make it inevitable that failures will occur.

The U.S. NASA Mars exploration program has had a somewhat better record of success in Mars exploration, achieving success in 13 out of 20 missions launched (a 65% success rate), and succeeding in six out of seven (an 86% success rate) of the launches of Mars landers.

Manned missions

Many people have long advocated a manned mission to Mars as the next logical step for a manned space program after lunar exploration. Aside from the prestige such a mission would bring, advocates argue that humans would easily be able to outperform robotic explorers, justifying the expenses. Critics contend, however, that robots can perform better than humans at a fraction of the expense. A list of hypothetical or proposed manned Mars missions proposals is located at manned mission to Mars.

Timeline of Mars exploration

Mission (1960–1969)	Launch	Arrival at Mars	Termination	Objective	Result
Marsnik 1 (Mars 1960A)	10 October 1960		10 October 1960	Flyby	Launch failure
Marsnik 2 (Mars 1960B)	14 October 1960		14 October 1960	Flyby	Launch failure
Sputnik 22 (Mars 1962A)	24 October 1962		24 October 1962	Flyby	Broke up shortly after launch
Mars 1	1 November 1962		21 March 1963	Flyby	Some data collected, but lost contact before reaching Mars
Sputnik 24 (Mars 1962B)	4 November 1962		19 January 1963	Lander	Failed to leave Earth's orbit
Mariner 3	5 November 1964		5 November 1964	Flyby	Failure during launch ruined trajectory.
Mariner 4	28 November 1964	14 July 1965	21 December 1967	Flyby	Success (first successful flyby)

Zond 2	30 November 1964		May 1965	Flyby	Lost contact
Mariner 6	25 February 1969	31 July 1969	August 1969	Flyby	Success
Mariner 7	27 March 1969	5 August 1969	August 1969	Flyby	Success
Mars 1969A	27 March 1969		27 March 1969	Orbiter	Launch failure
Mars 1969B	2 April 1969		2 April 1969	Orbiter	Launch failure

Mission (1970–1989)	**Launch**	**Arrival at Mars**	**Termination**	**Objective**	**Result**
Mariner 8	8 May 1971		8 May 1971	Orbiter	Launch failure
Cosmos 419 (Mars 1971C)	10 May 1971		12 May 1971	Orbiter	Launch failure
Mariner 9	30 May 1971	13 November 1971	27 October 1972	Orbiter	Success (first successful orbit)
Mars 2	19 May 1971	27 November 1971	22 August 1972	Orbiter	Success
			27 November 1971	Lander / rover	Crashed on surface of Mars
			22 August 1972	Orbiter	Success
Mars 3	28 May 1971	2 December 1971	2 December 1971	Lander / rover	Partial Success. First successful landing; landed softly, but ceased transmission within 15 seconds.
Mars 4	21 July 1973	10 February 1974	10 February 1974	Orbiter	Did not enter orbit, but made a close flyby
Mars 5	25 July 1973	2 February 1974	21 February 1974	Orbiter	Partial success. Entered orbit, and returned data, but failed within 9 days

Mars 6	5 August 1973	12 March 1974	12 March 1974	Lander	Partial success. Data returned during descent, but not after landing on Mars
Mars 7	9 August 1973	9 March 1974	9 March 1974	Lander	Landing probe separated prematurely; entered heliocentric orbit.
Viking 1	20 August 1975	20 July 1976	17 August 1980	Orbiter	Success
			13 November 1982	Lander	Success
Viking 2	9 September 1975	3 September 1976	25 July 1978	Orbiter	Success
			11 April 1980	Lander	Success
Phobos 1	7 July 1988		2 September 1988	Orbiter	Contact lost while on route to Mars
				lander	Not deployed
Phobos 2	12 July 1988	29 January 1989	27 March 1989	Orbiter	Partial success: entered orbit and returned some data. Contact lost just before deployment of landers
				Landers	Not deployed

Mission (1990–1999)	Launch	Arrival at Mars	Termination	Objective	Result
Mars Observer	25 September 1992	24 August 1993	21 August 1993	Orbiter	Lost contact just before arrival
Mars Global Surveyor	7 November 1996	11 September 1997	5 November 2006	Orbiter	Success
Mars 96	16 November 1996		17 November 1996	Orbiter / landers	Launch failure
Mars	4	4 July	27	Lander / rover	Success

Pathfinder	December 1996	1997	September 1997		
Nozomi (Planet-B)	3 July 1998		9 December 2003	Orbiter	Complications while on route; Never entered orbit
Mars Climate Orbiter	11 December 1998	23 September 1999	23 September 1999	Orbiter	Crashed on surface due to metric-imperial mix-up
Mars Polar Lander	3 January 1999	3 December 1999	3 December 1999	Lander	Crash landed on surface due to improper hardware testing
Deep Space 2 (DS2)				Hard landers	

Mission (2000–present)	**Launch**	**Arrival at Mars**	**Termination**	**Objective**	**Result**
2001 Mars Odyssey	7 April 2001	24 October 2001	Currently operational	Orbiter	Success
Mars Express			Currently operational	Orbiter	Success
Beagle 2	2 June 2003	25 December 2003	6 February 2004	Lander	Lost contact in December 2003 after separation from Mars Express. Fate unknown.
MER-A Spirit	10 June 2003	4 January 2004	Currently operational, stuck	Rover	Success
MER-B Opportunity	7 July 2003	25 January 2004	Currently operational	Rover	Success
Rosetta	2 March 2004	February 25, 2007	Currently operational	Gravity assist enroute to comet 67P/Churyumov-Gerasimenko	Success
Mars Reconnaissance Orbiter	12 August 2005	10 March 2006	Currently operational	Orbiter	Success
Phoenix	4 August 2007	25 May 2008	10 November 2008	Lander	Success
Dawn	27 September	Feb. 17, 2009	Currently operational	Gravity assist to Vesta	(Successful launch;

	2007				successful to date)

Future missions	Launch schedule	Estimated arrival at Mars	—	Objective	Notes
Phobos-Grunt	2012			Orbiter, lander, sample return	Will attempt to bring samples of Phobos' soil back to Earth in 2014 (*or* 2012).
Yinghuo-1				Orbiter	Will travel with the Russian Phobos-Grunt mission
MSL Curiosity	15 September 2011	2012		Rover	Powered by radioisotopes, it will perform chemical and physical analysis on martian soil and atmosphere.
MetNet	2011–2019			Multi-lander network	Simultaneous meteorological measurements at multiple locations.
Northern Light	2012			Lander / rover	Solar powered, it will perform chemical and physical analysis on Martian soil and atmosphere.
MAVEN	2013			Orbiter	Part of the Mars Scout Program
Mars mission	Between 2013-2015			Orbiter	The ISRO has begun the conceptual phase for an orbiter mission to Mars.
ARES (martian	Possibly by 2016			aircraft	Search for life on Mars, water,

rocketplane)			atmospherics, magnetics
and ExoMars	2016	Orbiter, static lander	TGM orbiter will deliver the ExoMars static lander.
	2018	Two rovers	ExoMars rover and MAX-C rover.
and Mars sample return mission	Possibly by 2020	Orbiter, lander, rover, sample return	Being considered but not yet funded or scheduled.

Phobos

The Russian space mission Phobos-Grunt, Scheduled to launch in 2011, will begin exploration of the Phobos and Martian circumterrestrial orbit, and study whether the moons of Mars, or at least Phobos, could be a "trans-shipment point" for spaceships travelling to Mars.

Chapter- 4

Exploration of Jupiter

Jupiter as seen by the space probe *Cassini*. This is the most detailed global color portrait of Jupiter ever assembled.

The **exploration of Jupiter** has to date been conducted via close observations by automated spacecraft. It began with the arrival of *Pioneer 10* into the Jovian system in 1973, and, as of 2008, has continued with seven further spacecraft missions. All of these missions were undertaken by NASA, and all save one have been flybys that take detailed observations without the probe landing or entering orbit. These probes make Jupiter the most visited of the Solar System's outer planets. Plans for more missions to the Jovian system are under development, none of which are scheduled to arrive at the planet before 2016. Sending a craft to Jupiter entails many technical difficulties, especially due to the probes' large fuel requirements and the effects of the planet's harsh radiation environment.

The first spacecraft to visit Jupiter was *Pioneer 10* in 1973, followed a few months later by *Pioneer 11*. Aside from taking the first close-up pictures of the planet, the probes discovered its magnetosphere and its largely fluid interior. The *Voyager 1* and *Voyager 2* probes visited the planet in 1979, and studied its moon and the ring system, discovering the volcanic activity of Io and the presence of water ice on the surface of Europa. *Ulysses* further studied Jupiter's magnetosphere in 1992 and then again in 2000. The *Cassini* probe approached the planet in 2000 and took very detailed images of its atmosphere. The *New Horizons* spacecraft passed by Jupiter in 2007 and made improved measurements of its and its satellites' parameters.

The *Galileo* spacecraft is the only one to have actually entered an orbit around Jupiter, arriving in 1995 and studying the planet until 2003. During this period *Galileo* gathered a large amount of information about the Jovian system, making close approaches to all of the four giant Galilean moons and finding evidence for thin atmospheres on three of them, as well as the possibility of liquid water beneath their surfaces. It also discovered a magnetic field around Ganymede. As it approached Jupiter, it also witnessed the impact of Comet Shoemaker-Levy 9. In December 1995, it sent an atmospheric probe into the Jovian atmosphere, so far the only craft to do so.

Future probes planned by NASA include the Juno spacecraft, due to launch in 2011, which will enter a polar orbit around Jupiter to determine whether it possesses a rocky core, and the Europa Jupiter System Mission, due to launch sometime around 2020, which will engage in an extended study of the planets moon system, particularly Europa and Ganymede, and settle the long-running scientific debate over whether an ocean of liquid water exists under Europa's icy surface. Some NASA administrators have even speculated as to the possibility of manned exploration of Jupiter, but such missions are not considered feasible with current technology.

Technical requirements

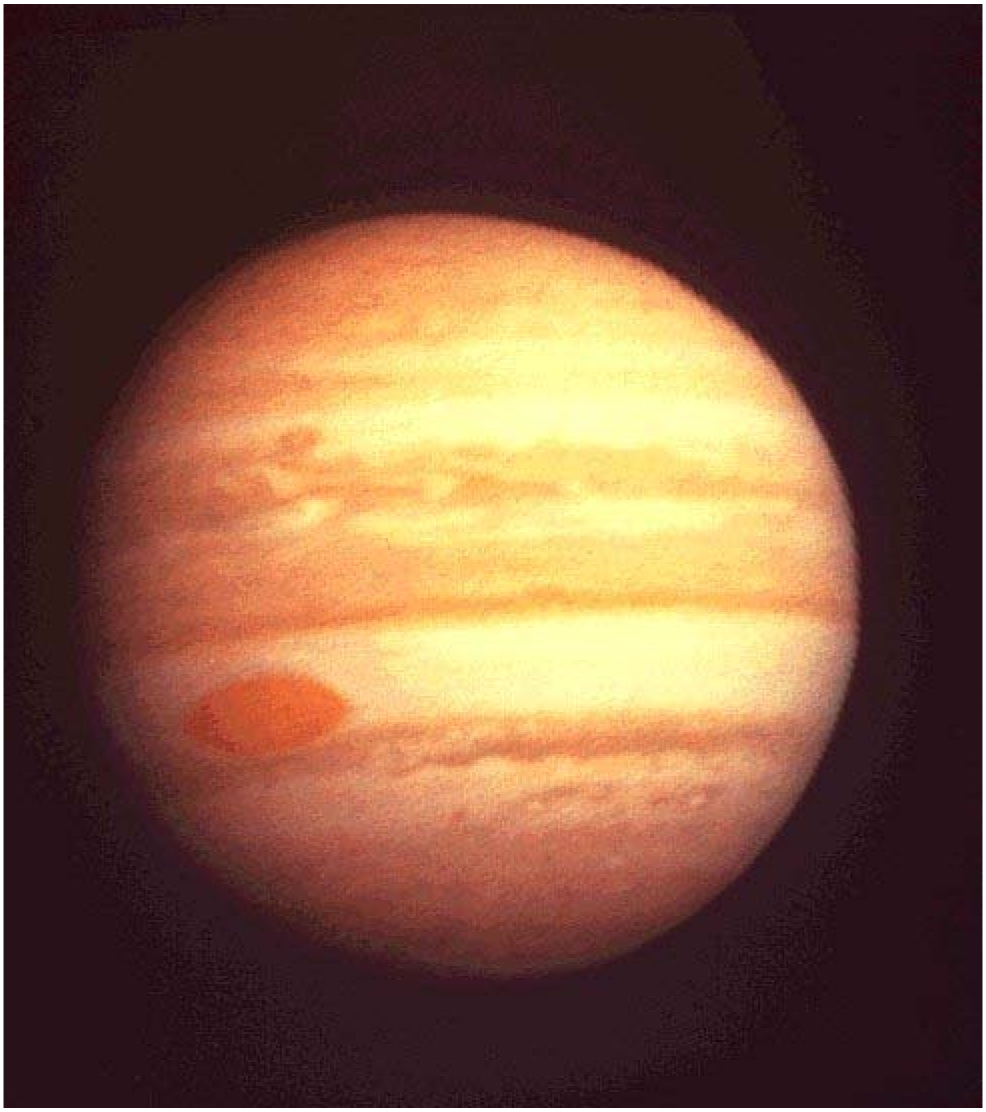
Flights from Earth to other planets in the Solar System have a high energy cost. It requires **almost** the same amount of energy for a spacecraft to reach Jupiter from Earth's orbit as it does to lift it into orbit in the first place. In astrodynamics, this energy expenditure is defined by the net change in the spacecraft's velocity, or delta-V. The energy needed to reach Jupiter from an Earth orbit requires a delta-V of about 9 km/s, compared to the 9.0–9.5 km/s to reach a low Earth orbit from the ground. However, gravity assists through planetary flybys (such as by Earth or Venus) can be used to reduce the energetic requirement (i.e., the fuel) at launch, albeit at the cost of a significantly longer flight durations to reach a target such as Jupiter as compared to the direct trajectory. Ion thrusters capable of a delta v of more than 10 kilometers/s were used on the Dawn spacecraft. This is more than enough delta v to do a Jupiter fly-by mission from a solar orbit of the same radius as earth's orbit without gravity assist.

A major problem in sending space probes to Jupiter is that the planet has no solid surface on which to land, as there is a smooth transition between the planet's atmosphere and its fluid interior. Any probes descending into the atmosphere are eventually crushed by the immense pressures within Jupiter.

Another major issue is the amount of radiation to which a space probe is subjected, due to the harsh charged-particle environment around Jupiter. For example, when *Pioneer 11* made its closest approach to the planet, the level of radiation was ten times more powerful than *Pioneer'*s designers had predicted, leading to fears that the probes would not survive; however, with a few minor glitches, the probe managed to pass through the radiation belts. It did however lose most of the images of the moon Io, as the radiation had caused *Pioneer*'s imaging photo polarimeter to receive a number of false commands. The subsequent and far more technologically advanced *Voyager* spacecraft had to be redesigned to cope with the massive radiation levels. The *Galileo* spacecraft, over the eight years it orbited the planet, the probe's radiation dose far exceeded its design specifications, and its systems failed on several occasions. The spacecraft's gyroscopes often exhibited increased errors, and electrical arcs sometimes occurred between its rotating and non-rotating parts, causing it to enter safe mode, which led to total loss of the data from the 16th, 18th and 33rd orbits. The radiation also caused phase shifts in *Galileo*'s ultra-stable quartz oscillator.

Flyby missions

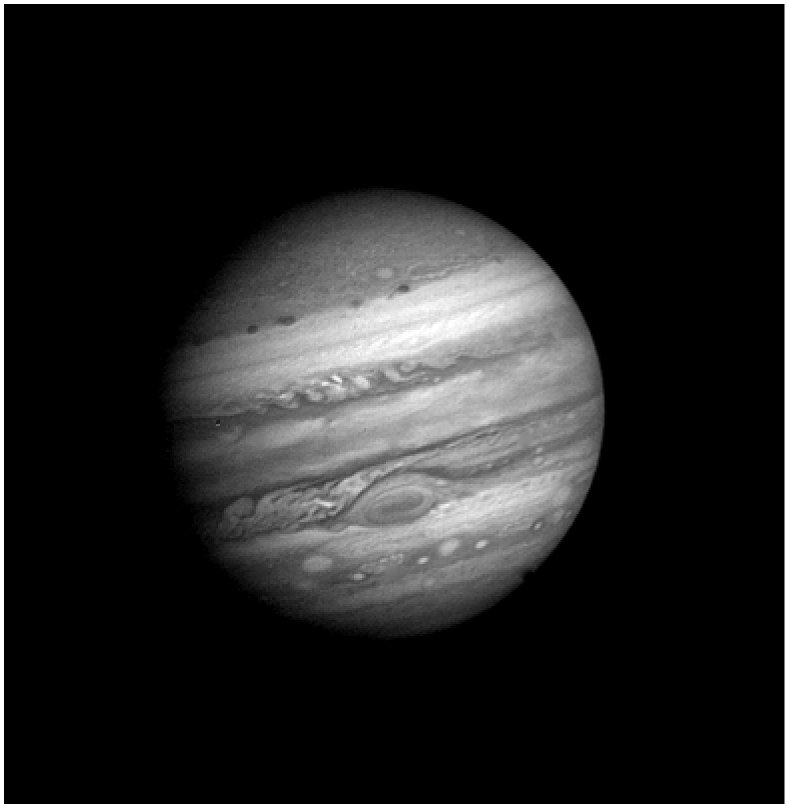
Pioneer program (1973 and 1974)



Pioneer 10 was the first spacecraft to visit Jupiter

The first spacecraft to explore Jupiter was *Pioneer 10*, which flew past the planet in December 1973, followed by *Pioneer 11* thirteen months later. *Pioneer 10* obtained the first-ever close-up images of Jupiter and its Galilean moons; the spacecraft studied the planet's atmosphere, detected its magnetic field, observed its radiation belts and determined that Jupiter is mainly fluid. *Pioneer 11* made its closest approach, within some 34,000 km of Jupiter's cloud tops, on December 4, 1974. It obtained dramatic images of the Great Red Spot, made the first observation of Jupiter's immense polar regions, and determined the mass of Jupiter's moon Callisto. The information gathered by these two spacecraft helped astronomers and engineers improve the design of future probes to cope more effectively with the environment around the giant planet.

Voyager program (1979)



Time-lapse sequence from the approach of *Voyager 1* to Jupiter

Voyager 1 began photographing Jupiter in January 1979 and made its closest approach on March 5, 1979, at a distance of 349,000 km from Jupiter's center. This close approach allowed for greater image resolution, though the flyby's short duration meant that most observations of Jupiter's moons, rings, magnetic field, and radiation environment were made in the 48-hour period bracketing the approach, even though *Voyager 1* continued photographing the planet until April. It was soon followed by *Voyager 2*, which made its closest approach on July 9, 1979, 576 million km away from the planet's cloud tops. The probe discovered Jupiter's ring, observed intricate vortices in its atmosphere, observed active volcanoes on Io, a process analogous to plate tectonics on Ganymede, and numerous craters on Callisto.

The *Voyager* missions vastly improved our understanding of the Galilean moons, and also discovered Jupiter's rings. They also took the first close up images of the planet's atmosphere, revealing the Great Red Spot as a complex storm moving in a counter-clockwise direction. An array of other smaller storms and eddies were found throughout the banded clouds. Two new, small satellites, Adrastea and Metis, were discovered orbiting just outside the ring, making them the first of Jupiter's moons to be identified by a spacecraft. A third new satellite, Thebe, was discovered between the orbits of Amalthea and Io.

The discovery of volcanic activity on the moon Io was the greatest unexpected finding of the mission, as it was the first time an active volcano was observed on a celestial body other than Earth. Together, the *Voyagers* recorded the eruption of nine volcanoes on Io, as well as evidence for other eruptions occurring between the Voyager encounters.

Europa displayed a large number of intersecting linear features in the low-resolution photos from *Voyager 1*. At first, scientists believed the features might be deep cracks, caused by crustal rifting or tectonic processes. However, the high-resolution photos from *Voyager 2*, taken closer to Jupiter, left scientists puzzled as the features in these photos were almost entirely lacking in topographic relief. This led many to suggest that these cracks might be similar to ice floes on Earth, and that Europa might have a liquid water interior. Europa may be internally active due to tidal heating at a level about one-tenth that of Io, and as a result, the moon is thought to have a thin crust less than 30 kilometers (18 miles) thick of water ice, possibly floating on a 50-kilometers-deep (30 mile) ocean.

Ulysses (1992)

On February 8, 1992, the *Ulysses* solar probe flew past Jupiter's north pole at a distance of 451,000 km. This swing-by maneuver was required for *Ulysses* to attain a very high-inclination orbit around the Sun, increasing its inclination to the ecliptic to 80.2 degrees. The giant planet's gravity bent the spacecraft's flightpath downward and away from the ecliptic plane, placing it into a final orbit around the Sun's north and south poles. The size and shape of the probe's orbit were adjusted to a much smaller degree, so that its aphelion remained at approximately 5 AU (Jupiter's distance from the Sun), while its perihelion lay somewhat beyond 1 AU (Earth's distance from the Sun). During its Jupiter encounter, the probe made measurements of the planet's magnetosphere. Since the probe had no cameras, no images were taken. In February 2004, the probe arrived again at the vicinity of Jupiter. This time the distance from the planet was much greater—about 240 million km—but it made further observations of Jupiter.

Cassini (2000)

The most detailed map of Jupiter ever produced was taken by *Cassini* from above the South pole

In 2000, the *Cassini* probe, *en route* to Saturn, flew by Jupiter and provided some of the highest-resolution images ever taken of the planet. It made its closest approach on December 30, 2000, and made many scientific measurements. About 26,000 images of Jupiter were taken during the months-long flyby. It produced the most detailed global color portrait of Jupiter yet, in which the smallest visible features are approximately 60 km (40 miles) across.

A major finding of the flyby, announced on March 6, 2003, was of Jupiter's atmospheric circulation. Dark belts alternate with light zones in the atmosphere, and the zones, with their pale clouds, had previously been considered by scientists to be areas of upwelling air, partly because on Earth clouds tend to be formed by rising air. But analysis of *Cassini* imagery showed that the dark belts contain individual storm cells of upwelling bright-white clouds, too small to see from Earth. Anthony Del Genio of NASA's Goddard Institute for Space Studies said that "the belts must be the areas of net-rising atmospheric motion on Jupiter, [so] the net motion in the zones has to be sinking".

Other atmospheric observations included a swirling dark oval of high atmospheric-haze, about the size of the Great Red Spot, near Jupiter's north pole. Infrared imagery revealed aspects of circulation near the poles, with bands of globe-encircling winds, with adjacent bands moving in opposite directions. The same announcement also discussed the nature of Jupiter's rings. Light scattering by particles in the rings showed the particles were irregularly shaped (rather than spherical) and likely originated as ejecta from micrometeorite impacts on Jupiter's moons, probably on Metis and Adrastea. On December 19, 2000, the *Cassini* spacecraft captured a very low resolution image of the moon Himalia, but it was too distant to show any surface details.

New Horizons (2007)

The *New Horizons* probe, en route to Pluto, flew by Jupiter for a gravity assist and was the first probe launched directly towards Jupiter since the *Ulysses* in 1990. Its Long Range Reconnaissance Imager (LORRI) took its first photographs of Jupiter on September 4, 2006. The spacecraft began further study of the Jovian system in December 2006, and made its closest approach on February 28, 2007.

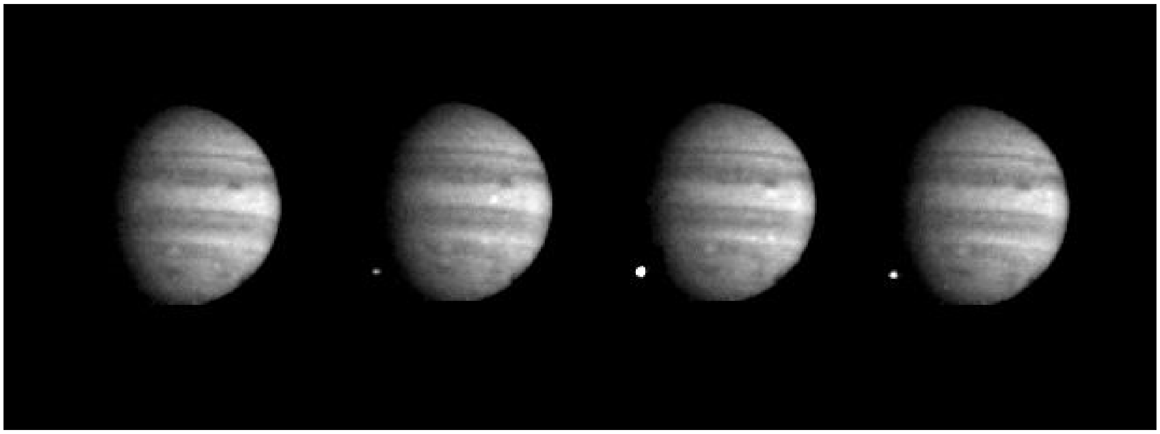
While close to Jupiter, *New Horizons'* instruments made refined measurements of the orbits of Jupiter's inner moons, particularly Amalthea. The probe's cameras measured volcanoes on Io, studied all four Galilean moons in detail, and made long-distance studies of the outer moons Himalia and Elara. The craft also studied Jupiter's Little Red Spot and the planet's magnetosphere and tenuous ring system.

On March 19, 2007 the Command and Data Handling computer experienced an uncorrectable memory error and rebooted itself, causing the spacecraft to go into safe mode. The craft fully recovered within two days, with some data loss on Jupiter's magnetotail. No other data loss events were associated with the encounter.

Galileo orbital mission (1995–2003)

So far, the only spacecraft to orbit Jupiter is the *Galileo* orbiter, which went into orbit around Jupiter on December 7, 1995. It orbited the planet for over seven years, making 35 orbits before it was destroyed during a controlled impact with Jupiter on September 21, 2003. During this period it gathered a large amount of information about the Jovian system, although the amount of information was not as great as intended because the deployment of its high-gain radio transmitting antenna failed. The major events during the eight-year study included multiple flybys of all of the Galilean moons, as well as Amalthea (the first probe to do so). It also witnessed the impact of Comet Shoemaker-

Levy 9 as it approached Jupiter in 1994 and the sending of an atmospheric probe into the Jovian atmosphere in December 1995.



A sequence of Galileo images taken several seconds apart, shows the appearance of the fireball appearing on the dark side of Jupiter from one of the fragments of the comet Shoemaker-Levy 9 hitting the planet.

Cameras on the *Galileo* spacecraft observed fragments of the Shoemaker-Levy 9 comet between July 16 and July 22, 1994 as they collided with Jupiter's southern hemisphere at a speed of approximately 60 kilometres per second. This was the first direct observation of an extraterrestrial collision of solar system objects. While the impacts took place on the side of Jupiter hidden from Earth, Galileo, then at a distance of 1.6 AU from the planet, was able to see the impacts as they occurred. Its instruments detected a fireball which reached a peak temperature of about 24,000 K, compared to the typical Jovian cloudtop temperature of about 130 K, with the plume from the fireball reaching a height of over 3,000 km.

An atmospheric probe was released from the spacecraft in July, 1995, entering the planet's atmosphere on December 7, 1995. After a high-g descent into the Jovian atmosphere, the probe discarded the remains of its heat shield, and it parachuted through 150 km of the atmosphere, collecting data for 57.6 minutes, before being crushed by the pressure and temperature to which it was subjected (about 22 times Earth normal, at a temperature of 153 °C). It would have melted thereafter, and possibly vaporized. The *Galileo* orbiter itself experienced a more rapid version of the same fate when it was deliberately steered into the planet on September 21, 2003 at a speed of over 50 km/s, in order to avoid any possibility of it crashing into and contaminating Europa.

Major scientific results of the *Galileo mission* include:

- the first observation of ammonia clouds in another planet's atmosphere—the atmosphere creates ammonia ice particles from material coming up from lower depths;

- confirmation of extensive volcanic activity on Io—which is 100 times greater than that found on Earth; the heat and frequency of eruptions are reminiscent of early Earth;
- observation of complex plasma interactions in Io's atmosphere which create immense electrical currents that couple to Jupiter's atmosphere;
- providing evidence for supporting the theory that liquid oceans exist under Europa's icy surface;
- first detection of a substantial magnetic field around a satellite (Ganymede);
- magnetic data evidence suggesting that Europa, Ganymede and Callisto have a liquid-saltwater layer under the visible surface;
- evidence for a thin atmospheric layer on Europa, Ganymede, and Callisto known as a 'surface-bound exosphere';
- understanding of the formation of the rings of Jupiter (by dust kicked up as interplanetary meteoroids which smash into the planet's four small inner moons) and observation of two outer rings and the possibility of a separate ring along Amalthea's orbit;
- identification of the global structure and dynamics of a giant planet's magnetosphere.

Proposed missions

NASA is planning a mission to study Jupiter in detail from a polar orbit. Named *Juno*, the spacecraft is planned to launch in August 2011. The spacecraft will be placed in a polar orbit to study the planet's composition, gravity field, magnetic field, and polar magnetosphere. *Juno* will also search for clues about how Jupiter formed, including whether the planet has a rocky core, the amount of water present within the deep atmosphere, and how the mass is distributed within the planet. Juno will also study Jupiter's deep winds, which can reach speeds of 600 km/h.

The *Europa Jupiter System Mission* (EJSM) is a joint NASA/ESA proposal for exploration of Jupiter and its moons. In February 2009 it was announced that ESA/NASA had given this mission priority ahead of the *Titan Saturn System Mission*. The proposal includes a launch date of around 2020 and consists of the NASA-led *Jupiter Europa Orbiter*, and the ESA-led *Jupiter Ganymede Orbiter*. ESA's contribution will still face funding competition from other ESA projects.

Cancelled missions

Because of the possibility of subsurface liquid oceans on Jupiter's moons Europa, Ganymede and Callisto, there has been great interest in studying the icy moons in detail. Funding difficulties have delayed progress. The *Europa Orbiter* was a planned NASA mission to Europa, which was canceled in 2002. Its main objectives included determining the presence or absence of a subsurface ocean and identifying candidate sites for future lander missions. Then there was NASA's *JIMO* (*Jupiter Icy Moons Orbiter*) that was canceled in 2005. A European *Jovian Europa Orbiter* mission was also studied. These missions were superseded by the Europa Jupiter System Mission (EJSM) described above.

Manned exploration

While it is not possible to land on Jupiter itself, it is possible to land on the Galilean moons, leading to the possibility of future manned exploration. Particular targets are Europa, due to its potential for life, and Callisto, due to its relatively low radiation dose. In 2003, NASA proposed a program called Human Outer Planets Exploration (HOPE) that involved a manned mission to the Galilean moons. NASA has projected a possible attempt some time in the 2040s. In the Vision for Space Exploration policy announced in January 2004, NASA has discussed manned missions beyond Mars, mentioning that a "human research presence" may be desirable on Jupiter's moons. Before the JIMO mission was cancelled, NASA administrator Sean O'Keefe stated that "human explorers will follow."

Potential for colonization

NASA has speculated on the feasibility of mining the atmospheres of the outer planets, particularly for helium-3, an isotope of helium rare on Earth, but highly desired in nuclear fusion research. Factories stationed in orbit could mine the gas and deliver it to visiting craft. However, the Jovian system in general poses particular disadvantages for colonizing because of its severe radiation environment and its particularly deep gravity well. Its radiation would deliver about 36 Sv (3600 rem) per day to unshielded colonists at Io and about 5.4 Sv (540 rems) per day to unshielded colonists at Europa. Exposure of approximately .75 Sv over a period of a few days is enough to cause radiation poisoning, and about 5 Sv over a few days is fatal.

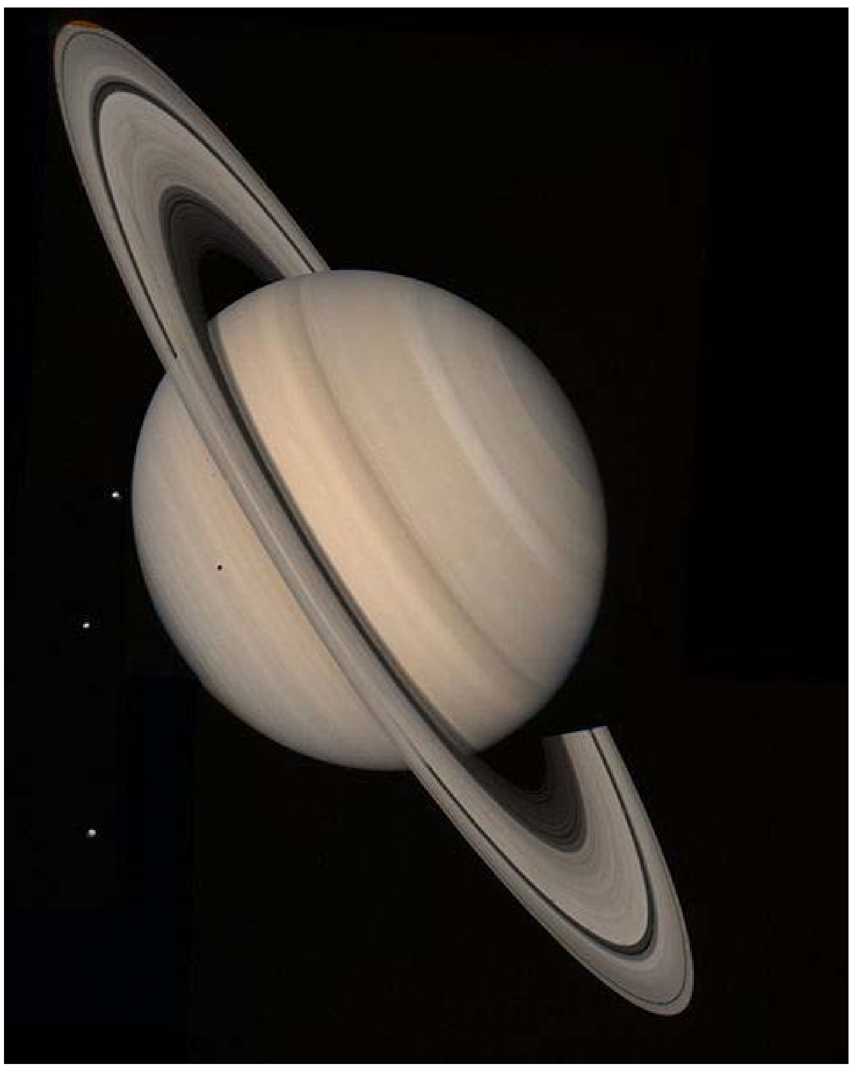
Ganymede is the largest moon in the Solar System. Ganymede is the only moon with a magnetosphere but it is overshadowed by Jupiter's magnetic field. Ganymede receives about 0.08 Sv (8 rem) of radiation per day. Callisto being further from Jupiter's powerful radiation belt is subject to only 10 mSv a day. One of the main targets chosen by the HOPE study was Callisto. The possibility was mooted of building a surface base on Callisto, because of the low radiation levels at the moon's distance from Jupiter and its geological stability. Callisto is the only one of Jupiter's Galilean satellites for which human exploration is feasible. The levels of ionizing radiation on Io, Europa and Ganymede are inimical to human life, and adequate protective measures have yet to be devised.

It could be possible to build a surface base that would produce fuel for further exploration of the solar system. In 1997, the Artemis Project designed a plan to colonize Europa. According to the plan, explorers would drill down into the Europan ice crust, entering the postulated subsurface ocean, where they would inhabit artificial air pockets.

Chapter- 5

Exploration of Saturn, Uranus, Neptune, Pluto

Exploration of Saturn



A picture of Saturn taken by Voyager 2

The **exploration of Saturn** has been solely done by robotic probes. Like all gas giants, there is no solid surface for a solid probe to land on. Most missions therefore have been flybys, although the *Cassini–Huygens* spacecraft is currently in orbit.

Flybys

Pioneer 11 flyby

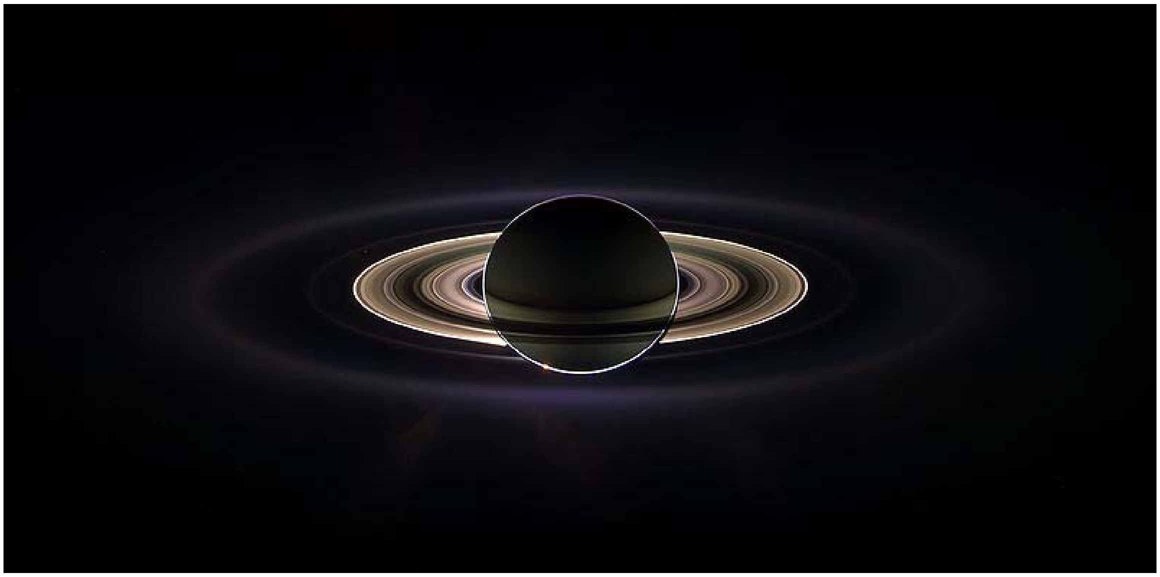
Pioneer 11 image of Saturn

Saturn was first visited by Pioneer 11 in September 1979. It flew within 20,000 km of the top of the planet's cloud layer. Low-resolution images were acquired of the planet and a few of its moons; the resolution of the images was not good enough to discern surface features. The spacecraft also studied the rings; among the discoveries were the thin F-ring and the fact that dark gaps in the rings are bright when viewed towards the Sun, or in other words, they are not empty of material. Pioneer 11 also measured the temperature of Titan at 250 degrees K.

Voyager

The probes Voyager 1 and Voyager 2 flew past Saturn in the early 1980s, studying the planet, its rings and its moons. Voyager 2 went on to study Uranus and Neptune.

Cassini orbiter



Saturn eclipses the Sun, as seen from Cassini

On July 1, 2004, the Cassini-Huygens spacecraft performed the SOI (Saturn Orbit Insertion) maneuver and entered into orbit around Saturn. Before the SOI, Cassini had already studied the system extensively. In June 2004, it had conducted a close flyby of Phoebe, sending back high-resolution images and data.

The orbiter, completed two Titan flybys before releasing the Huygens probe on December 25, 2004. Huygens descended onto the surface of Titan on January 14, 2005, sending a flood of data during the atmospheric descent and after the landing. During 2005 Cassini conducted multiple flybys of Titan and icy satellites.

On March 10, 2006, NASA reported that the Cassini probe found evidence of liquid water reservoirs that erupt in geysers on Saturn's moon Enceladus.

On September 20, 2006, a Cassini probe photograph revealed a previously undiscovered planetary ring, outside the brighter main rings of Saturn and inside the G and E rings.

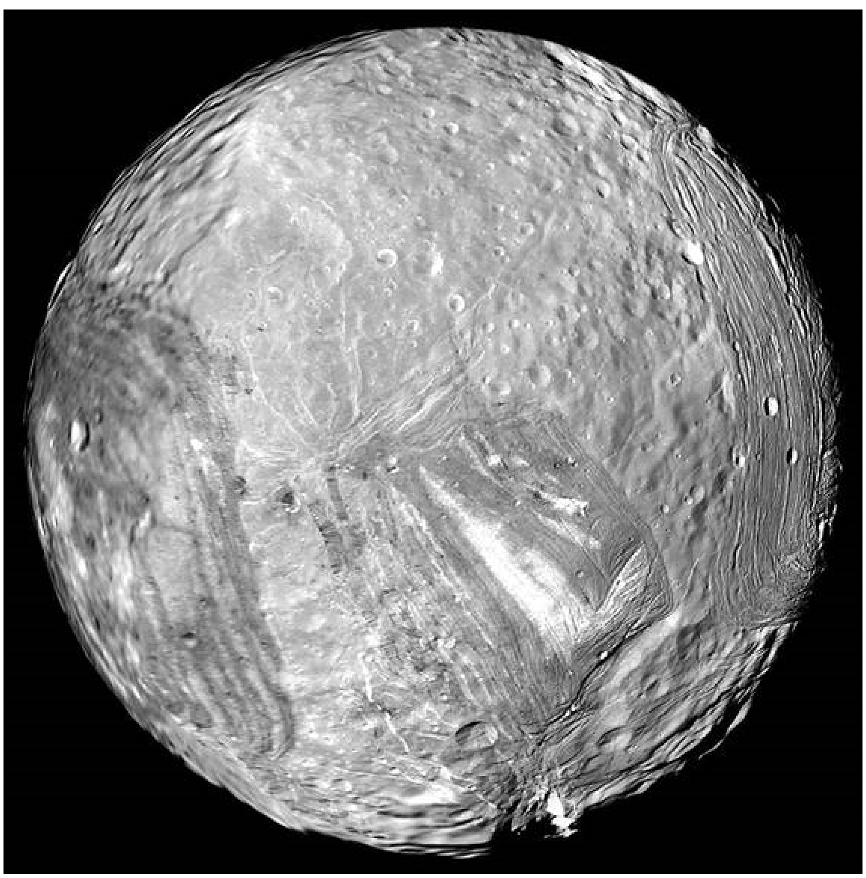
In July 2006, Cassini saw the first proof of hydrocarbon lakes near Titan's north pole, which was confirmed in January 2007. In March 2007, additional images near Titan's north pole discovered hydrocarbon "seas", the largest of which is almost the size of the Caspian Sea.

As of 2009 the probe has discovered and confirmed 4 new satellites. Its primary mission ended in 2008 when the spacecraft completed 74 orbits around the planet. The probe however is expected to have at least one mission extension lasting thorugh 2010.

Future missions

The Titan Saturn System Mission (**TSSM**) is a joint NASA/ESA proposal for an exploration of Saturn and its moons Titan and Enceladus, where many complex phenomena have been revealed by the recent Cassini–Huygens mission. TSSM was competing against the Europa Jupiter System Mission proposal for funding. In February 2009 it was announced that ESA/NASA had given the EJSM mission priority ahead of TSSM, although TSSM will continue to be studied for a later launch date. The Titan Saturn System Mission (TSSM) was created by the merging of the ESA's **Titan and Enceladus Mission** (**TandEM**) with NASA's **Titan Explorer 2007** flagship study.

Exploration of Uranus



Voyager 2 image showing the tortured surface of Miranda

Uranus viewed from 18 million kilometers

The **exploration of Uranus** has been solely through the Voyager 2 spacecraft, with no other visits currently planned. The closest approach to Uranus occurred on January 24, 1986. *Voyager 2* discovered 10 previously unknown moons; studied the planet's unique atmosphere, caused by its axial tilt of 97.77°; and examined its ring system.

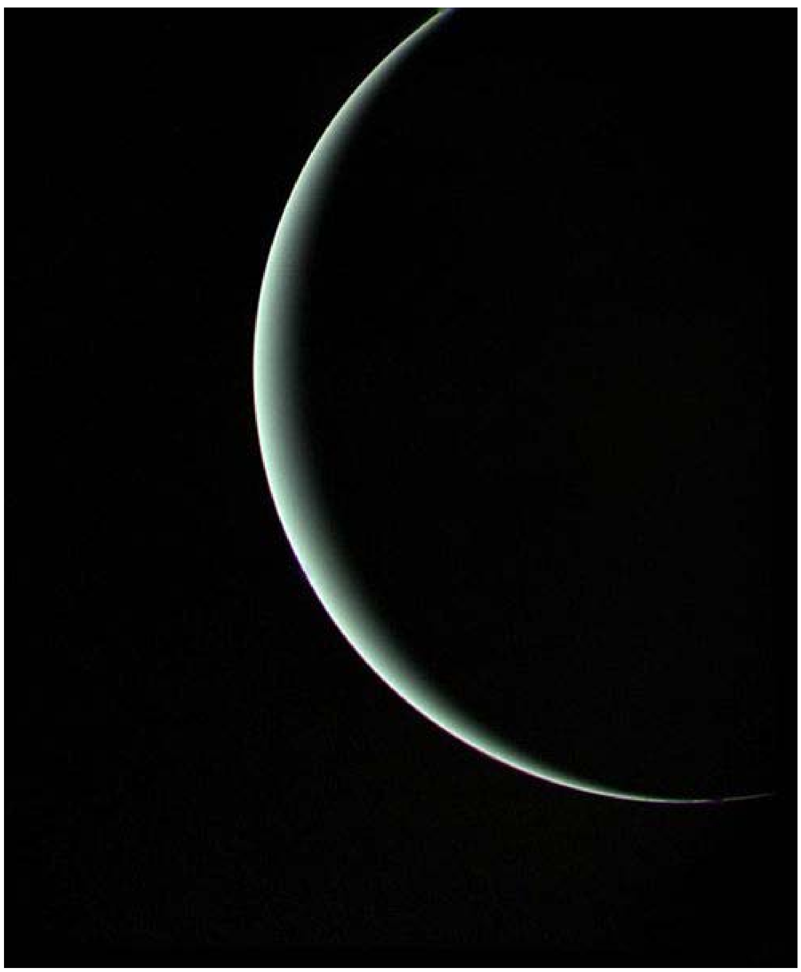
Voyager 2

In its first solo planetary flyby (since Voyager 1 stopped the outer planet grand tour at Saturn and its moon Titan), Voyager 2 made its closest approach to Uranus on January 24, 1986, coming within 81,500 kilometers (50,600 miles) of the planet's cloud tops.

Uranus is the third largest planet in the Solar System. It orbits the Sun at a distance of about 2.8 billion kilometers (1.7 billion miles) and completes one orbit every 84 years. The length of a day on Uranus as measured by Voyager 2 is 17 hours, 14 minutes. Uranus is distinguished by the fact that it is tipped on its side. Its unusual position is thought to be the result of a collision with a planet-sized body early in the solar system's history. Given its odd orientation, with its polar regions exposed to sunlight or darkness for long periods, scientists were not sure what to expect at Uranus.

Voyager 2 found that one of the most striking influences of this sideways position is its effect on the tail of the magnetic field, which is itself tilted 60 degrees from the planet's axis of rotation. The magnetotail was shown to be twisted by the planet's rotation into a long corkscrew shape behind the planet.

The presence of a magnetic field at Uranus was not known until Voyager's arrival. The intensity of the field is roughly comparable to that of Earth's, though it varies much more from point to point because of its large offset from the center of Uranus. The peculiar orientation of the magnetic field suggests that the field is generated at an intermediate depth in the interior where the pressure is high enough for water to become electrically conducting.



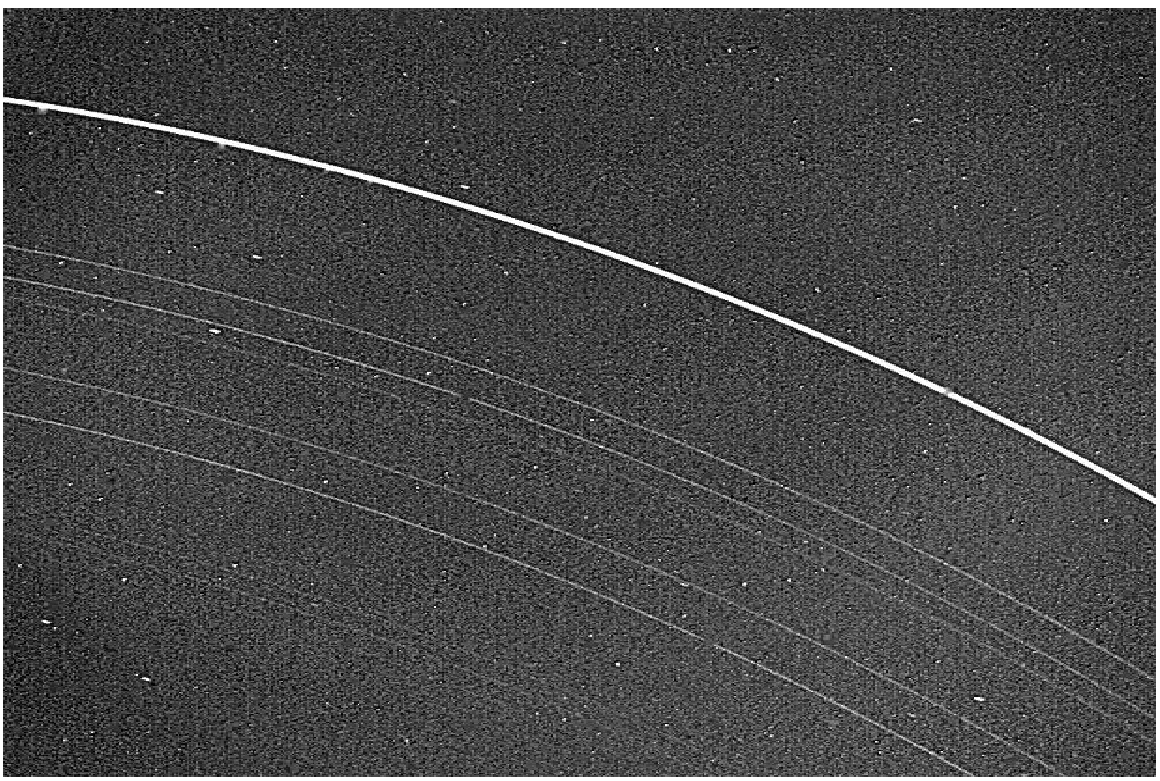
A picture of Uranus taken by Voyager 2 as it headed away from Uranus, towards the planet Neptune.

Radiation belts at Uranus were found to be of an intensity similar to those at Saturn. The intensity of radiation within the belts is such that irradiation would quickly darken (within 100,000 years) any methane trapped in the icy surfaces of the inner moons and ring particles. This may have contributed to the darkened surfaces of the moons and ring particles, which are almost uniformly gray in color.

A high layer of haze was detected around the sunlit pole, which also was found to radiate large amounts of ultraviolet light, a phenomenon dubbed "dayglow." The average temperature is about 60 kelvins (-350 degrees Fahrenheit). Surprisingly, the illuminated and dark poles, and most of the planet, show nearly the same temperature at the cloud tops.

Voyager found 10 new moons, bringing the total number to 15 at the time. Most of the new moons are small, with the largest measuring about 150 kilometers (about 90 miles) in diameter.

The moon Miranda, innermost of the five large moons, was revealed to be one of the strangest bodies yet seen in the solar system. Detailed images from Voyager's flyby of the moon showed huge fault canyons as deep as 20 kilometers (12 miles), terraced layers, and a mixture of old and young surfaces. One theory holds that Miranda may be a reaggregation of material from an earlier time when the moon was fractured by a violent impact.



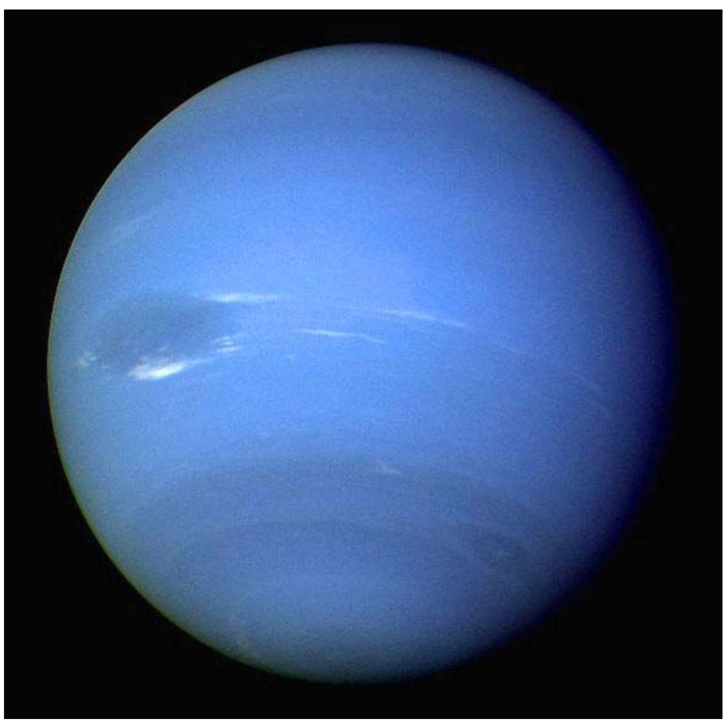
Voyager 2 shot of the Uranian dark rings

The five large moons appear to be ice-rock conglomerates like the satellites of Saturn. Titania is marked by huge fault systems and canyons indicating some degree of geologic, probably tectonic, activity in its history. Ariel has the brightest and possibly youngest surface of all the Uranian moons and also appears to have undergone geologic activity that led to many fault valleys and what seem to be extensive flows of icy material. Little geologic activity has occurred on Umbriel or Oberon, judging by their old and dark surfaces.

All nine previously known rings were studied by the spacecraft and showed the Uranian rings to be distinctly different from those at Jupiter and Saturn. The ring system may be relatively young and did not form at the same time as Uranus. Particles that make up the rings may be remnants of a moon that was broken by a high-velocity impact or torn up by gravitational effects.

Exploration of Neptune

The **exploration of Neptune** has only begun with one explorer, Voyager 2, which visited on August 25, 1989. The possibility of a Neptune Orbiter was discussed, yet other than that, no other missions have been given serious thought. As Neptune is a gas giant and has no solid surface, a surface mission such as a lander or rover is impossible.



Neptune

Voyager 2

In Voyager 2's last planetary encounter, the spacecraft swooped only 3,000 miles above Neptune's north pole, the closest approach it made to any body since it left Earth. Voyager 2 studied Neptune's atmosphere, Neptune's rings, its magnetosphere, and Neptune's moons. Several discoveries were made, including the discovery of the Great Dark Spot and Triton's geysers.

Voyager 2 revealed that Neptune's atmosphere was very dynamic, even though it receives only 3% of the sunlight Jupiter receives. Voyager 2 discovered an anticyclone called the Great Dark Spot, similar to Jupiter's Great Red Spot and Little Red Spot. However, images taken by the Hubble Space Telescope revealed that the Great Dark Spot had disappeared. Also seen in Neptune's atmosphere at that time was an almond-shaped spot designated D2, and a bright, quickly moving cloud high above the cloud decks dubbed "Scooter".

Voyager 2 spacecraft

Voyager 2 found four rings and evidence for ring arcs, or incomplete rings above Neptune. Neptune's magnetosphere was also studied by Voyager 2. The planetary radio astronomy instrument found that Neptune's day lasts sixteen hours, seven minutes. Voyager 2 also discovered auroras, like on Earth, but much more complex.

Voyager 2 discovered six moons orbiting Neptune, but only three were photographed in detail: Proteus, Nereid, and Triton. Proteus turned out to be an ellipsoid, as large as an ellipsoid could become without rounding in a sphere. Proteus is very dark in color, almost like soot.

Voyager 2 image of Proteus

Nereid, though discovered in 1949, still has very little known about it. Triton was flown by at about 25,000 miles away, and became the last solid world Voyager 2 would explore within the Solar System. Triton was revealed to have remarkable active geysers and polar caps. A very thin atmosphere was found, as well as thin clouds.

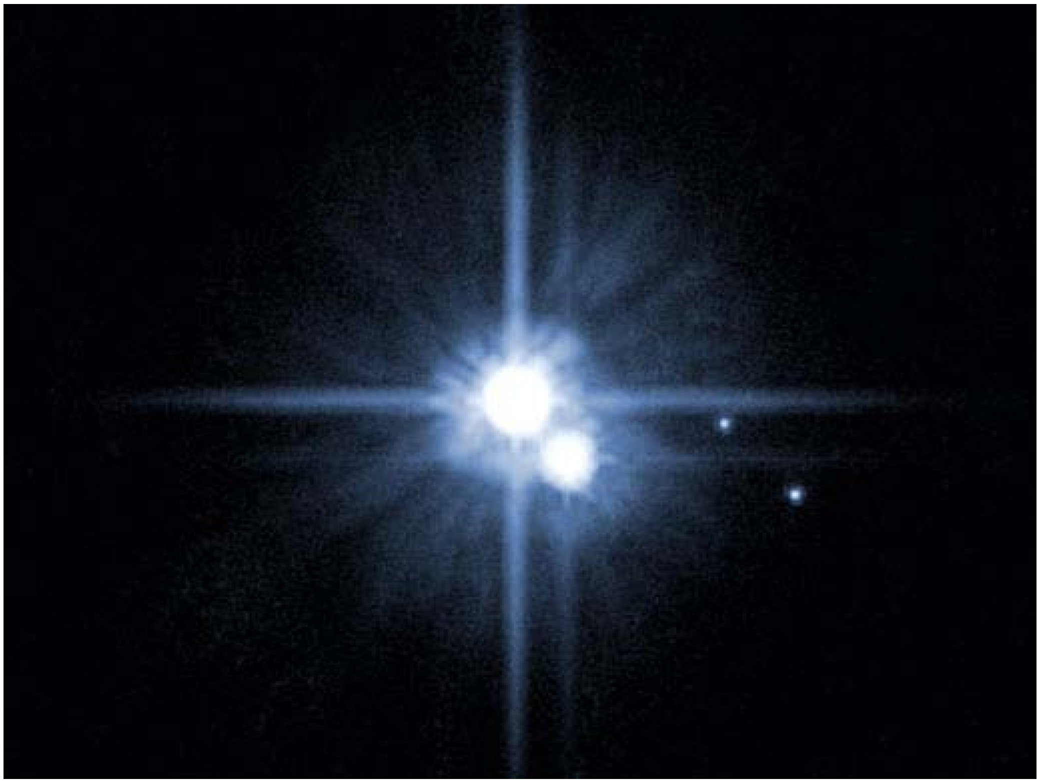
Voyager 2 image of Triton

Planned future missions

NASA has researched several mission possibilities for Cassini–Huygens-like missions to this planet, but budgetary and other constraints have so far yet to yield any success.

It is known that any future mission will have RTGs and similar instrumentation to Voyager craft, but with more cameras and storage capacity; and will need better error correction than Voyager.

Exploration of Pluto



Pluto with its moons

Pluto

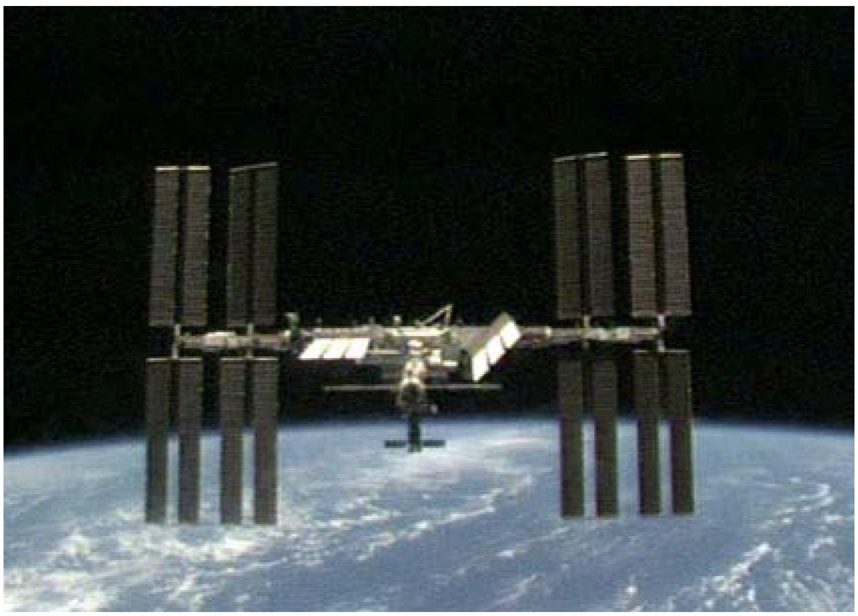
The dwarf planet Pluto (considered a planet until the IAU redefinition of "planet" in October 2006) presents significant challenges for spacecraft because of its great distance from Earth (requiring high velocity for reasonable trip times) and small mass (making capture into orbit very difficult at present). *Voyager 1* could have visited Pluto, but controllers opted instead for a close flyby of Saturn's moon Titan, resulting in a trajectory incompatible with a Pluto flyby. *Voyager 2* never had a plausible trajectory for reaching Pluto.

Pluto continues to be of great interest, despite its reclassification as the lead and nearest member of a new and growing class of distant icy bodies of intermediate size, in mass between the remaining eight planets and the small rocky objects historically termed asteroids (and also the first member of the important subclass, defined by orbit and known as "Plutinos"). After an intense political battle, a mission to Pluto dubbed *New Horizons* was granted funding from the US government in 2003. *New Horizons* was launched successfully on January 19, 2006. In early 2007 the craft made use of a gravity assist from Jupiter. Its closest approach to Pluto will be on July 14, 2015; scientific observations of Pluto will begin five months prior to closest approach and will continue for at least a month after the encounter.

Chapter- 6

Space Flight and Militarisation of Space

Space Flight



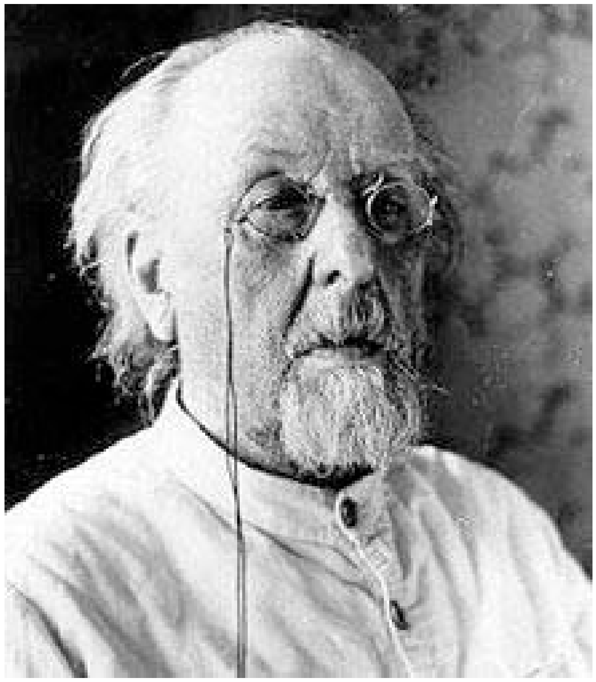
The International Space Station in earth orbit after a visit from the crew of STS-119

Spaceflight or **space flight** is the use of space technology to achieve the flight of spacecraft into and through outer space.

Spaceflight is used in space exploration, and also in commercial activities like space tourism and satellite telecommunications. Additional non-commercial uses of spaceflight include space observatories, reconnaissance satellites and other earth observation satellites.

A spaceflight typically begins with a rocket launch, which provides the initial thrust to overcome the force of gravity and propels the spacecraft from the surface of the Earth. Once in space, the motion of a spacecraft—both when unpropelled and when under propulsion—is covered by the area of study called astrodynamics. Some spacecraft remain in space indefinitely, some disintegrate during atmospheric reentry, and others reach a planetary or lunar surface for landing or impact.

History



Tsiolkovsky, "the father of human space flight"

The realistic proposal of space travel 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. He also proved in the laboratory that rockets would work in the vacuum of space; not all scientists of that day believed they would. This paper was highly influential on Hermann Oberth and Wernher Von Braun, later key players in spaceflight.

The first rocket to reach space was the German V-2 Rocket, on a test flight in June, 1944, although sub-orbital flight is not considered a spaceflight in Russia. On October 4, 1957, the Soviet Union launched Sputnik 1, which became the first artificial satellite to orbit the Earth. The first human spaceflight was Vostok 1 on April 12, 1961, aboard which Soviet cosmonaut Yuri Gagarin made one orbit around the Earth. The lead architects behind the Soviet space program's Vostok 1 mission were the rocket scientists Sergey Korolyov and Kerim Kerimov.

Rockets remain the only currently practical means of reaching space. Other non-rocket spacelaunch technologies such as scramjets still fall far short of orbital speed.

Earth-launched spaceflight

Reaching space

Proton Rocket heading for space

The most commonly used definition of outer space is everything beyond the Kármán line, which is 100 kilometers (62 mi) above the Earth's surface. (The United States sometimes defines outer space as everything beyond 50 miles (80 km) in altitude.)

In order for a projectile to reach outer space from the surface, it needs a minimum delta-v. This velocity is much lower than escape velocity.

For manned launch systems launch escape systems are frequently fitted to allow astronauts to escape in the case of catastrophic failures.

Sub-orbital spaceflight

On a sub-orbital spaceflight the spacecraft reaches space and then returns to the atmosphere after following a (primarily) ballistic trajectory. This is usually because of insufficient specific orbital energy, in which case a suborbital flight will last only a few minutes, but it is also possible for an object with enough energy for an orbit to have a trajectory that intersects the earth's atmosphere, sometimes after many hours. Pioneer 1 was NASA's first space probe intended to reach the Moon. A partial failure caused it to instead follow a suborbital trajectory to an altitude of 113,854 kilometers (70,746 mi) before reentering the Earth's atmosphere 43 hours after launch.

The most generally recognized boundary of space is the Kármán line (actually a sphere) 100 km above sea level. (NASA alternatively defines an astronaut as someone who has flown more than 50 miles or 80 km above sea level.) It is not generally recognized by the public that the increase in potential energy required to pass the Kármán line is only about 3% of the orbital energy (potential plus kinetic energy) required by the lowest possible earth orbit (a circular orbit just above the Kármán line.) In other words, it is far easier to reach space than to stay there.

On May 17, 2004, Civilian Space eXploration Team launched the GoFast Rocket on a suborbital flight, the first amateur spaceflight. On June 21, 2004, SpaceShipOne was used for the first privately-funded human spaceflight.

Orbital spaceflight

A minimal orbital spaceflight requires much higher velocities than a minimal sub-orbital flight, and so it is technologically much more challenging to achieve. To achieve orbital spaceflight, the tangential velocity around the Earth is as important as altitude. In order to perform a stable and lasting flight in space, the spacecraft must reach the minimal orbital speed required for a closed orbit.

Leaving orbit

Achieving a closed orbit is not essential to lunar and interplanetary voyages, for which spacecraft need to exceed Earth escape velocity (or to closely approach it for lunar flights). Early Russian space vehicles successfully achieved very high altitudes without going into orbit. NASA considered launching Apollo missions directly into lunar trajectories but adopted the strategy of first entering a temporary parking orbit and then performing a separate burn several orbits later onto a lunar trajectory. This costs additional propellant because the parking orbit perigee must be high enough to prevent reentry while direct injection can have an arbitrarily low perigee because it will never be reached.

However, the parking orbit approach greatly simplified Apollo mission planning in several important ways. It substantially widened the allowable launch windows, increasing the chance of a successful launch despite minor technical problems during the countdown. The parking orbit was a stable "mission plateau" that gave the crew and controllers several hours to thoroughly check out the spacecraft after the stresses of launch before committing it to a long lunar flight; the crew could quickly return to earth, if necessary, or an alternate earth-orbital mission could be conducted. The parking orbit also enabled translunar trajectories that avoided the densest parts of the Van Allen radiation belts.

Apollo missions minimized the performance penalty of the parking orbit by keeping its altitude as low as possible. For example, Apollo 15 used an unusually low parking orbit (even for Apollo) of 92.5 by 91.5 nautical miles (171x169 km) where there was significant atmospheric drag. But it was partially overcome by continuous venting of hydrogen from the third stage of the Saturn V, and was in any event tolerable for the short stay.

Robotic missions do not require an abort capability or radiation minimization, and because modern launchers routinely meet "instantaneous" launch windows, space probes to the moon and other planets generally use direct injection to maximize performance. Although some might coast briefly during the launch sequence, they do not complete one or more full parking orbits before the burn that injects them onto an earth escape trajectory.

Note that the escape velocity from a celestial body decreases with altitude above that body. However, it is more fuel-efficient for a craft to burn its fuel as close to the ground as possible. This is another way to explain the performance penalty associated with establishing the safe perigee of a parking orbit.

Plans for future crewed interplantary spaceflight missions often include final vehicle assembly in Earth orbit, such as NASA's Project Orion and Russia's Kliper/Parom tandem.

Other ways of reaching space

Many ways other than rockets to reach space have been proposed. Ideas such as the Space Elevator, while elegant, are currently infeasible, whereas electromagnetic launchers such as launch loops have no known show stoppers. Other ideas include rocket assisted jet planes such as Reaction Engines Skylon or the trickier scramjets. Gun launch has been proposed for cargo.

Spaceports

Saturn V on the launch pad before the launch of Apollo 4

A spaceflight usually starts from a spaceport (cosmodrome), which may be equipped with launch complexes and launch pads for vertical rocket launches, and runways for takeoff and landing of carrier airplanes and winged spacecraft. Spaceports are situated well away from human habitation for noise and safety reasons.

A launch is often restricted to certain launch windows. These windows depend upon the position of celestial bodies and orbits relative to the launch site. The biggest influence is often the rotation of the Earth itself. Once launched, orbits are normally located within relatively constant flat planes at a fixed angle to the axis of the Earth, and the Earth rotates within this orbit.

Launch pads, takeoff

A launch pad is a fixed structure designed to dispatch airborne vehicles. It generally consists of a launch tower and flame trench. It is surrounded by equipment used to erect, fuel, and maintain launch vehicles.

Reentry and landing/splashdown

Reentry

Vehicles in orbit have large amounts of kinetic energy. This energy must be discarded if the vehicle is to land safely without vaporizing in the atmosphere. Typically this process requires special methods to protect against aerodynamic heating. The theory behind reentry is due to Harry Julian Allen. Based on this theory, reentry vehicles present blunt shapes to the atmosphere for reentry. Blunt shapes mean that less than 1% of the kinetic energy ends up as heat that reaches the vehicle and the heat energy instead ends up in the atmosphere.

Landing

Recovery of Discoverer 14 return capsule

The Mercury, Gemini, and Apollo capsules all landed in the sea. These capsules were designed to land at relatively slow speeds. Russian capsules for Soyuz make use of braking rockets as were designed to touch down on land. The Space Shuttle glides into a touchdown at high speed.

Recovery

After a successful landing the spacecraft, its occupants and cargo can be recovered. In some cases, recovery has occurred before landing: while a spacecraft is still descending on its parachute, it can be snagged by a specially designed aircraft. This mid-air retrieval technique was used to recover the film canisters from the Corona spy satellites.

Expendable launch systems

All current spaceflight except NASA's Space Shuttle and the SpaceX Falcon 1 use multi-stage expendable launch systems to reach space.

Reusable launch systems

The *Space Shuttle Columbia* seconds after engine ignition on mission STS-1

The first reusable spacecraft, the X-15, was air-launched on a suborbital trajectory on July 19, 1963. The first partially reusable orbital spacecraft, the Space Shuttle, was launched by the USA on the 20th anniversary of Yuri Gagarin's flight, on April 12, 1981.

During the Shuttle era, six orbiters were built, all of which have flown in the atmosphere and five of which have flown in space. The *Enterprise* was used only for approach and landing tests, launching from the back of a Boeing 747 and gliding to deadstick landings at Edwards AFB, California. The first Space Shuttle to fly into space was the *Columbia*, followed by the *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*. The *Endeavour* was built to replace the *Challenger*, which was lost in January 1986. The *Columbia* broke up during reentry in February 2003.

The first (and so far only) automatic partially reusable spacecraft was the Buran (Snowstorm), launched by the USSR on November 15, 1988, although it made only one flight. This spaceplane was designed for a crew and strongly resembled the U. S. Space Shuttle, although its drop-off boosters used liquid propellants and its main engines were located at the base of what would be the external tank in the American Shuttle. Lack of funding, complicated by the dissolution of the USSR, prevented any further flights of Buran.

Per the Vision for Space Exploration, the Space Shuttle is due to be retired in 2010 due mainly to its old age and high cost of the program reaching over a billion dollars per flight. The Shuttle's human transport role is to be replaced by the partially reusable Crew Exploration Vehicle (CEV) no later than 2014. The Shuttle's heavy cargo transport role is to be replaced by expendable rockets such as the Evolved Expendable Launch Vehicle (EELV) or a Shuttle Derived Launch Vehicle.

Scaled Composites SpaceShipOne was a reusable suborbital spaceplane that carried pilots Mike Melvill and Brian Binnie on consecutive flights in 2004 to win the Ansari X Prize. The Spaceship Company will build its successor SpaceShipTwo. A fleet of SpaceShipTwos operated by Virgin Galactic planned to begin reusable private spaceflight carrying paying passengers (space tourists) in 2008, but this was delayed due to an accident in the propulsion development.

Space disasters

All launch vehicles contain a huge amount of energy that is needed for some part of it to reach orbit. There is therefore some risk that this energy can be released prematurely and suddenly, with significant effects. When a Delta II rocket exploded 13 seconds after launch on January 17, 1997, there were reports of store windows 10 miles (16 km) away being broken by the blast.

Space is a fairly predictable environment, but there are still risks of accidental depressurisation and the potential failure of equipment, some of which may be very newly developed.

In 2004 the International Association for the Advancement of Space Safety was established in the Netherlands to further international cooperation and scientific advancement in space systems safety.

Space weather

Space weather is the concept of changing environmental conditions in outer space. It is distinct from the concept of weather within a planetary atmosphere, and deals with phenomena involving ambient plasma, magnetic fields, radiation and other matter in space (generally close to Earth but also in interplanetary, and occasionally interstellar medium). "Space weather describes the conditions in space that affect Earth and its technological systems. Our space weather is a consequence of the behavior of the sun, the nature of Earth's magnetic field, and our location in the solar system."

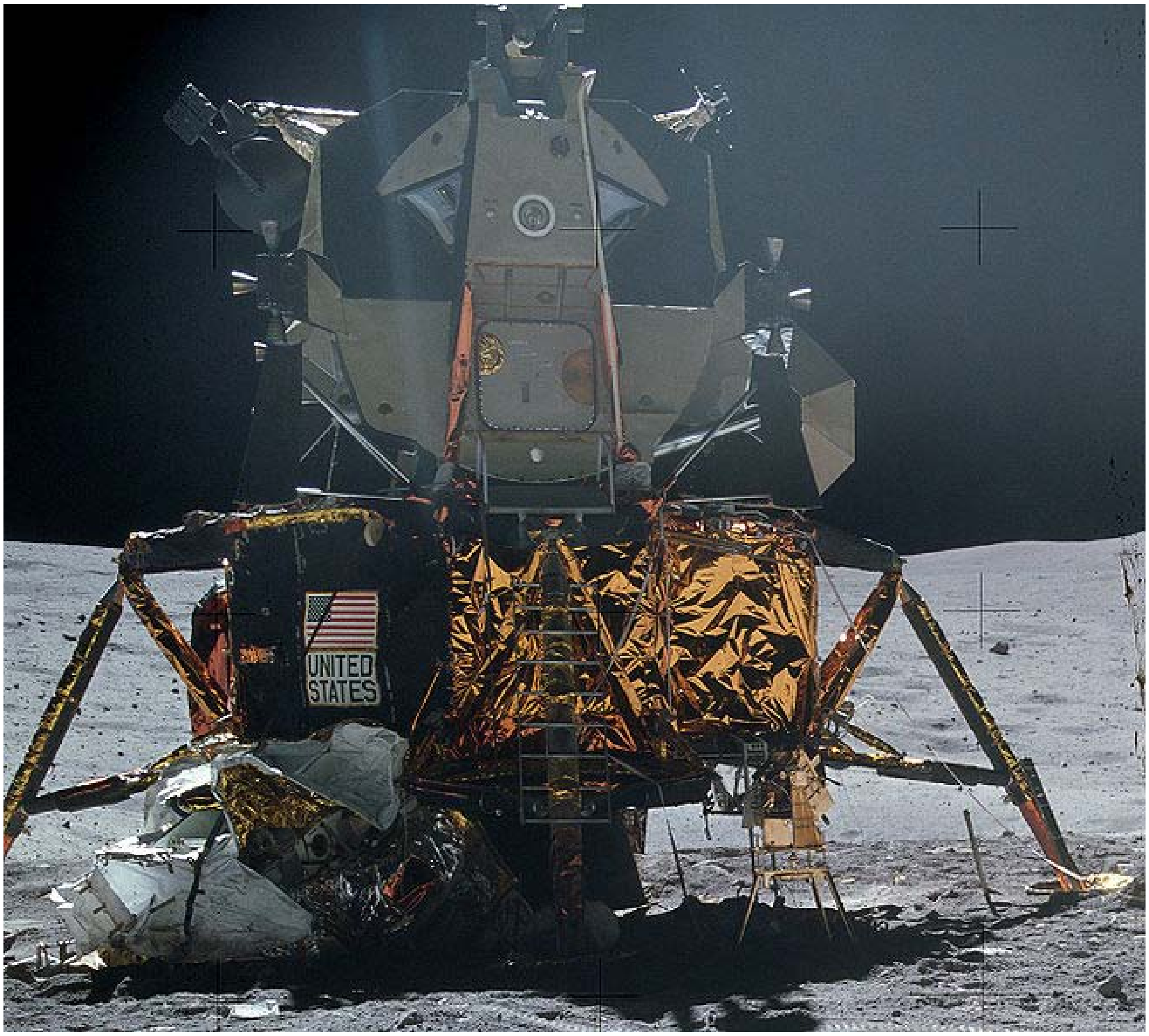
Space weather exerts a profound influence in several areas related to space exploration and development. Changing geomagnetic conditions can induce changes in atmospheric density causing the rapid degradation of spacecraft altitude in Low Earth orbit. Geomagnetic storms due to increased solar activity can potentially blind sensors aboard spacecraft, or interfere with on-board electronics. An understanding of space environmental conditions is also important in designing shielding and life support systems for manned spacecraft.

Environmental considerations

Rockets as a class are not inherently grossly polluting. However, some rockets use toxic propellants, and most vehicles use propellants that are not carbon neutral. Many solid rockets have chlorine in the form of perchlorate or other chemicals, and this can cause temporary local holes in the ozone layer. Re-entering spacecraft generate nitrates which also can temporarily impact the ozone layer. Most rockets are made of metals that can have an environmental impact during their construction.

In addition to the atmospheric effects there are effects on the near-Earth space environment. There is the possibility that orbit could become inaccessible for generations due to exponentially increasing space debris caused by spalling of satellites and vehicles (Kessler syndrome). Many launched vehicles today are therefore designed to be re-entered after use.

Spacecraft



The Apollo Lunar Module on the lunar surface

Spacecraft are vehicles capable of controlling their trajectory through space.

The first 'true spacecraft' is sometimes said to be Apollo Lunar Module, since this was the only manned vehicle to have been designed for, and operated only in space; and is notable for its non aerodynamic shape.

Human spaceflight

The first human spaceflight was Vostok 1 on April 12, 1961, on which cosmonaut Yuri Gagarin of the USSR made one orbit around the Earth. In official Soviet documents, there is no mention of the fact that Gagarin parachuted the final seven miles. The international rules for aviation records stated that "The pilot remains in his craft from launch to landing". This rule, if applied, would have "disqualified" Gagarins space-flight. Currently the only spacecraft regularly used for human spaceflight are Russian Soyuz spacecraft and the U.S. Space Shuttle fleet. Each of those space programs have used other spacecraft in the past. Recently, the Chinese Shenzhou spacecraft has been used three times for human spaceflight, and SpaceshipOne twice.

Weightlessness

Astronauts on the ISS in weightless conditions. Michael Foale can be seen exercising in the foreground.

In a microgravity environment such as that provided by a spacecraft in orbit around the Earth, humans experience a sense of "weightlessness." Short-term exposure to microgravity causes space adaptation syndrome, a self-limiting nausea caused by derangement of the vestibular system. Long-term exposure causes multiple health issues. The most significant is bone loss, some of which is permanent, but microgravity also leads to significant deconditioning of muscular and cardiovascular tissues.

Radiation

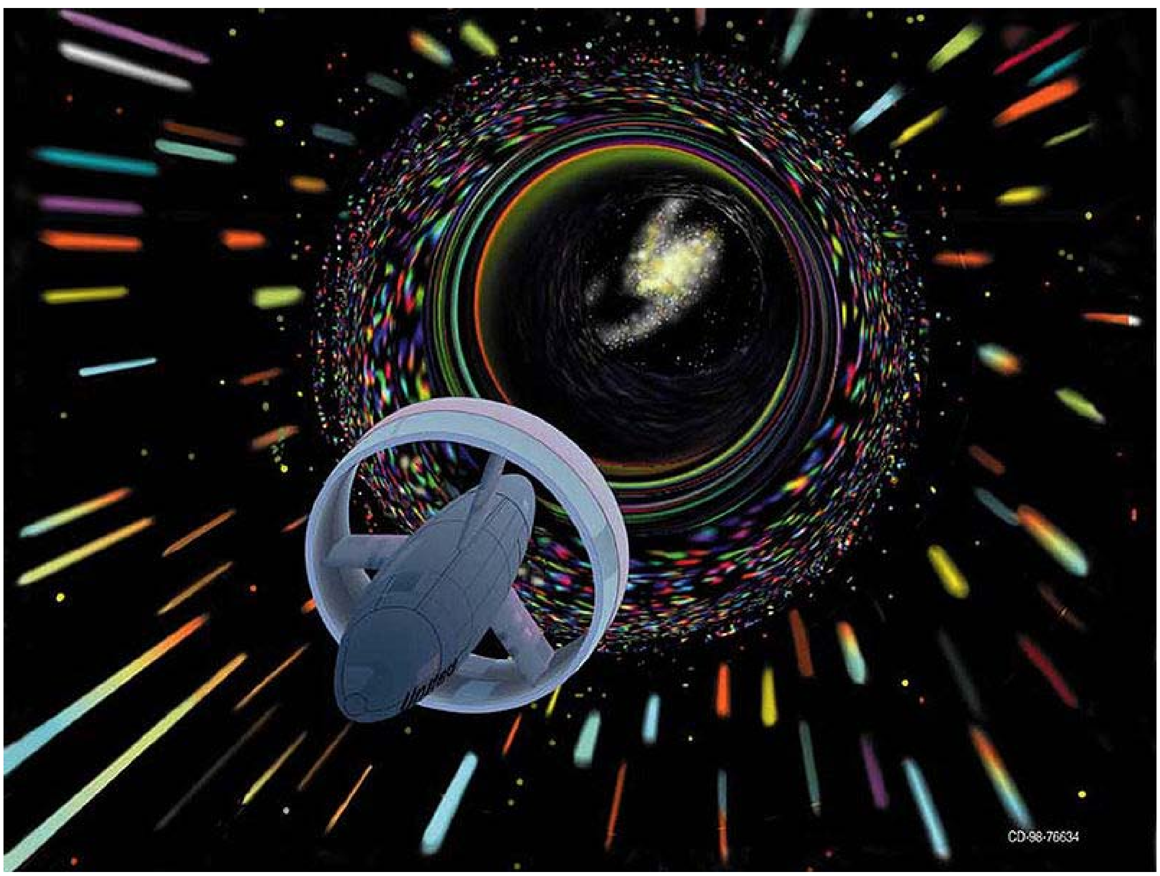
Once above the atmosphere, radiation due to the Van Allen belts, solar radiation and cosmic radiation issues occur and increase.

Further away from the Earth, solar flares can give a fatal radiation dose in minutes, and cosmic radiation would significantly increase the chances of cancer over a decade exposure or more.

Life support

In human spaceflight, the **life support system** is a group of devices that allow a human being to survive in outer space. NASA often uses the phrase **Environmental Control and Life Support System** or the acronym **ECLSS** when describing these systems for its human spaceflight missions. The life support system may supply: air, water and food. It must also maintain the correct body temperature, an acceptable pressure on the body and deal with the body's waste products. Shielding against harmful external influences such as radiation and micro-meteorites may also be necessary. Components of the life support system are life-critical, and are designed and constructed using safety engineering techniques.

Interplanetary spaceflight



An artist's imaginative impression of a vehicle entering a wormhole for interstellar travel

Interplanetary travel is travel between planets within a single planetary system. In practice, the use of the term is confined to travel between the planets of the Solar System.

Interstellar spaceflight

Five spacecraft are currently leaving the Solar System on escape trajectories. The one farthest from the Sun is Voyager 1, which is more than 100 AU distant and is moving at 3.6 AU per year. In comparison Proxima Centauri, the closest star other than the Sun, is 267,000 AU distant. It will take Voyager 1 over 74,000 years to reach this distance. Vehicle designs using other techniques, such as nuclear pulse propulsion are likely to be able to reach the nearest star significantly faster.

Another possibility that could allow for human interstellar spaceflight is to make use of time dilation, as this would make it possible for passengers in a fast-moving vehicle to travel further into the future while aging very little, in that their great speed slows down the rate of passage of on-board time. However, attaining such high speeds would still require the use of some new, advanced method of propulsion.

Intergalactic spaceflight

Intergalactic travel involves spaceflight between galaxies, and is considered much more technologically demanding than even interstellar travel and, by current engineering terms, is considered science fiction.

Astrodynamics

Astrodynamics is the study of spacecraft trajectories, particularly as they relate to gravitational and propulsion effects. Astrodynamics allows for a spacecraft to arrive at its destination at the correct time without excessive propellant use.

Spacecraft propulsion

Spacecraft today predominantly use rockets for propulsion, but other propulsion techniques such as ion drives are becoming more common, particularly for unmanned vehicles, and this can significantly reduce the vehicle's mass and increase its delta-v.

Costs, market and uses of spaceflight

Current spaceflights are frequently, but not invariably paid for by governments; but there are strong launch markets such as satellite television that is purely commercial, although the launchers themselves are often at least partly funded by governments.

Uses for spaceflight include:

- Earth observation satellites such as Spy satellites, weather satellites
- Space exploration
- Space tourism is a small market at present
- Communication satellites
- Satellite navigation

There is growing interest in spacecraft and flights paid for by commercial companies and even private individuals. It is thought that some of the high cost of access to space is due to governmental inefficiencies; and certainly the costs of the governmental paperwork surrounding NASA is legendary. If a commercial company were able to be more efficient, costs could come down significantly. Space launch vehicles such as Falcon I have been wholly developed with private finance and the quoted costs for launch are lower.

Militarization of space

A ground-based interceptor, designed to destroy incoming ICBMs, is lowered into its silo at the missile defence complex at Fort Greely, Alaska, July 22, 2004.

The **militarization of space** is the placement and development of weaponry and military technology in outer space.

History

Acquisition of high grounds for military advantage has been a perennial feature of military campaigns. For thousands of years, military tacticians have exploited the concept of "capturing" or "keeping" the high ground in military campaigns. Fortifications were built on high points, with walls that enabled archers to rain down deadly volleys. Mobile towers served as siege weapons. Ships were equipped with crow's nests that facilitated long-range reconnaissance. Hot air balloons were lofted by Napoleon, during the American Civil War, and the first World War to observe troop movements. Aircraft were initially seen as useful for high level reconnaissance, which was quickly followed by aerial battles.

Aircraft revolutionised warfare during the twentieth century, leading to "command of the air" as a key strategic concept. By extension, following the shooting down of high altitude aircraft like the U-2, the quest for safer observation went further into space. Initial attempts for control of the environment of space was led by both the US and the Soviet Union. They conducted exercises for controlling the realm of space with nuclear and conventional devices such as anti-satellite weapons (ASATs). Thus, the militarisation of space took place during the 1960s, and is now evolving into weaponisation of space with actual placement of weapons by space-faring nations for decisive military advantage. Militarisation of space is the next step in this endless struggle to gain higher ground than the enemy. The idea of placing weapons in space can be found first in 20th century science fiction stories, but it was not until World War II and the Cold War that such concepts became reality.

While military activities have certainly taken place in space (since the launch of Sputnik by the Russian military), and space is an operating location for many military spacecraft (such as imaging & communications satellites) or a temporary transit medium for weapons (such as ballistic missiles), permanent placement of operational weapons in space has never been conducted. Many fear that the permanent placement of weapons in space (as opposed to non-weapon assets) will result in destabilisation of the strategic situation between the great powers, and cause what might be referred to as an arms race, leading to enormous expenditures of national resources on all sides, decreasing overall security for every nation, while benefiting only the arms industry, who funds many of the various advocates for weaponization of space.

World War II and the V-2 rocket

As early as 1927 members of the *Verein für Raumschiffahrt (VfR)* ("Spaceflight Society") had started experimenting with liquid-fuelled rockets. Rockets using a solid propellant had been used as weapons by all sides in WWI, and as a result, the Treaty of Versailles forbade solid fuel rocket research in Germany. By 1932 the Reichswehr started taking notice of their developments for potential long-range artillery use, and a team led by

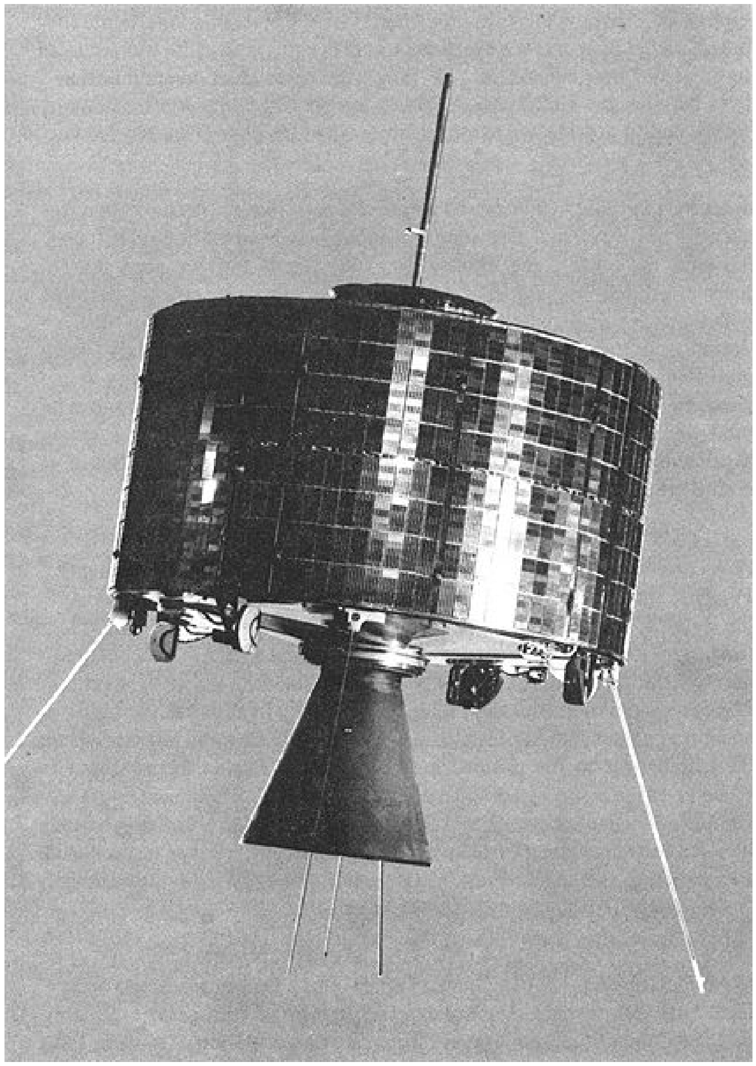
General Walter Dornberger was shown a test vehicle designed and flown by Wernher von Braun. Although the rocket was of limited ability, Dornberger saw von Braun's genius and pushed for him to join the military.

Von Braun did so, as eventually did most of the other members of the society. In December 1934 von Braun scored another success with the flight of the A2 (*A* for *Aggregat*) rocket, a small model powered by ethanol and liquid oxygen, with work on the design continuing in an attempt to improve reliability. Many different liquid fuels had been developed, but the German military specifically encouraged the use of ethanol as a rocket fuel because Germany had always been hampered by a shortage of crude-oil-based fuels. Throughout WWII a wide variety of military rockets were fuelled by ethanol that was primarily derived from potatoes.

By 1936 the team had moved on from the A2 and started work on both the A3 and A4. The latter was a full-sized design with a range of about 175 km (110 miles), a top altitude of 80 km and a payload of about a tonne. This increase in capability had come through a complete redesign of the engine by Walter Thiel. It was clear that von Braun's designs were turning into real weapons.

The A3 proved to be problematic, and a redesign was started as the A5. This version was completely reliable, and by 1941 the team had fired about 70 A5 rockets. The first A4 flew in March 1942, flying about 1.6 km and crashing into the water. The second launch reached an altitude of 11 km before exploding. The third rocket, launched on October 3, 1942, changed things by following its trajectory perfectly. It landed 193 km away, and became the first man-made object to enter space. Production started in 1943 on the wonder weapon *Vergeltungswaffe 2* (reprisal weapon 2), or the V-2 as it became better known, at the insistence of Goebbels' propaganda ministry.

The Cold War



The Syncom satellites set major milestones in space communications, Syncom 2 was the first geosynchronous satellite, Syncom 3 was placed in the first geostationary orbit.

During the Cold War, the world's two great superpowers — the Soviet Union and the United States of America — spent large proportions of their GDP on developing military technologies. In 1957, the USSR launched the first artificial satellite, *Sputnik 1*. The ability to place objects in orbit stimulated space research and started the Space Race.

By the end of the 1960s, both countries regularly deployed satellites. Spy satellites were used by militaries to take accurate pictures of their rivals' military installations. As time passed the resolution and accuracy of orbital reconnaissance alarmed both sides of the iron curtain. Both the United States and the Soviet Union began to develop anti-satellite weapons to blind or destroy each other's satellites. Laser weapons, kamikaze style satellites, as well as orbital nuclear explosion were researched with varying levels of success. Spy satellites were, and continue to be, used to monitor the dismantling of military assets in accordance with arms control treaties signed between the two superpowers. To use spy satellites in such a manner is often referred to in treaties as "national technical means of verification".

The superpowers developed ballistic missiles to enable them to use nuclear weaponry across great distances. As rocket science developed, the range of missiles increased and intercontinental ballistic missiles (ICBM) were created, which could strike virtually any target on Earth in a timeframe measured in minutes rather than hours or days. In order to cover large distances ballistic missiles are usually launched into sub-orbital spaceflight. An intercontinental missile's altitude halfway through delivery is ca. 1200 km.

Test of the LG-118A Peacekeeper missile, each one of which can carry 10 independently targeted nuclear warheads along trajectories outside of the Earth's atmosphere.

As soon as intercontinental missiles were developed, military planners began programmes and strategies to counter their effectiveness.

USA

Early American efforts included the Nike-Zeus Program, Project Defender, the Sentinel Program and the Safeguard Program. The late 1950s Nike-Zeus Program involved firing Nike nuclear missiles against oncoming ICBMs thus exploding nuclear warheads over the North Pole. This idea was soon scrapped and work began on Project Defender in the 1960s. Project Defender attempted to destroy Soviet ICBMs at launch with satellite weapon systems, which orbited over Russia. This programme proved unfeasible with the technology from that era. Work then began on the Sentinel Program which used anti-ballistic missiles (ABM) to shoot down incoming ICBMs. The Safeguard Program was deployed in the mid 1970's and was based on the Sentinel Program. Since the ABM treaty only allowed for construction of a single ABM facility to protect either the nation's capital city or an ICBM field, the Stanley R. Mickelsen Safeguard Complex was constructed near Nekoma, North Dakota to protect the Grand Forks ICBM facility. Though it was only operational as an ABM facility for less than a year, the Perimeter Acquisition Radar (PAR), one of Safeguard's components, was still operational as of 2005. One major problem with the Safeguard Program, and past ABM systems, was that the interceptor missiles, though state of the art, required nuclear warheads to destroy incoming ICBMs. Future ABMs will likely be more accurate and utilize hit-to-kill or conventional warheads to knock down incoming warheads. The technology involved in such systems was shaky at best, and deployment was limited by the ABM treaty of 1972.

In 1983 American president Ronald Reagan proposed the "Strategic Defense Initiative" — a space-based system to protect the United States from attack by strategic nuclear missiles. The plan was ridiculed by some as unrealistic and expensive, and Dr. Carol Rosin nicknamed the policy "Star Wars", after the popular science-fiction movie franchise. The late astronomer Carl Sagan, amongst others, pointed out that in order to defeat "Star Wars" the Soviet Union had only to build more missiles, allowing them to overcome the defense by sheer force of numbers. Proponents of the "Star Wars" policy champion the strategy of technology for hastening the Soviet Union's downfall. According to this viewpoint, Communist leaders were forced to either shift large portions of their GDP to counter perceived "Star Wars" weapon systems or watch as their expensive nuclear stockpiles were rendered obsolete.

United States Space Command (USSPACECOM), a unified command of the United States military was created in 1985 to help institutionalize the use of outer space by the United States Armed Forces. The Commander in Chief of U.S. Space Command (CINCUSSPACECOM), with headquarters at Peterson Air Force Base, Colorado was also the Commander in Chief of the binational U.S.-Canadian *North American Aerospace Defense Command* (CINCNORAD) and for the majority of time during USSPACECOM's existence also the Commander of the U.S. Air Force major command Air Force Space Command. Military space operations coordinated by USSPACECOM proved to be very valuable for the U.S.-led coalition in the 1991 Persian Gulf War.

The U.S. military has relied on communications, intelligence, navigation, missile warning and weather satellite systems in areas of conflict since the early 1990s, including the Balkans, Southwest Asia and Afghanistan. Space systems are considered indispensable providers of tactical information to U.S. warfighters.

As part of the ongoing initiative to transform the U.S. military, on June 26, 2002, Secretary of Defense Donald Rumsfeld announced that U.S. Space Command would merge with USSTRATCOM. The UCP directed that Unified Combatant Commands be capped at ten, and with the formation of the new United States Northern Command, one would have to be deactivated in order to maintain that level. Thus the USSPACECOM merger into USSTRATCOM.

USSR

The Soviet Union was also researching innovative ways of gaining space supremacy. Two of their most notable efforts were the Fractional Orbital Bombardment System (FOBS) and Polyus orbital weapons system.

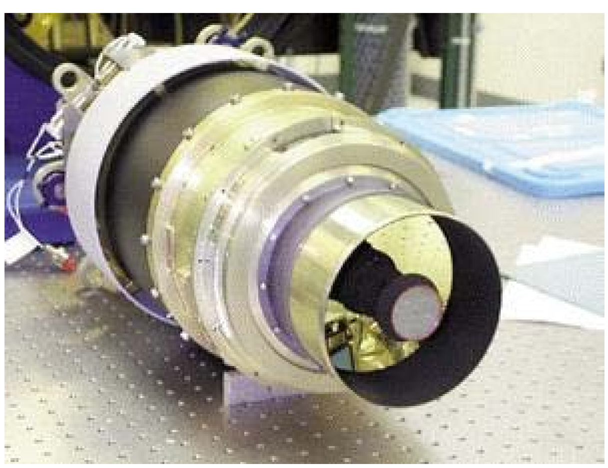
FOBS was a Soviet ICBM in the 1960s that once launched would go into a low Earth orbit whereupon it would de-orbit for an attack. This system would create a path to North America over the South Pole, striking targets from the opposite direction from which NORAD early warning systems are oriented. The missile was phased out in January 1983 in compliance with the SALT II treaty.

The SALT II treaty (1979) prohibited the deployment of FOBS systems:

> *Each Party undertakes not to develop, test, or deploy:*
> *(...)*
> *(c) systems for placing into Earth orbit nuclear weapons or any other kind of weapons of mass destruction, including fractional orbital missiles;*

On May 15, 1987, an Energia rocket flew for the first time. The payload was a prototype orbital weapons platform Polyus (also known as Polus, Skif-DM or 17F19DM), the final version of which according to some reports could be armed with nuclear space mines and defensive cannon. The Polyus weapons platform was designed to defend itself against anti-satellite weapons with recoilless cannon. It was also equipped with a sensor blinding laser to confuse approaching weapons and could launch test targets to validate the fire control system. The attempt to place the satellite into orbit failed.

Post-Cold War



A Lightweight Exo-Atmospheric Projectile (LEAP), which attaches to a modified SM-2 Block IV missile used by the U.S. Navy

As the Cold War ended with the implosion of the Soviet Union the space race between the two superpowers ended. The United States of America was left as the only superpower on Earth with a large concentration of the world's wealth and technological advancement. Despite the United States' new status in the world, the monopoly of space militarisation is in no way certain. Countries such as China, Japan, and India have begun their own space programmes, while the European Union collectively works to create satellite systems to rival those of the United States.

The USSR Space Forces were established as the Ministry of Defense Space Units in 1982. In 1991 the Soviet Union was broken up. The Russian Armed Forces were established on 7 May 1992, enabling the creation of Russian Space Forces later that year on 10 August. In July 1997 the Space Force was dissolved as a separate service arm and incorporated to the Strategic Rocket Forces along with the Space Missile Defense Forces, which previously were part of the Troops of Air Defense. The Russian Space Forces were officially reborn on June 1, 2001 as an independent section of the Russian military.

Post Cold War space militarisation seems to revolve around three types of applications. (The word "seems" is used because much of this subject matter is inconclusively verifiable, due to the high level of secrecy that exists among the great powers with regard to the details of space sensing systems.) The first application is the continuing development of "spy" or reconnaissance satellites which began in the Cold War era, but has progressed significantly since that time. Spy satellites perform a variety of missions such as high resolution photography (IMINT), communications eavesdropping (SIGINT), and covert communications (HUMINT). These tasks are performed on a regular basis both during peacetime and war operations. Satellites are also used by the nuclear states to provide early warning of missile launches, locate nuclear detonations, and detect preparations for otherwise clandestine or surprise nuclear tests (at least those tests or preparations carried out above-ground); this was the case when, in 1998, India and Pakistan both conducted a series of nuclear tests; in addition, a nuclear-detection satellite of the Vela type was also reported to have detected a nuclear detonation in the Indian Ocean in 1978 that was believed to be a South African nuclear test in what was famously called the Vela Incident. Early-warning satellites can also be used to detect tactical missile launches; this capability was used during Desert Storm when America was able to provide advanced warning to Israel of Iraqi SS-1 SCUD missile launches.

Spy satellites

Types of spy satellites

- United States
    - Lacrosse/Onyx
    - Misty/Zirconic
    - Samos
    - Quasar
    - Vela
- Soviet Union

    - Cosmos
    - Almaz (manned)
    - Yantar
    - Zenit
- United Kingdom
    - Zircon (project cancelled)
    - Skynet
- France
    - Helios 1B (destroyed), Helios 2A
- Germany
    - SAR-Lupe 1-5
- Italy
    - COSMO-SkyMed
- People's Republic of China
    - Fanhui Shi Weixing
- India
    - Technology Experiment Satellite

Global Positioning Systems

The second application of space militarisation currently in use is GPS or Global Positioning System. The US military refers to it as NAVSTAR GPS - Navigation Signal Timing and Ranging Global Positioning System. This satellite navigation system is used for determining one's precise location and providing a highly accurate time reference almost anywhere on Earth or in Earth orbit. It uses an intermediate circular orbit (ICO) satellite constellation of at least 24 satellites. The GPS system was designed by and is controlled by the United States Department of Defense and can be used by anyone, free of charge. The cost of maintaining the system is approximately US$400 million per year, including the replacement of aging satellites. The first of 24 satellites that form the current GPS constellation (Block II) was placed into orbit on February 14, 1989. The 52nd GPS satellite since the beginning in 1978 was launched November 6, 2004 aboard a Delta II rocket. The primary military purposes are to allow improved command and control of forces through improved location awareness, and to facilitate accurate targeting of smart bombs, cruise missiles, or other munitions. The satellites also carry nuclear detonation detectors, which form a major portion of the United States Nuclear Detonation Detection System. On May 1, 2000, US President Bill Clinton announced that "Selective Availability" may be used to jam civilian GPS units in a war zone or global alert while allowing military units to use GPS as they saw fit. However, European concern about the level of control over the GPS network and commercial issues has resulted in the planned Galileo positioning system. Russia already operates an independent system called GLONASS (global navigation system), the system operates with 24 satellites that are deployed in 3 orbital planes as opposed to the 4 GPS is deployed in.

Military communication systems

The third current application of militarisation of space can be demonstrated by the emerging military doctrine of network-centric warfare. Network-centric warfare relies heavily on the use of high speed communications which allows all soldiers and branches of the military to view the battlefield in real-time. Real-time technology improves the situational awareness of all of the military's assets and commanders in a given theatre. For example, a soldier in the battle zone can access satellite imagery of enemy positions two blocks away, and if necessary e-mail the coordinates to a bomber or weapon platform hovering overhead while the commander, hundreds of miles away, watches as the events unfold on a monitor. This high-speed communication is facilitated by a separate internet created by the military for the military. Communication satellites hold this system together by creating an informational grid over the given theatre of operations. The Department of Defense is currently working to establish a Global Information Grid to connect all military units and branches into a computerised network in order to share information and create a more efficient military.

Military spaceplanes

It was revealed that Soviet officials were concerned that the US Space Shuttle program had such military objectives such as to make a sudden dive into the atmosphere to drop bombs on Moscow and these concerns were part of the motivation behind pursuing their own Buran program.

The NASA uncrewed spaceplane project X-37 was transferred to the US Department of Defense in 2004. It is unclear what its military mission would be. The X-37 is akin to a space version of Unmanned aerial vehicle or Unmanned combat air vehicle.

Weapons in space

Space weapons are weapons used in space warfare. They include weapons that can attack space systems in orbit (i.e. anti-satellite weapons), attack targets on the earth from space or disable missiles travelling through space. In the course of the militarisation of space, such weapons were developed mainly by the contesting superpowers during the Cold War, and some remain under development today. Space weapons are also a central theme in military science fiction and sci-fi video games.

Terrestrial-type weapons in space

Soviet Union, and later Russian cosmonauts have regularly carried small arms (handguns) on spacecraft, as part of the special emergency kit included in landing capsules. The weapon was included to protect the cosmonauts from wild animals after re-entry if the capsule landed in a wilderness area and could not be quickly retrieved. United States Astronauts are also provided a firearm for similar use

The Russian space station Salyut 3 was fitted with a 23mm cannon, which was successfully test fired at target satellites, at ranges from 500 m to 3000 m.

Space warfare

Space warfare is combat that takes place in outer space, i.e. outside the atmosphere. Technically, as a distinct classification, it refers to battles where the targets themselves are in space. Space warfare therefore includes *ground-to-space warfare*, such as attacking satellites from the Earth, as well as *space-to-space warfare*, such as satellites attacking satellites.

It does not include the use of satellites for espionage, surveillance, or military communications, however useful those activities might be. It does not technically include *space-to-ground warfare*, where orbital objects attack ground, sea or air targets directly, but the public and media frequently use the term to include any conflict which includes space as a theater of operations, regardless of the intended target. For example, a rapid delivery system in which troops are deployed from orbit might be described as "space warfare," even though the military uses the term as described above.

A film was produced by the U.S. Military in the early 1960s called *Space and National Security* which depicted space warfare. From 1985 to 2002 there was a United States Space Command, which in 2002 merged with the United States Strategic Command. There is a Russian Space Force, which was established on August 10, 1992, and which became an independent section of the Russian military on June 1, 2001.

Only a few incidents of space warfare have occurred in world history, and all were training missions, as opposed to actions against real opposing forces. In the mid-1980s a USAF pilot in an F-15 successfully shot down the P78-1, a communications satellite in a 345 mile (555 km) orbit.

In 2007 the People's Republic of China used a missile system to destroy one of its obsolete satellites, and in 2008 the United States similarly destroyed its malfunctioning satellite USA 193. To date, there have been no human casualties resulting from conflict in space, nor has any ground target been successfully neutralized from orbit.

International treaties governing space limit or regulate conflicts in space and limit the installation of weapon systems, especially nuclear weapons.

Space treaties

As both sides stagnated under the pressures of mutual assured destruction (MAD) blocs of countries worked together to avoid extending the threat of nuclear weapons to space based launchers.

Outer Space Treaty

The Outer Space Treaty, considered by the Legal Subcommittee in 1966. Later that year, agreement was reached in the General Assembly. The treaty included the following principles:

- the exploration and use of outer space shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind;
- outer space shall be free for exploration and use by all States;
- outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means;
- States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner;
- the Moon and other celestial bodies shall be used exclusively for peaceful purposes;
- Astronauts shall be regarded as the envoys of mankind;
- States shall be responsible for national space activities whether carried out by governmental or non-governmental activities;
- States shall be liable for damage caused by their space objects; and
- States shall avoid harmful contamination of space and celestial bodies.

In summary, the treaty initiated the banning of signatories' placing of nuclear weapons or any other weapons of mass destruction in orbit of Earth, installing them on the moon or any other celestial body, or to otherwise station them in outer space. The United States, the United Kingdom, and the Soviet Union signed the treaty and it entered into effect on October 10, 1967. As of January 1, 2005, 98 States have ratified, and an additional 27 have signed the Outer Space Treaty.

Space Preservation Treaty

The Space Preservation Treaty was a proposed 2006 UN General Assembly resolution against all space weapons. In the UN General Assembly voting, the US most consistently voted or abstained against most provisions.

National Missile Defense (NMD)

The logo of the Missile Defense Agency

With the fall of the Soviet Union and the end of the Cold War defense spending was reduced and space research was chiefly focused on peaceful research. American military research is focused on a more modest goal of preventing the United States from being subject to nuclear blackmail or nuclear terrorism by a rogue state.

On 16 December 2002, US President George W. Bush signed National Security Presidential Directive which outlined a plan to begin deployment of operational ballistic missile defense systems by 2004. The following day the US formally requested from the UK and Denmark use of facilities in RAF Fylingdales, England and Thule, Greenland, respectively, as a part of the NMD Program. The administration continued to push the program, despite publicized failures and the objections of some scientists who opposed it. The projected cost of the program for the years 2004 to 2009 was 53 billion US dollars, making it the largest single line in The Pentagon's budget.

Chapter- 7

Space Colonization

Artist Les Bossinas' 1989 concept of Mars mission

Space Colonization (space settlement, space humanization, space habitation) is autonomous (self-sufficient) human habitation outside of Earth. It is a long-term goal of national space programs.

The first space colony may be on the Moon, or on Mars. Ample quantities of all the necessary materials, such as solar energy and water, are on the Moon, Mars, or near Earth asteroids.

In 2005 NASA Administrator Michael Griffin identified space colonization as the ultimate goal of current spaceflight programs, saying:

... the goal isn't just scientific exploration ... it's also about extending the range of human habitat out from Earth into the solar system as we go forward in time ... In the long run a single-planet species will not survive ... If we humans want to survive for hundreds of thousands or millions of years, we must ultimately populate other planets. Now, today the technology is such that this is barely conceivable. We're in the infancy of it. ... I'm talking about that one day, I don't know when that day is, but there will be more human beings who live off the Earth than on it. We may well have people living on the moon. We may have people living on the moons of Jupiter and other planets. We may have people making habitats on asteroids ... I know that humans will colonize the solar system and one day go beyond.

– Michael D. Griffin

The NASA Lunar outpost, providing a permanent human presence on the moon, is at the planning stage. There is an ongoing development of technologies that may be used in future space colonization projects.

Method

Building colonies in space would require access to water, food, space, people, construction materials, energy, transportation, communications, life support, simulated gravity, and radiation protection. It is likely the colonies would be located by proximity to such resources. The practice of space architecture seeks to transform spaceflight from a heroic test of human endurance to a normality within the bounds of comfortable experience.

Materials

Colonies on the Moon, Mars, or asteroids could extract local materials. The moon is deficient in volatiles such as argon, helium and compounds of carbon, hydrogen and nitrogen. The LCROSS impacter was targeted at the Cabeus crater which was chosen as having a high concentration of water for the moon. A plume of material erupted in which some water was detected. Anthony Colaprete estimated that the Cabeus crater contains material with 1% water or possibly more. Water ice should also be in other permanently shadowed craters near the lunar poles. Although helium is present only in low concentrations on the moon, where it is deposited into regolith by the solar wind, an estimated million tons of He3 exists over all. It also has industrially significant oxygen, silicon, and metals such as iron, aluminum, and titanium. Launching materials from Earth is expensive, so bulk materials could come from the Moon, a Near-Earth Object (NEO—an asteroid or comet with an orbit near Earth), Phobos, or Deimos, where gravitational forces are much smaller, there is no atmosphere, and there is no biosphere to damage. Many NEOs contain substantial amounts of metals, oxygen, hydrogen, and carbon. Certain NEOs may contain nitrogen.

Farther out, Jupiter's Trojan asteroids are thought to be high in water ice and probably other volatiles.

Energy

Solar energy in orbit is abundant, reliable, and is commonly used to power satellites today. There is no night in space, and no clouds or atmosphere to block sunlight. The solar energy available at any distance, *d,* from the Sun can be calculated by the formula $E = 1367/d^2$ watts per square meter, where *d* is measured in astronomical units.

Particularly in the weightless conditions of space, sunlight can be used directly, using large solar ovens made of lightweight metallic foil so as to generate thousands of degrees of heat; or reflected onto crops to enable photosynthesis to proceed.

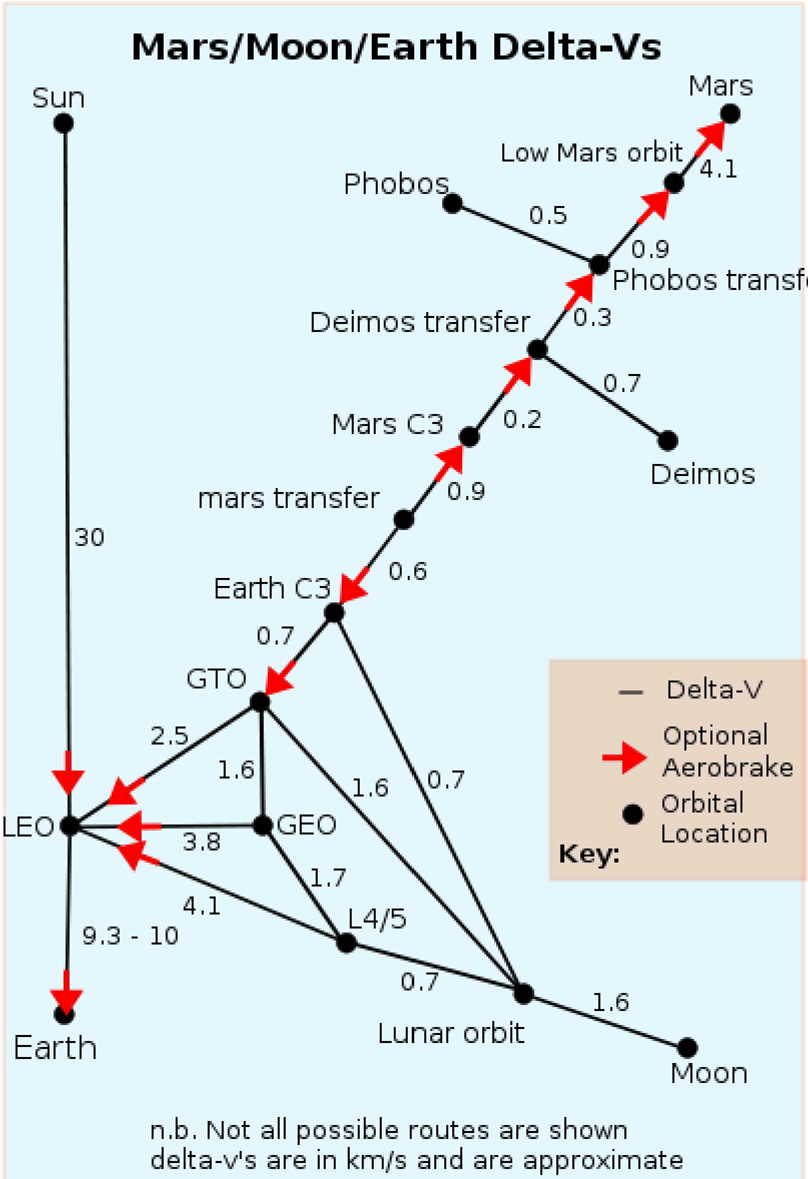
Large structures would be needed to convert sunlight into significant amounts of electrical power for settlers' use. In highly electrified nations on Earth, electrical consumption can average 1 kilowatt/person (or roughly 10 megawatt-hours per person per year.)

Energy may be an eventual export item for space settlements, perhaps using wireless power transmission e.g. via microwave beams to send power to Earth or the Moon. This method has zero emissions, so would have significant benefits such as elimination of greenhouse gases and nuclear waste. Ground area required per watt would be less than conventional solar panels.

The Moon has nights of two Earth weeks in duration and Mars has night, dust, and is farther from the Sun, reducing solar energy available by a factor of about ½-⅔, and possibly making nuclear power more attractive on these bodies. Alternatively, energy could be transmitted to the lunar and martian surfaces from solar power satellites.

For both solar thermal and nuclear power generation in airless environments, such as the Moon and space, and to a lesser extent the very thin Martian atmosphere, one of the main difficulties is dispersing the inevitable heat generated. This requires fairly large radiator areas.

Transportation



Delta-v's in km/s for various orbital maneuvers using conventional rockets. Red arrows show where optional aerobraking can be performed in that particular direction, black numbers give delta-v in km/s that apply in either direction.

Space access

Transportation to orbit is often the limiting factor in space endeavours. To settle space, much cheaper launch vehicles are required, as well as a way to avoid serious damage to the atmosphere from the thousands, perhaps millions, of launches required. One possibility is the air-breathing hypersonic spaceplane under development by NASA and other organizations, both public and private. There are also proposed projects such as building a space elevator or a mass driver; or launch loops.

Cislunar and solar system travel

Transportation of large quantities of materials from the Moon, Phobos, Deimos, and Near Earth asteroids to orbital settlement construction sites is likely to be necessary.

Transportation using off-Earth resources for propellant in conventional rockets would be expected to massively reduce in-space transportation costs compared to the present day. Propellant launched from the Earth is likely to be prohibitively expensive for space colonization, even with improved space access costs.

Other technologies such as tether propulsion, VASIMR, ion drives, solar thermal rockets, solar sails, magnetic sails, and nuclear thermal propulsion can all potentially help solve the problems of high transport cost once in space.

For lunar materials, one well-studied possibility is to build mass drivers to launch bulk materials to waiting settlements. Alternatively, lunar space elevators might be employed.

Communication

Compared to the other requirements, communication is easy for orbit and the Moon. A great proportion of current terrestrial communications already passes through satellites. Yet, as colonies further from the earth are considered, communication becomes more of a burden. Transmissions to and from Mars suffer from significant delays due to the speed of light and the greatly varying distance between conjunction and opposition — the lag will range between 7 and 44 minutes — making real-time communication impractical. Other means of communication that do not require live interaction such as e-mail and voice mail systems should pose no problem.

Life support

In space settlements, a closed ecological system must recycle or import all the nutrients without "crashing." The closest terrestrial analogue to space life support is possibly that of the nuclear submarine. Nuclear submarines use mechanical life support systems to support humans for months without surfacing, and this same basic technology could presumably be employed for space use. However, nuclear submarines run "open loop"— extracting oxygen from seawater, and typically dumping carbon dioxide overboard, although they recycle existing oxygen. Recycling of the carbon dioxide has been approached in the literature using the Sabatier process or the Bosch reaction.

The Biosphere 2 project in Arizona has shown that a complex, small, enclosed, man-made biosphere can support eight people for at least a year, although there were many problems. A year or so into the two-year mission oxygen had to be replenished, which strongly suggests that they achieved atmospheric closure.

The relationship between organisms, their habitat and the non-Earth environment can be:

- Organisms and their habitat fully isolated from the environment (examples include artificial biosphere, Biosphere 2, life support system)
- Changing the environment to become a life-friendly habitat, a process called terraforming.
- Changing organisms to become more compatible with the environment

A combination of the above technologies is also possible.

97–99% of the light energy provided to the plant ends up as heat and needs to be dissipated somehow to avoid overheating the habitat.

Radiation protection

Cosmic rays and solar flares create a lethal radiation environment in space. In Earth orbit, the Van Allen belts make living above the Earth's atmosphere difficult. To protect life, settlements must be surrounded by sufficient mass to absorb most incoming radiation. About five to ten tons of material per square meter of surface area is required. This can be leftover material (slag) from processing lunar soil and asteroids into oxygen, metals, and other useful materials, however it represents a significant obstacle to maneuvering vessels with such massive bulk. Inertia would necessitate powerful thrusters to start or stop rotation, or electric motors to spin two massive portions of a vessel in opposite senses. Shielding material can be stationary around a rotating interior. Hull-metals can also be magnetized to provide additional protection without adding mass.

Self-replication

Self-replication is an optional attribute, but some think it the ultimate goal because it allows a much more rapid increase in colonies, while eliminating costs to and dependence on Earth. It could be argued that the establishment of such a colony would be Earth's first act of self-replication. Intermediate goals include colonies that expect only information from Earth (science, engineering, entertainment) and colonies that just require periodic supply of light weight objects, such as integrated circuits, medicines, genetic material and tools.

Population size

In 2002, the anthropologist John H. Moore estimated that a population of 150–180 would allow normal reproduction for 60 to 80 generations — equivalent to 2000 years.

A much smaller initial population of as little as two female humans should be viable as long as human embryos are available from Earth. Use of a sperm bank from Earth also allows a smaller starting base with negligible inbreeding.

Researchers in conservation biology have tended to adopt the "50/500" rule of thumb initially advanced by Franklin and Soule. This rule says a short-term effective population size (N_e) of 50 is needed to prevent an unacceptable rate of inbreeding, while a long-term N_e of 500 is required to maintain overall genetic variability. The $N_e = 50$ prescription corresponds to an inbreeding rate of 1% per generation, approximately half the maximum rate tolerated by domestic animal breeders. The $N_e = 500$ value attempts to balance the rate of gain in genetic variation due to mutation with the rate of loss due to genetic drift.

Location

Location is a frequent point of contention between space colonization advocates.

The location of colonization can be on a physical body or free-flying:

- On a planet, natural satellite, or asteroid
- In orbit around the Earth, Sun, Lagrangian point or other object

Planetary locations

Some planetary colonization advocates cite the following potential locations:

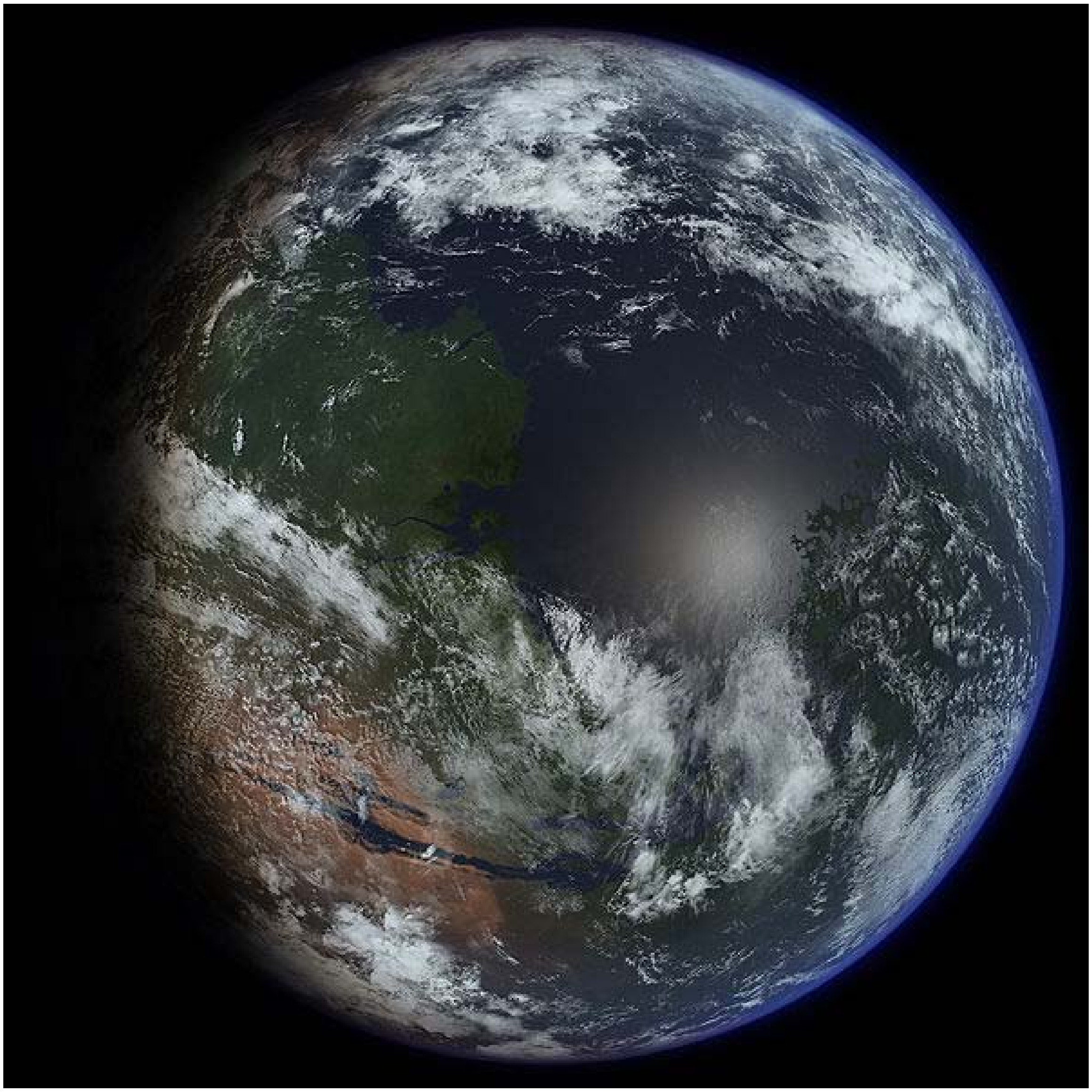
Mars

The surface of Mars is about the same size as the dry land surface of Earth. The ice in Mars' south polar cap, if spread over the planet, would be a layer 12 meters (39 feet) thick and there is carbon (locked as carbon dioxide in the atmosphere).

Mars may have gone through similar geological and hydrological processes as Earth and therefore contain valuable mineral ores. Equipment is available to extract *in situ* resources (e.g., water, air) from the Martian ground and atmosphere. There is interest in colonizing Mars in part because life could have existed on Mars at some point in its history, and may even still exist in some parts of the planet.

However, its atmosphere is very thin (averaging 800 Pa or about 0.8% of Earth sea-level atmospheric pressure); so the pressure vessels necessary to support life are very similar to deep space structures. The climate of Mars is colder than Earth's. Its gravity is only around a third that of Earth's; it is unknown whether this is sufficient to support human beings for extended periods (all long-term human experience to date has been at around Earth gravity or one g).

The atmosphere is thin enough, when coupled with Mars' lack of magnetic field, that radiation is more intense on the surface, and protection from solar storms would require radiation shielding.



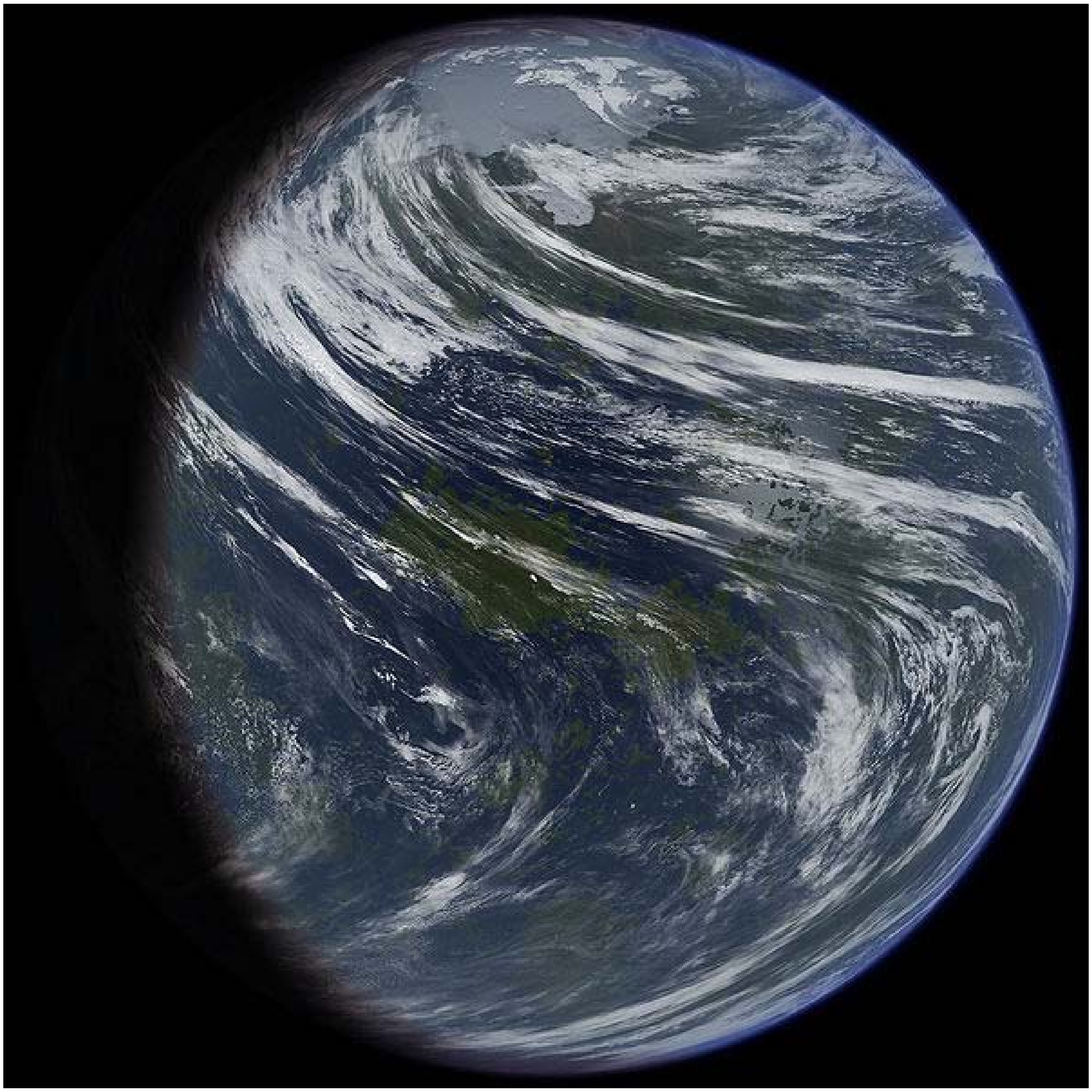
An artist's conception of a terraformed Mars (2009)

Terraforming Mars would make life outside of pressure vessels on the surface possible. There is some discussion of it actually being done.

Mercury

There is a suggestion that Mercury could be colonized using the same technology, approach and equipment that is used in colonization of the Moon. Such colonies would almost certainly be restricted to the polar regions due to the extreme daytime temperatures elsewhere on the planet. The recent discovery of ionized water has astounded scientists. This discovery significantly improves the small planet's prospects as a future colony.

Venus



Artist's impression of a terraformed Venus

While the surface of Venus is far too hot and features atmospheric pressure at least 90 times that at sea level on Earth, its massive atmosphere offers a possible alternate location for colonization. At an altitude of approximately 50 km, the pressure is reduced to a few atmospheres, and the temperature would be between 40–100 °C, depending on the altitude. This part of the atmosphere is probably within dense clouds which contain some sulfuric acid. Even these may have a certain benefit to colonization, as they present a possible source for the extraction of water.

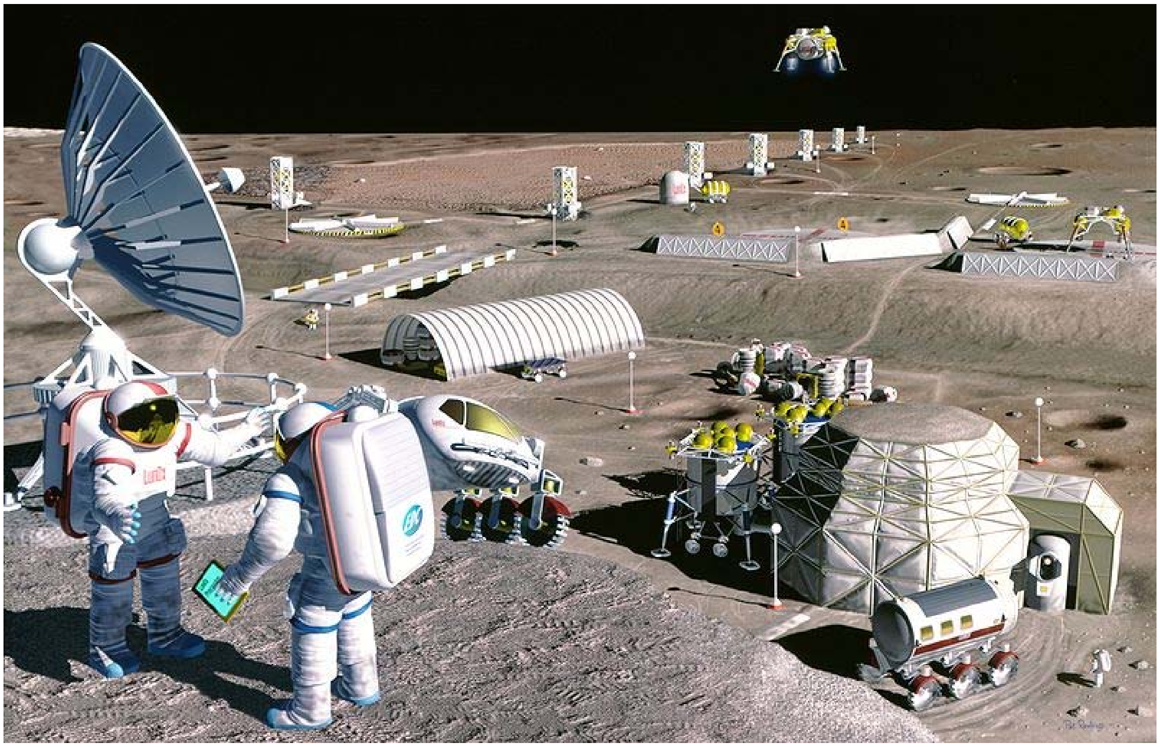
Gas giants

It may be possible to colonize the three farthest gas giants with floating cities in their atmospheres. By heating hydrogen balloons, large masses can be suspended underneath at roughly Earth gravity. A human colony on Jupiter would be less practical due to its high gravity, escape velocity and radiation. Such colonies could export Helium-3 for use in fusion reactors if they ever become practical. Escape from the gas giant planets (especially Jupiter) seems well beyond current or near-term foreseeable chemical rocket technology however, due to the combination of large velocity and high acceleration needed even to achieve low orbit.

Paul Birch suggested a method of colonizing the gas giants that did not use buoyancy to support the colony in the atmosphere. He suggested a strip colony extending completely around the planet. It would rotate at the same speed as the planetary atmosphere at the equator and be held above the atmosphere by rotating mass internal to the strip and connected to the strip by only magnetic force. This rotating mass would be isolated from the strip colony by a vacuum. The extent of the strip colony could be such that the bottom edge is within the atmosphere for communication with the planet and extraction of raw materials. In the vacuum environment outside the top edge of the strip, electromagnetic acceleration to or from orbital velocity would provide communication with interplanetary space. This sort of colony would be especially suitable for Saturn, Uranus and Neptune for which the gravitational attraction at the altitude of the visible atmosphere is near one Earth gravity. A robotic levitated equatorial strip colony at Jupiter could allow the extraction of raw materials from that planet.

Satellite locations

The Moon



Moon colony (1995)

Due to its proximity and familiarity, Earth's Moon is discussed as a target for colonization. It has the benefits of proximity to Earth and lower escape velocity, allowing for easier exchange of goods and services. A drawback of the Moon is its low abundance of volatiles necessary for life such as hydrogen, nitrogen, and carbon. Water ice deposits that exist in some polar craters could serve as a source for these elements. An alternative solution is to bring hydrogen from near earth asteroids and combine it with oxygen extracted from lunar rock.

The moon's low surface gravity is also a concern (it is unknown whether 1/6g is sufficient to support human habitation for long periods).

Jovian moons - Europa, Callisto and Ganymede

The Artemis Project designed a plan to colonize Europa, one of Jupiter's moons. Scientists were to inhabit igloos and drill down into the Europan ice crust, exploring any sub-surface ocean. This plan discusses possible use of "air pockets" for human inhabitation. Europa is considered one of the more habitable bodies in the solar system and so merits investigation as a possible abode for life.

Ganymede is the largest moon in the Solar System. It may be attractive as Ganymede is the only moon with a magnetosphere and so is less irradiated at the surface. The presence of magnetosphere, likely indicates a convecting molten core within Ganymede, which may in turn indicate a rich geologic history for the moon.

NASA performed a study called *HOPE* (Revolutionary Concepts for **H**uman **O**uter **P**lanet **E**xploration) regarding the future exploration of the solar system. The target chosen was Callisto. It could be possible to build a surface base that would produce fuel for further exploration of the solar system.

The three out of four largest moons of Jupiter (Europa, Ganymede and Callisto) have an abundance of volatiles making future colonization possible.

Phobos and Deimos

The moons of Mars may be a target for space colonization. Low delta-v is needed to reach the Earth from Phobos and Deimos, allowing delivery of material to cislunar space, as well as transport around the Martian system. The moons themselves may be suitable for habitation, with methods similar to those for asteroids.

Titan, Enceladus and other Saturnian moons

Titan is suggested as a target for colonization, because it is the only moon in our solar system to have a dense atmosphere and is rich in carbon-bearing compounds. Robert Zubrin identified Titan as possessing an abundance of all the elements necessary to support life, making Titan perhaps the most advantageous locale in the outer Solar System for colonisation, and saying "In certain ways, Titan is the most hospitable extraterrestrial world within our solar system for human colonisation".

Enceladus is a small, icy moon orbiting close to Saturn, notable for its extremely bright surface and the geyser-like plumes of ice and water vapor that erupt from its southern polar region. If Enceladus has liquid water, it joins Mars and Jupiter's moon Europa as one of the prime places in the solar system to look for extraterrestrial life and possible future settlements.

Other large satellites: Rhea, Iapetus, Dione, Tethys and Mimas, all have large quantities of volatiles, which can be used to support settlement.

Moons of Uranus, Neptune's Triton and beyond

The five large moons of Uranus (Miranda, Ariel, Umbriel, Titania and Oberon) and Triton - Neptune's moon, although very cold, have large amounts of frozen water and other volatiles and could potentially be settled, only they would require a lot of nuclear power to sustain the habitats. Triton's thin atmosphere also contains some nitrogen and even some frozen nitrogen on the surface (the surface temperature is 38 K or about -391° Fahrenheit). Pluto is estimated to have a very similar structure to Triton.

Asteroids

Near Earth Asteroids

Many small asteroids in orbit around the Sun have the advantage that they pass closer than Earth's moon several times per decade. In between these close approaches to home, the asteroid may travel out to a furthest distance of some 350,000,000 kilometers from the Sun (its aphelion) and 500,000,000 kilometers from Earth.

Main Belt Asteroids

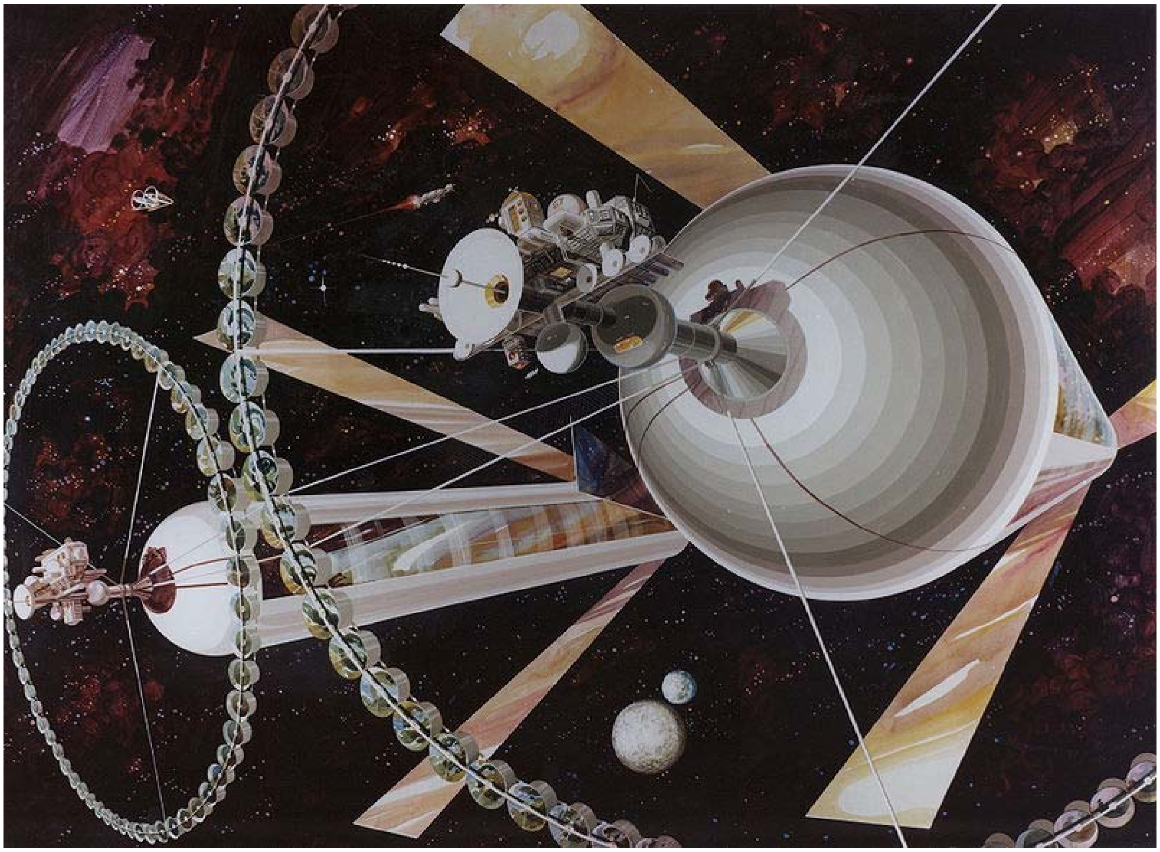
Colonization of asteroids would require space habitats. The asteroid belt has significant overall material available, the largest object being Ceres, although it is thinly distributed as it covers a vast region of space. Unmanned supply craft should be practical with little technological advance, even crossing 1/2 billion kilometers of cold vacuum. The colonists would have a strong interest in assuring that their asteroid did not hit Earth or any other body of significant mass, but would have extreme difficulty in moving an asteroid of any size. The orbits of the Earth and most asteroids are very distant from each other in terms of delta-v and the asteroidal bodies have enormous momentum. Rockets or mass drivers can perhaps be installed on asteroids to direct their path into a safe course.

Ceres

Ceres is a dwarf planet in the main asteroid belt, comprising about one third the mass of the whole belt and being the sixth largest body in the inner Solar System by mass and volume. Being the largest body in the asteroid belt, Ceres could become the main base and transport hub for future asteroid mining infrastructure, allowing mineral resources to be transported further to Mars, the Moon and Earth. It may be possible to Paraterraform Ceres, making life easier for the colonists. Given its low gravity and fast rotation, a space elevator would also be practical.

Free space

Space habitats



O'Neill cylinders space colony (Island Three design from the 1970s)

Artist's conception of a space habitat called the Stanford torus, by Don Davis (1976).

Locations in space would necessitate a space habitat, also called space colony and orbital colony, or a space station which would be intended as a permanent settlement rather than as a simple waystation or other specialized facility. They would be literal "cities" in space, where people would live and work and raise families. Many designs have been proposed with varying degrees of realism by both science fiction authors and scientists.

A space habitat would serve as a proving ground for a generation ship which could function as a long-term home for hundreds or thousands of people. Such a space habitat could be isolated from the rest of humanity but near enough to Earth for help. This would test if thousands of humans can survive on their own before sending them beyond the reach of help.

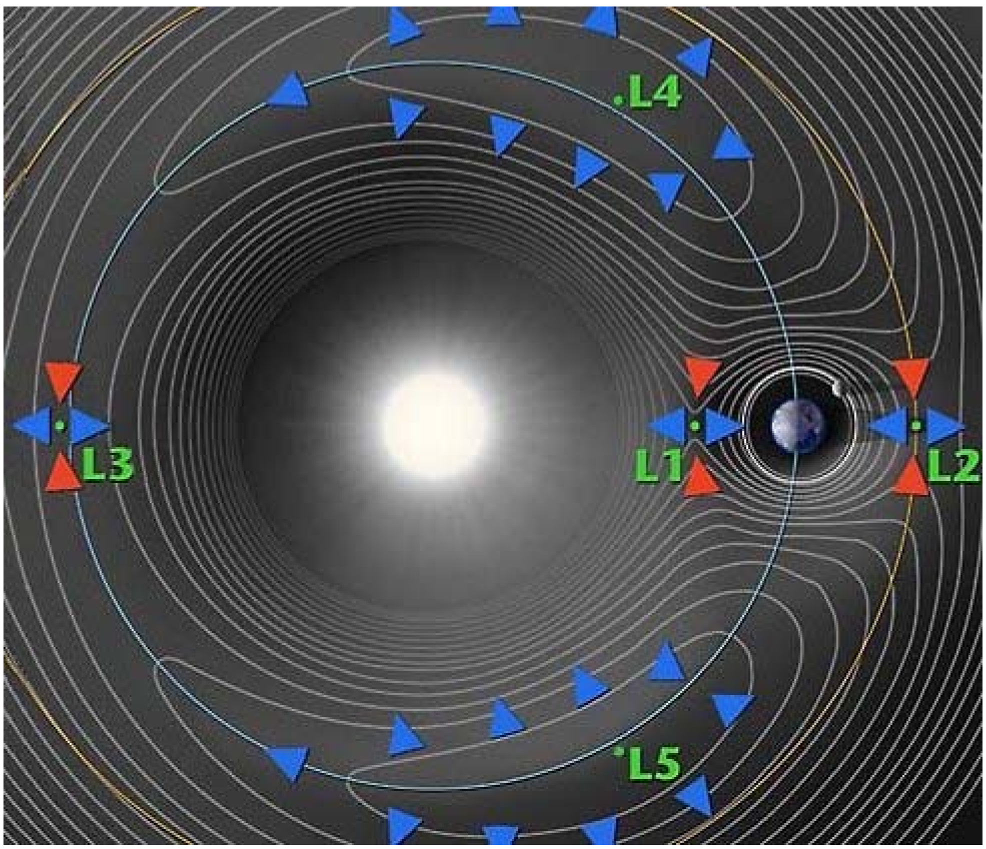
Earth orbit

Compared to other locations, Earth orbit has substantial advantages and one major, but solvable, problem. Orbits close to Earth can be reached in hours, whereas the Moon is days away and trips to Mars take months. There is ample continuous solar power in high Earth orbits, whereas all planets lose sunlight at least half the time. Weightlessness makes construction of large colonies considerably easier than in a gravity environment. Astronauts have demonstrated moving multi-ton satellites by hand. 0g recreation is available on orbital colonies, but not on the Moon or Mars. Finally, the level of (pseudo-) gravity is controlled at any desired level by rotating an orbital colony. Thus, the main living areas can be kept at 1 g, whereas the Moon has 1/6 g and Mars 1/3 g. It's not known what the minimum g-force is for ongoing health but 1 g is known to ensure that children grow up with strong bones and muscles.

The main disadvantage of orbital colonies is lack of materials. These may be expensively imported from the Earth, or more cheaply from extraterrestrial sources, such as the Moon (which has ample metals, silicon, and oxygen), Near Earth Asteroids, comets, or elsewhere. Other disadvantages of orbital colonies are orbital decay, and atmospheric pollution in the case of Earth.

As of 2009, the International Space Station provides a temporary, yet still non-autonomous, human presence in Low Earth orbit.

Lagrange points



A contour plot of the effective potential of the Sun and Earth, showing the five Lagrange points.

Another near-Earth possibility are the five Earth-Moon Lagrange points. Although they would generally also take a few days to reach with current technology, many of these points would have near-continuous solar power capability since their distance from Earth would result in only brief and infrequent eclipses of light from the Sun.

The five Earth-Sun Lagrange points would totally eliminate eclipses, but only L_1 and L_2 would be reachable in a few days' time. The other three Earth-Sun points would require months to reach.

However, the fact that Lagrange points L_4 and L_5 tend to collect dust and debris, while L_1-L_3 require active station-keeping measures to maintain a stable position, make them somewhat less suitable places for habitation than was originally believed. Additionally, the orbit of L_2 - L_5 takes them out of the protection of the Earth's magnetosphere for approximately two-thirds of the time, exposing them to the health threat from cosmic rays.

Statites

Statites or "static satellites" employ solar sails to position themselves in orbits that gravity alone could not accomplish. Such a solar sail colony would be free to ride solar radiation pressure and travel off the ecliptic plane. Navigational computers with an advanced understanding of flocking behavior could organize several statite colonies into the beginnings of the true "swarm" concept of a Dyson sphere.

Outside the solar system

Looking beyond our solar system, there are billions of potential suns with possible colonization targets.

The long-term survival of the human race is at risk as long as it is confined to a single planet. Sooner or later, disasters such as an asteroid collision or nuclear war could wipe us all out. But once we spread out into space and establish independent colonies, our future should be safe. There isn't anywhere like the Earth in the solar system, so we would have to go to another star.

– Stephen Hawking, Physicist

Interstellar travel

Many scientific papers have been published about interstellar travel. Given sufficient travel time and engineering work, both unmanned and generational voyages seem possible, though representing a very considerable technological and economic challenge unlikely to be met for some time, particularly for manned probes.

The main difficulty is the vast distances that have to be covered. This means that a very high speed is needed. Otherwise, the time involved, with most realistic propulsion methods, would be from decades to millennia. Hence an interstellar ship would be much more severely exposed to the hazards found in interplanetary travel, including hard vacuum, radiation, weightlessness, and micrometeoroids.

Intergalactic travel

Intergalactic travel, as it pertains to humans, is impractical by modern engineering ability and is considered highly speculative. It would require the available means of propulsion to become advanced far beyond what is currently thought possible to engineer in order to bring a large craft close to the speed of light. Unless the craft were capable of reaching extreme relativistic speeds, another obstacle would be to navigate the spacecraft between galaxies and succeed in reaching any chosen galaxy, star, planet or other body, as this would need an improvement over current understanding of galactic movements and their coordination. The craft would have to be of considerable size, without reaching speeds with noteworthy relativistic effect as mentioned above it would also need a life support system and structural design able to support human life through thousands of generations and last the millions of years required, including the propulsion system -- which would have to work perfectly the millions of years after it was built to slow down the machine for its final approach. Even for unmanned probes which would be much lighter in mass, the problem exists that the information they send can only travel at light speed, which would mean millions of years just to receive the data they send.

Current physics states that an object within space-time cannot exceed the speed of light, which seemingly limits any object to the millions of years it would at best take for a craft traveling near the speed of light to reach any remote galaxy. Science fiction frequently employs speculative concepts such as wormholes and hyperspace as more practical means of intergalactic travel to work around this issue. However, some scientists are optimistic in regard to future research into techniques considered even in concept sheer science fiction in the past.

Starship

Space colonization technology could in principle allow human expansion at high, but sub-relativistic speeds, substantially less than the speed of light, c. An interstellar colony ship would be similar to a space habitat, with the addition of major propulsion capabilities and independent energy generation. Hypothetical starship concepts proposed both by scientists and in hard science fiction include:

- A generation ship would travel much slower than light, with consequent interstellar trip times of many decades or centuries. The crew would go through generations before the journey is complete, so that none of the initial crew would be expected to survive to arrive at the destination, assuming current human lifespans.
- A sleeper ship, in which most or all of the crew spend the journey in some form of hibernation or suspended animation, allowing some or all who undertake the journey to survive to the end.

- An Embryo-carrying Interstellar Starship (EIS), much smaller than a generation ship or sleeper ship, transporting human embryos or DNA in a frozen or dormant state to the destination. (Obvious biological and psychological problems in birthing, raising, and educating such voyagers, neglected here, may not be fundamental.)
- A nuclear fusion or fission powered ship (e.g., ion drive) of some kind, achieving velocities of up to perhaps 10% *c* permitting one-way trips to nearby stars with durations comparable to a human lifetime.
- A Project Orion-ship, a nuclear-powered concept proposed by Freeman Dyson which would use nuclear explosions to propel a starship. A special case of the preceding nuclear rocket concepts, with similar potential velocity capability, but possibly easier technology.
- Laser propulsion concepts, using some form of beaming of power from the Solar System might allow a light-sail or other ship to reach high speeds, comparable to those theoretically attainable by the fusion-powered electric rocket, above. These methods would need some means, such as supplementary nuclear propulsion, to stop at the destination, but a hybrid (light-sail for acceleration, fusion-electric for deceleration) system might be possible.

The above concepts all appear limited to high, but still sub-relativistic speeds, due to fundamental energy and reaction mass considerations, and all would entail trip times which might be enabled by space colonization technology, permitting self-contained habitats with lifetimes of decades to centuries. Yet human interstellar expansion at average speeds of even 0.1% of *c* would permit settlement of the entire Galaxy in less than one half of a galactic rotation period of ~250,000,000 years, which is comparable to the timescale of other galactic processes. Thus, even if interstellar travel at near relativistic speeds is never feasible (which cannot be clearly determined at this time), the development of space colonization could allow human expansion beyond the Solar System without requiring technological advances that cannot yet be reasonably foreseen. This could greatly improve the chances for the survival of intelligent life over cosmic timescales, given the many natural and human-related hazards that have been widely noted.

The star Tau Ceti, about twelve light years away, has an abundance of cometary and asteroidal material in orbit around it. These materials could be used for the construction of space habitats for human settlement.

Terrestrial analogues to space colonies

The most famous attempt to build an analogue to a self-sufficient colony is Biosphere 2, which attempted to duplicate Earth's biosphere.

Many space agencies build testbeds for advanced life support systems, but these are designed for long duration human spaceflight, not permanent colonization.

Remote research stations in inhospitable climates, such as the Amundsen-Scott South Pole Station or Devon Island Mars Arctic Research Station, can also provide some practice for off-world outpost construction and operation. The Mars Desert Research Station has a habitat for similar reasons, but the surrounding climate is not strictly inhospitable.

Nuclear Submarines provide an example of conditions encountered in artificial space environment. Crews of these vessels often spend long periods (6 months or more) submerged during their deployments. However, the submarine environment provides a somewhat open life support system since the vessel can replenish supplies of fresh water and oxygen from seawater.

Other examples of small groups in isolated living conditions are record long-distance flights, long-distance (single-handed) sails, oil platforms, prisons, bunkers, small islands and underground bases.

The study of terrestrial analogues is also a central focus in space architecture.

Literature

The literature for space colonization began in 1869 when Edward Everett Hale wrote about an inhabited artificial satellite.

The Russian schoolmaster and physicist Konstantin Tsiolkovsky foresaw elements of the space community in his book *Beyond Planet Earth* written about 1900. Tsiolkovsky had his space travelers building greenhouses and raising crops in space.

Others have also written about space colonies as Lasswitz in 1897 and Bernal, Oberth, Von Pirquet and Noordung in the 1920s. Wernher von Braun contributed his ideas in a 1952 *Colliers* article. In the 1950s and 1960s, Dandridge M. Cole published his ideas.

Another seminal book on the subject was the book *The High Frontier: Human Colonies in Space* by Gerard K. O'Neill in 1977 which was followed the same year by *Colonies in Space* by T. A. Heppenheimer.

M. Dyson wrote *Home on the Moon; Living on a Space Frontier* in 2003; Peter Eckart wrote *Lunar Base Handbook* in 2006 and then Harrison Schmitt's *Return to the Moon* written in 2007.

Debate

Justification

In 2001, the space news website Space.com asked Freeman Dyson, J. Richard Gott and Sid Goldstein for reasons why some humans should live in space. Their answers were:

- Spread life and beauty throughout the Universe
- Ensure the survival of our species
- Make money from solar power satellites, asteroid mining, and space manufacturing
- Save the environment of Earth by moving people and industry into space
- Provide entertainment value in order to distract from immediate surroundings
- Ensure sufficient supply of rare materials, including from the Outer Solar System – natural gas (in connection with expected worldwide hydrocarbons peak) and drinking water (in connection with expected worldwide water shortage)

Nick Bostrom argued that from a utilitarian perspective space colonization should be a chief goal as it would enable a very large population living for a very long period of time (possibly billions of years) which would produce an enormous amount of utility (or happiness). He claims that it is more important to reduce existential risks to increase the probability of eventual colonization rather than to accelerate technological development so that space colonization could happen sooner.

Louis J. Halle, formerly of the United States Department of State, wrote in *Foreign Affairs* (Summer 1980) that the colonization of space will protect humanity in the event of global nuclear warfare.

The scientist Paul Davies also supports the view that if a planetary catastrophe threatens the survival of the human species on Earth, a self-sufficient colony could "reverse-colonize" the Earth and restore human civilization.

The author and journalist William E. Burrows and the biochemist Robert Shapiro proposed a private project, the Alliance to Rescue Civilization, with the goal of establishing an off-Earth backup of human civilization.

Objections

Colonizing space would require massive amounts of financial, physical and human capital devoted to research, development, production, and deployment.

The fundamental problem of public things, needed for survival, such as space programs, is the free rider problem. Convincing the public to fund such programs would require additional self-interest arguments: If the objective of space colonization is to provide a "backup" in case everyone on Earth is killed, then why should someone on Earth pay for something that is only useful after they're dead? This assumes that space colonization is not widely acknowledged as a sufficiently valuable social goal.

Other objections include concern about creating a culture in which humans are no longer seen as human, but rather as material assets. The issues of human dignity, morality, philosophy, culture, bioethics, and the threat of megalomaniac leaders in these new "societies" would all have to be addressed in order for space colonization to meet the psychological and social needs of people living in isolated colonies or generation ships..

As an alternative or addendum for the future of the human race, many science fiction writers have focused on the realm of the 'inner-space', that is the computer aided exploration of the human mind and human consciousness.

Counter arguments

The argument of need

The population of Earth continues to increase, while its carrying capacity and available resources do not. If the resources of space are opened to use and viable life-supporting habitats can be built, the Earth will no longer define the limitations of growth. On the other hand, extrapolations made using available figures for population growth, shows that the population of Earth will stop growing around 2070.

Furthermore, even if humanity manages to avoid devastating Earth through war, pestilence, pollution, global cooling, global warming, and even cometary impacts, the Earth will ultimately become uninhabitable by the heating from the Sun as it ages. If humanity has not made permanent habitations in space by the time any one of these incidents occurs, it may very well go extinct.

> "Maybe the reason civilizations don’t get around to colonizing other planets is that there’s a narrow window when they have the tools, population and will to do so, and the window usually closes on them."
>
> --John Tierney
>
> "If it’s true that civilizations normally go extinct because they get stuck on their home planets, then the odds are against us"
>
> --John Tierney

The argument of benefits

Detractors of the development of permanent space colonies and infrastructure often cite the very high initial investment costs of space colonies and permanent space infrastructure yet they ignore all potential returns on that investment. The long-term vision of developing space infrastructure is that it will provide long-term benefits far in excess of the initial start-up costs. Therefore, such a development program should be viewed more as a long-term investment and not like current social spending programs that incur spending commitments but provide little or no return on that investment.

Because current space launch costs are so high (on the order of $4,000 to $40,000 / kg launched into orbit) any serious plan to develop space infrastructure at a reasonable cost must include developing the ability of that infrastructure to manufacture most or all of its requirements plus those for permanent human habitation in space. Therefore, the initial investments must be made in the development of the initial capacity to provide these necessities: Materials, Energy, Transportation, Communication, Life support, Radiation protection, Self-replication, and Population.

Once the needs of the permanent settlements have been met, any additional production capacity could be use to either extend that initial infrastructure (a concept commonly called "bootstrapping") or traded back to Earth in payment of the initial investment or in exchange for goods more easily manufactured on the Earth.

Although some items of the infrastructure requirements above can already be easily produced on the Earth and would therefore not be very valuable as trade items (oxygen, water, base metal ores, silicates, etc.), other high value items are more abundant, more easily produced, of higher quality, or can only be produced in space. These would provide (over the long-term) a very high return on the initial investment in space infrastructure.

Some of these high trade value goods include precious metals, gem stones, power, solar cells, ball bearings, semi-conductors, and pharmaceuticals.

> “ ... the smallest Earth-crossing asteroid 3554 Amun is a mile-wide (2 km) lump of iron, nickel, cobalt, platinum, and other metals; it contains 30 times as much metal as Humans have mined throughout history, although it is only the smallest of dozens of known metallic asteroids and worth perhaps US$ 20 trillion if mined slowly to meet demand at 2001 market prices. ”

> “ In the 2,900 km³ of Eros, there is more aluminium, gold, silver, zinc and other base and precious metals than have ever been excavated in history or indeed, could ever be excavated from the upper layers of the Earth's crust. ”

The main impediments to commercial exploitation of these resources are the very high cost of initial investment, the very long period required for the expected return on those investments (estimated to be 50 years or more by some), and because it has never been done before - the high-risk nature of the investment.

The argument of nationalism

Space proponents counter this argument by pointing out that humanity as a whole has been exploring and expanding into new territory since long before Europe's colonial period, going back into prehistory (the nationalist argument also ignores multinational cooperative space efforts); that seeing the Earth as a single, discrete object instills a powerful sense of the unity, connectedness of the human environment, and of the immateriality of political borders; and that in practice, international collaboration in space has shown its value as a unifying and cooperative endeavor.

Advocacy

Space advocacy organizations include

- The Alliance to Rescue Civilization plans to establish backups of human civilization on the Moon and other locations away from Earth.
- The Colonize the Cosmos site advocates orbital colonies.
- The Artemis Project plans to set up a private lunar surface station.
- The British Interplanetary Society, founded in 1933, is the world's longest established space society.
- The Living Universe Foundation has a detailed plan in which the entire galaxy is colonized.
- The Mars Society promotes Robert Zubrin's Mars Direct plan and the settlement of Mars.
- The National Space Society is an organization with the vision of "people living and working in thriving communities beyond the Earth."
- The Planetary Society is the largest space interest group, but has an emphasis on robotic exploration and the search for extraterrestrial life.
- The Space Frontier Foundation promotes strong free market, capitalist views about space development.
- The Space Settlement Institute is searching for ways to make space colonization happen in our lifetimes.
- The Space Studies Institute was founded by Gerard K. O'Neill to fund the study of space habitats.
- Students for the Exploration and Development of Space (SEDS) is a student organization founded in 1980 at MIT and Princeton.
- Foresight Nanotechnology Institute – The space challenge.

Chapter- 8

Space Architecture

A 1990 artist rendering of Space Station Freedom, a project that eventually evolved into the International Space Station

Space architecture, in its simplest definition, is the theory and practice of designing and building inhabited environments in outer space. The architectural approach to spacecraft design addresses the total built environment, drawing from diverse disciplines including physiology, psychology, and sociology as well as technical fields. Like architecture on Earth, the attempt is to go beyond the component elements and systems and gain a broad understanding of the issues that affect design success. Much space architecture work has been in designing concepts for orbital space stations and lunar and Martian exploration ships and surface bases for the world's space agencies, chiefly the National Aeronautics and Space Administration (NASA).

The practice of involving architects in the space program grew out of the Space Race, although its origins can be seen much earlier. The need for their involvement stemmed from the push to extend space mission durations and address the needs of astronauts including but beyond minimum survival needs. Space architecture is currently represented in several institutions. The Sasakawa International Center for Space Architecture (SICSA) is an academic organization with the University of Houston that offers a Master of Science in Space Architecture. SICSA also works design contracts with corporations and space agencies. In Europe, International Space University is deeply involved in space architecture research. The International Conference on Environmental Systems meets annually to present sessions on human spaceflight and space human factors. Within the American Institute of Aeronautics and Astronautics, the Space Architecture Technical Committee has been formed. Despite the historical pattern of large government-led space projects and university-level conceptual design, the advent of space tourism threatens to shift the outlook for space architecture work.

Etymology

The word *space* in space architecture is referring to the *outer space* definition, which is from English *outer* and *space*. *Outer* can be defined as "situated on or toward the outside; external; exterior" and first originated around 1350-1400 in Middle English. *Space* is "an area, extent, expanse, lapse of time," the aphetic of Old French *espace* dating to 1300. *Espace* is from Latin *spatium*, "room, area, distance, stretch of time," and is of uncertain origin. In space architecture, speaking of *outer space* usually means the region of the universe outside Earth's atmosphere, as opposed to outside the atmospheres of all terrestrial bodies. This allows the term to include such domains as the lunar and Martian surfaces.

Architecture, the concatenation of *architect* and *-ure*, dates to 1563, coming from Middle French *architecte*. This term is of Latin origin, formerly *architectus*, which came from Greek *arkhitekton*. *Arkitekton* means "master builder" and is from the combination of *arkhi-* "chief" and *tekton* "builder". The human experience is central to architecture - the primary difference between space architecture and spacecraft engineering.

There is some debate over the terminology of space architecture. Some consider the field to be a specialty within architecture that applies architectural principles to space applications. Others such as professor Ted Hall of the University of Michigan see space architects as generalists, with what is traditionally considered architecture (Earth-bound or terrestrial architecture) being a subset of a broader space architecture. Any structures that fly in space will likely remain for some time highly dependent on Earth-based infrastructure and personnel for financing, development, construction, launch, and operation. Therefore it is a matter of discussion how much of these earthly assets are to be considered part of space architecture. The technicalities of the term space architecture are open to some level of interpretation.

Origins

The interior of Verne's moon-bound projectile

Humans have looked to the cosmos in wonder since time immemorial. Ideas of people traveling to space were first published in science fiction stories, like Jules Verne's 1865 *From the Earth to the Moon*. In this story several details of the mission (crew of three, spacecraft dimensions, Florida launch site) bear striking similarity to the Apollo moon landings that took place more than 100 years later. Verne's aluminum capsule had shelves stocked with equipment needed for the journey such as a collapsing telescope, pickaxes and shovels, firearms, oxygen generators, and even trees to plant. A curved sofa was built into the floor and walls and windows near the tip of the spacecraft were accessible by ladder. The projectile was shaped like a bullet because it was gun-launched from the ground, a method infeasible for transporting man to space due to the high acceleration forces produced. It would take rocketry to get humans to the cosmos.

An illustration of von Braun's rotating space station concept

The first serious theoretical work published on space travel by means of rocket power was by Konstantin Tsiolkovsky in 1903. Besides being the father of astronautics he conceived such ideas as the space elevator (inspired by the Eiffel Tower), a rotating space station that created artificial gravity along the outer circumference, airlocks, space suits for extra-vehicular activity (EVA), closed ecosystems to provide food and oxygen, and solar power in space. Tsiolkovsky believed human occupation of space was the inevitable path for our species. In 1952 Wernher von Braun published his own inhabited space station concept in a series of magazine articles. His design was an upgrade of earlier concepts but he took the unique step in going directly to the public with it. The spinning space station would have three decks and was to function as a navigational aid, meteorological station, Earth observatory, military platform, and way point for further exploration missions to outer space. It is said that the space station depicted in *2001: A Space Odyssey* traces its design heritage to Von Braun's work. Werner von Braun went on to devise mission schemes to the moon and Mars, each time publishing his grand plans in Collier's Weekly.

The flight of Yuri Gagarin on April 12, 1961 was humanity's maiden spaceflight. While the mission was a necessary first step, Gagarin was more or less confined to a chair with a small view port from which to observe the cosmos - a far cry from the possibilities of life in space. Following space missions gradually improved living conditions and quality of life in low earth orbit. Expanding room for movement, physical exercise regimens, sanitation facilities, improved food quality, and recreational activities all accompanied longer mission durations. Architectural involvement in space was realized in 1968 when a group of architects and industrial designers led by Raymond Loewy, over objections from engineers, prevailed in convincing NASA to include an observation window in the Skylab orbital laboratory. This milestone represents the introduction of the human psychological dimension to spacecraft design. Space architecture was born.

Theory

The subject of architectural theory has much application in space architecture. Some considerations, though, will be unique to the space context.

Ideology of building

Louis Sullivan famously coined the phrase 'form ever follows function'

In the first century BC, the Roman architect Vitruvius said all buildings should have three things: strength, utility, and beauty. Vitruvius's work *De Architectura*, the only surviving work on the subject from classical antiquity, would have profound influence on architectural theory for thousands of years to come. Even in space architecture these are some of the first things we consider. However, the tremendous challenge of living in space has led to habitat design based largely on functional necessity with little or no applied ornament. In this sense space architecture as we know it shares the form follows function principle with modern architecture.

Some theorists link different elements of the Vitruvian triad. Walter Gropius writes:

> 'Beauty' is based on the perfect mastery of all the scientific, technological and formal prerequisites of the task ... The approach of Functionalism means to design the objects organically on the basis of their own contemporary postulates, without any romantic embellishment or jesting.

As space architecture continues to mature as a discipline, dialogue on architectural design values will open up just as it has for Earth.

Analogs

The Mars Desert Research Station is located in the Utah desert because of its relative similarity to the Martian surface

A starting point for space architecture theory is the search for extreme environments in terrestrial settings where humans have lived, and the formation of analogs between these environments and space. For example humans have lived in submarines deep in the ocean, in bunkers beneath the Earth's surface, and on Antarctica, and have safely entered burning buildings, radioactively contaminated zones, and the stratosphere with the help of technology. Aerial refueling enables Air Force One to stay airborne virtually indefinitely. Nuclear powered submarines generate oxygen using electrolysis and can stay submerged for months at a time. Many of these analogs can be very useful design references for space systems. In fact space station life support systems and astronaut survival gear for emergency landings bear striking similarity to submarine life support systems and military pilot survival kits, respectively.

Space missions, especially human ones, require extensive preparation. In addition to terrestrial analogs providing design insight, the analogous environments can serve as testbeds to further develop techonologies for space applications and train astronaut crews. The Flashline Mars Arctic Research Station is a simulated Mars base, maintained by the Mars Society, on Canada's remote Devon Island. The project aims to create conditions as similar as possible to a real Mars mission and attempts to establish ideal crew size, test equipment "in the field", and determine the best extra-vehicular activity suits and procedures. To train for EVAs in microgravity, space agencies make broad use of underwater and simulator training. The Neutral Buoyancy Laboratory, NASA's underwater training facility, contains full scale mockups of the Space Shuttle cargo bay and International Space Station modules. Technology development and astronaut training in space-analogous environments are essential to making living in space possible.

In space

Fundamental to space architecture is designing for physical and psychological wellness in space. What often is taken for granted on Earth - air, water, food, trash disposal - must be designed for in fastidious detail. Rigorous exercise regimens are required to alleviate muscular atrophy and other effects of space on the body. That space missions are (optimally) fixed in duration can lead to stress from isolation. This problem is not unlike that faced in remote research stations or military tours of duty, although non-standard gravity conditions can exacerbate feelings of unfamiliarity and homesickness. Furthermore confinement in limited and unchanging physical spaces appears to magnify interpersonal tensions in small crews and contribute to other negative psychological effects. These stresses can be mitigated by establishing regular contact with family and friends on Earth, maintaining health, incorporating recreational activities, and bringing along familiar items such as photographs and green plants. The importance of these psychological measures can be appreciated in the 1968 Soviet 'DLB Lunar Base' design:

> “...it was planned that the units on the moon would have a false window, showing scenes of the Earth countryside that would change to correspond with the season back in Moscow. The exercise bicycle was equipped with a synchronized film projector, that allowed the cosmonaut to take a 'ride' out of Moscow with return.”

Mir was a 'modular' space station. This approach allows a habitat to function before assembly is complete and its design can be changed by swapping modules.

The challenge of getting anything at all to space, due to launch constraints, has had a profound effect on the physical shapes of space architecture. All space habitats to date have used modular architecture design. Payload fairing dimensions (typically the width but also the height) of modern launch vehicles limit the size of rigid components launched into space. This approach to building large scale structures in space involves launching multiple modules separately and then manually assembling them afterward. Modular architecture results in a layout similar to a tunnel system where passage through several modules is often required to reach any particular destination. It also tends to standardize the internal diameter or width of pressurized rooms, with machinery and furniture placed along the circumference. These types of space stations and surface bases can generally only grow by adding additional modules in one or more direction. Finding adequate working and living space is often a major challenge with modular architecture.

As a solution, flexible furniture (collapsible tables, curtains on rails, deployable beds) can be used to transform interiors for different functions and change the partitioning between private and group space.

Eugène Viollet-le-Duc advocated different architectural forms for different materials. This is especially important in space architecture. The mass constraints with launching push engineers to find ever lighter materials with adequate material properties. Moreover challenges unique to the orbital space environment, such as rapid thermal expansion due to abrupt changes in solar exposure, and corrosion caused by particle and atomic oxygen bombardment, require unique materials solutions. Just as the industrial age produced new materials and opened up new architectural possibilities, advances in materials technology will change the prospects of space architecture. Carbon-fiber is already being incorporated into space hardware because of its high strength-to-weight ratio. It will interesting to see whether carbon-fiber or other composite materials will be adopted for major structural components in space. The architectural principle that champions using the most appropriate materials and leaving their nature unadorned is called truth to materials.

A notable difference between the orbital context of space architecture and Earth-based architecture is that structures in orbit do not need to support their own weight. This is possible because of the microgravity condition of objects in free fall. In fact much space hardware, such as the space shuttle's robotic arm, is designed only to function in orbit and wouldn't be able to lift its own weight on the Earth's surface. Microgravity also allows an astronaut to move an object of practically any mass, albeit slowly, provided she is adequately constrained to another object. Therefore structural considerations for the orbital environment are dramatically different from those of terrestrial buildings, and the biggest challenge to holding a space station together is usually launching and assembling the components intact. Construction on extraterrestrial surfaces still needs to be designed to support its own weight, but its weight will depend on the strength of the local gravitational field.

Ground Infrastructure

Human spaceflight currently requires a great deal of supporting infrastructure on Earth. All human orbital missions to date have been government-orchestrated. The organizational body that manages space missions is typically a national space agency, NASA in the case of the United States and Roscosmos for Russia. These agencies are funded at the federal level. At NASA, flight controllers are responsible for real-time mission operations and work onsite at NASA Centers. Most engineering development work involved with space vehicles is contracted-out to private companies, who in turn may employ subcontractors of their own, while fundamental research and conceptual design is often done in academia through research funding.

Varieties

Suborbital

Structures that cross the boundary of space but do not reach orbital speeds are considered suborbital architecture. For spaceplanes, the architecture has much in common with airliner architecture, especially those of small business jets.

Virgin Galactic

A mockup of the SpaceShipTwo interior

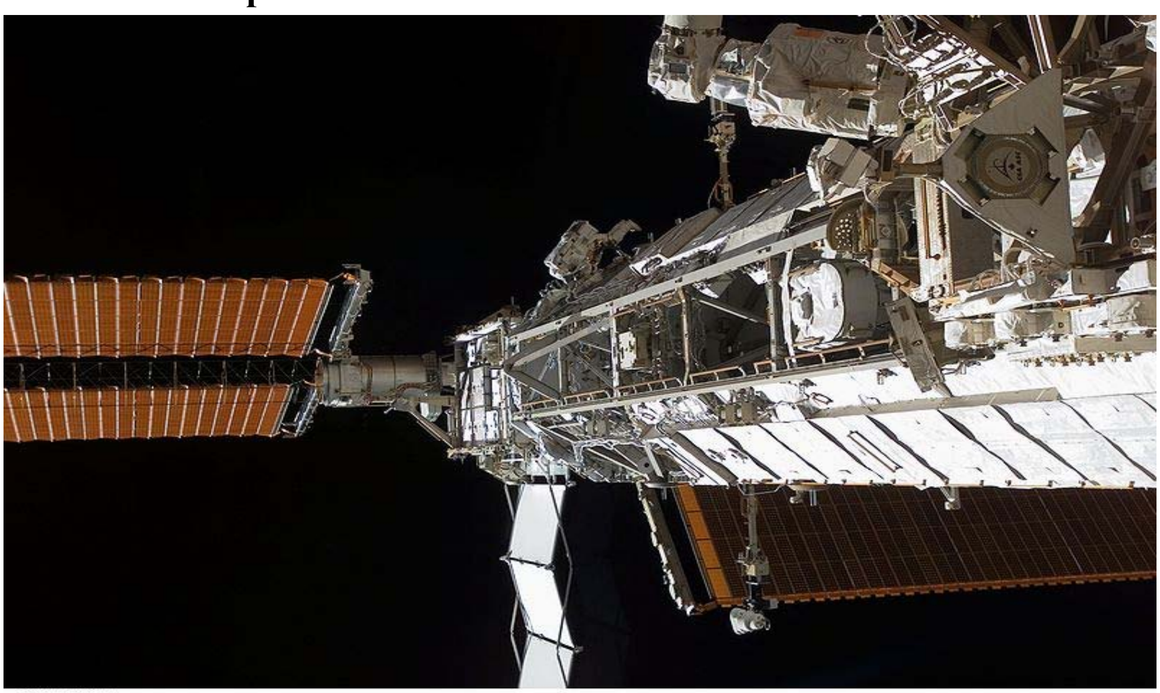
A new milestone was reached on June 21, 2004 when Mike Melvill pierced the boundary of space funded entirely by private means. The vehicle, SpaceShipOne, was developed by Scaled Composites as an experimental precursor to a privately operated fleet of spaceplanes for suborbital space tourism. The operational spaceplane model, SpaceShipTwo (SS2), will be carried to an altitude of about 15 kilometers by its B-29 Superfortress-sized carrier aircraft, WhiteKnightTwo. From there SS2 will detach and fire its rocket motor to bring the craft to its apogee of approximately 110 kilometers. Because SS2 is not designed to go into orbit around the Earth, it is an example of suborbital or aerospace architecture. Virgin Galactic is now accepting deposits of US$200,000 for about 6 minutes of weightlessness in the fringes of space.

The architecture of the SpaceShipTwo vehicle is somewhat different than what is common in previous space vehicles. Unlike the cluttered interiors with protruding machinery and many obscure switches of previous vehicles, this cabin looks more like something out of science fiction than a modern spacecraft. Both SS2 and the carrier aircraft are being built from lightweight composite materials instead of metal. When the time for weightlessness has arrived on a SS2 flight, the noise and turbulent vibration of the rocket motor will give way to silence and calm. Passengers will be able to see the sky turn from blue to black and make out the curvature of the Earth. Numerous double-paned windows that encircle the cabin will offer views in nearly all directions. Cushioned seats will recline flat into the floor to maximize room for floating. An always-pressurized interior will eliminate the need for bulky space suits. The spaceflight experience offered by Virgin Galactic promises to transform access to space and indeed the very idea of an astronaut.

Orbital

Orbital architecture is the architecture of structures designed to orbit around the Earth or another astronomical object. Examples of currently-operational orbital architecture are the International Space Station and the re-entry vehicles Space Shuttle, Soyuz spacecraft, and Shenzhou spacecraft. Historical craft include the Mir space station, Skylab, and the Apollo spacecraft. Orbital architecture usually addresses the condition of weightlessness, a lack of atmospheric and magnetospheric protection from solar and cosmic radiation, rapid day/night cycles, and possibly risk of orbital debris collision. In addition, re-entry vehicles must also be adapted both to weightlessness and to the high temperatures and accelerations experienced during atmospheric reentry.

International Space Station



Astronaut (upper center) works on the Integrated Truss Structure of the ISS

The International Space Station (ISS) is the only permanently inhabited structure currently in space. It is the size of an American football field and has a crew of six. With a living volume of 358 m^3, it has more interior room than the cargo beds of two American 18-wheeler trucks. However, because of the microgravity environment of the space station, there are not always well-defined walls, floors, and ceilings and all pressurized areas can be utilized as living and working space. The International Space Station is still under construction. Modules are primarily launched using the Space Shuttle and are assembled by its crew with the help of the working crew on-board the space station. ISS modules are often designed and built to barely fit inside the shuttle's payload bay, which is cylindrical with a 4.6 meter diameter.

An interior view of the Columbus module

Life aboard the space station is distinct from terrestrial life in some very interesting ways. Astronauts commonly "float" objects to one another; for example they will give a clipboard an initial nudge and it will coast to its receiver across the room. In fact, an astronaut can become so accustomed to this habit that he forgets it doesn't work anymore when he returns to Earth. The diet of ISS spacefarers is a combination of participating nations' space food. Each astronaut selects a personalized menu before flight. Many food choices reflect the cultural differences of the astronauts, such as bacon and eggs vs. fish products for breakfast (for the US and Russia, respectively). More recently such delicacies as Japanense beef curry, kimchi, and swordfish (Riviera style) have been featured on the orbiting outpost. As much of ISS food is dehydrated or sealed in pouches MRE-style, astronauts are quite excited to get relatively fresh food from shuttle and Progress resupply missions. Food is stored in packages that facilitate eating in microgravity by keeping the food constrained to the table. Spent packaging and trash must be collected to loaded into an available spacecraft for disposal. Waste management is not nearly as straight forward as it is on Earth. The ISS has many windows for observing Earth and space, one of the astronauts' favorite leisure activities. Since the sun rises every 90 minutes, the windows are covered at "night" to help maintain the 24-hour sleep cycle.

When a shuttle is operating in low earth orbit, the ISS serves as a safety refuge in case of emergency. The inability to fall back on the safety of the ISS during the latest Hubble Space Telescope Servicing Mission (because of different orbital inclinations) was the reason a backup shuttle was summoned to the launch pad. So, ISS astronauts operate with the mindset that they may be called upon to give sanctuary to a shuttle crew should something happen to compromise a mission. The International Space Station is a colossal cooperative project between many nations. The prevailing atmosphere on board is one of diversity and tolerance. This does not mean that it is perfectly harmonious. Astronauts experience the same frustrations and interpersonal quarrels as their Earth-based counterparts.

A typical day on the station might start with wakeup at 6:00am inside a private soundproof booth in the crew quarters. Astronauts would probably find their sleeping bags in an upright position tied to the wall, because orientation does not matter in space. The astronaut's thighs would be lifted about 50 degrees off the vertical. This is the neutral body posture in weightlessness - it would be excessively tiring to "sit" or "stand" as is common on Earth. Crawling out of his booth, an astronaut may chat with other astronauts about the day's science experiments, mission control conferences, interviews with Earthlings, and perhaps even a space walk or space shuttle arrival.

Bigelow Aerospace

Bigelow Aerospace took the unique step in securing two patents NASA held from development of the Transhab concept in regard to inflatable space structures. The company now has sole rights to commercial development of the inflatable module technology. On July 12, 2006 the *Genesis I* experimental space habitat was launched into low earth orbit. *Genesis I* demonstrated the basic viability of inflatable space structures, even carrying a payload of life science experiments. The second module, *Genesis II*, was launched into orbit on June 28, 2007 and tested out several improvements over its predecessor. Among these are reaction wheel assemblies, a precision measurement system for guidance, nine additional cameras, improved gas control for module inflation, and an improved on-board sensor suite.

While Bigelow architecture is still modular, the inflatable configuration allows for much more interior volume than rigid modules. The BA 330, Bigelow's full-scale production model, has more than twice the volume of the largest module on the ISS. Inflatable modules can be docked to rigid modules and are especially well suited for crew living and working quarters. NASA is considering attaching a Bigelow module to the ISS, after abandoning the Transhab concept more than a decade ago. The modules will likely have a solid inner core for structural support. Surrounding usable space could be partitioned into different rooms and floors. Bigelow Aerospace may choose to launch many of their modules independently, leasing their use to a wide variety of companies, organizations, and countries that can't afford their own space programs. Possible uses of this space include microgravity research and space manufacturing. Or we may see a private space hotel composed of numerous Bigelow modules for rooms, observatories, or even a recreational padded gymnasium. There is the option of using such modules for habitation quarters on long-term space missions in the solar system. One amazing aspect of spaceflight is that once a craft leaves an atmosphere, aerodynamic shape is a non-issue. For instance it's possible to apply a Trans Lunar Injection to an entire space station and send it to fly by the moon. Bigelow has expressed the possibility of their modules being modified for lunar and Martian surface systems as well.

Lunar

Lunar architecture exists both in theory and in practice. Today the archeological artifacts of temporary human outposts lay untouched on the surface of the moon. Five Apollo Lunar Module descent stages stand upright in various locations across the equatorial region of the Near Side, hinting at the extraterrestrial endeavors of mankind. From a distant past the moon has beckoned, rich with mystery and enigma. The leading hypothesis on the origin of the moon did not gain its current status until after lunar rock samples were analyzed. The moon is the furthest any humans have ever ventured from their home, and space architecture is what kept them alive and allowed them to function as humans.

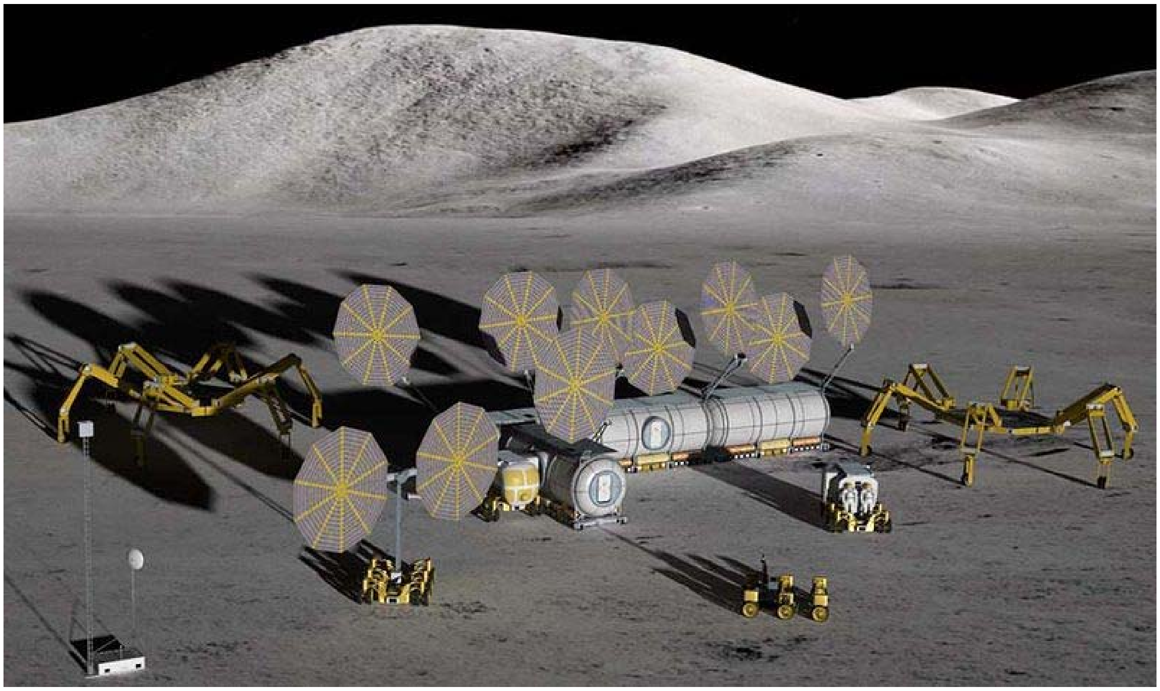
Apollo

On the cruise to the moon, Apollo astronauts had two "rooms" to choose from - the Command Module (CM) or the Lunar Module (LM). Indeed one can witness this in the film *Apollo 13* where the three astronauts were forced to use the LM as an emergency life boat. Passage between the two modules was possible through a pressurized docking tunnel, a major advantage over the Soviet design, which required donning a spacesuit to switch modules. The Command Module featured five windows made of three thick panes of glass. The two inner panes, made of aluminosilicate, ensured no cabin air leaked into space. The outer pane served as a debris shield and part of the heat shield needed for atmospheric reentry. The CM was a sophisticated spacecraft with all the systems required for successful flight but with an interior volume of 6.17 m^3 could be considered cramped for three astronauts. It had its design weaknesses such as no toilet (astronauts used much-hated 'relief tubes' and fecal bags). The coming of the space station would bring effective life support systems with waste management and water reclamation technologies.

The Lunar Module had two stages. A pressurized upper stage, termed the Ascent stage, was the first true spaceship as it could only operate in the vacuum of space. The Descent stage carried the engine used for descent, landing gear and radar, fuel and consumables, the famous ladder, and the Lunar Rover during later Apollo missions. The idea behind staging is to reduce mass later in a flight, and is the same strategy used in an Earth-launched multistage rocket. The LM pilot stood up during the descent to the moon. Landing was achieved via automated control with a manual backup mode. There was no airlock on the LM so the entire cabin had to be evacuated (air vented to space) in order to send an astronaut out to walk on the surface. To stay alive, both astronauts in the LM would have to get in their space suits at this point. The Lunar Module worked well for what it was designed to do. However, a big unknown remained throughout the design process - the effects of lunar dust. Every astronaut who walked on the moon tracked in lunar dust, contaminating the LM and later the CM during Lunar Orbit Rendezvous. These dust particles can't be brushed away in a vacuum, and have been described by John Young of Apollo 16 as being like tiny razor blades. It was soon realized that for humans to live on the moon, dust mitigation was one of many issues that had to be taken seriously.

Project Constellation

The Exploration Systems Architecture Study that followed the Vision for Space Exploration of 2004 recommended the development of a new class of vehicles that have similar capabilities to their Apollo predecessors with several key differences. In part to retain some of the Space Shuttle program workforce and ground infrastructure, the launch vehicles are to use Shuttle-derived technologies. Secondly, rather than launching the crew and cargo on the same rocket, the smaller Ares I is to launch the crew with the larger Ares V to handle the heavier cargo. The two payloads are to rendezvous in low earth orbit and then head to the moon from there. The Apollo Lunar Module could not carry enough fuel to reach the polar regions of the moon but the Altair lunar lander is being designed to access any part of the moon. While the Altair and surface systems are equally necessary for Project Constellation to reach fruition, the focus now is on developing the Orion spacecraft to shorten the gap in US access to orbit following the retirement of the Space Shuttle in 2010.



Some of the concepts NASA is working on

Even NASA has described Constellation architecture as 'Apollo on steroids'. Nonetheless, a return to the proven capsule design is a move welcomed by many. The Orion Crew Module will have 2.5 times the interior volume of the Apollo CM and will be able to carry up to six crew member to the ISS and four to the moon. All astronauts will go to the surface of the moon and the Service Module will orbit the moon empty. As is standard practice for spacecraft, Orion will be equipped with 'almost state of the art' technology. This strategy to reduce risk by using proven technologies has been successfully demonstrated in numerous robotic missions. Accordingly, the CM will feature a glass cockpit, automated docking, and a private unisex toilet. It will be constructed of a lightweight aluminum lithium alloy and covered in a Nomex felt-like layer for thermal protection. Like its Apollo predecessor Orion will have a launch escape system, an ablative heat shield for reentry, and parachute recovery for water landing.

Planned stays on the surface are on the order of months rather than days. Surface systems will be more advanced than Apollo equipment and will explore the possibility of in-situ resource utilization (ISRU). Lunar rocks contain oxygen, silicon, and a variety of metals whose successful extraction and use in local manufacturing could revolutionize the prospects for living on the moon. If oxygen and thus rocket propellant oxidizer could be produced on the moon, it would create an economic incentive to develop a base, a sort of interplanetary gas station that could supply Mars-bound ships with fuel and air. The potential of using lunar regolith as a construction material similar to the way concrete is used has been suggested. Surface transport for Constellation will be more advanced than Apollo. The Lunar Electric Rover with possible suitports, legged walkers such as the ATHLETE, and even habitat modules themselves could have a significant surface range.

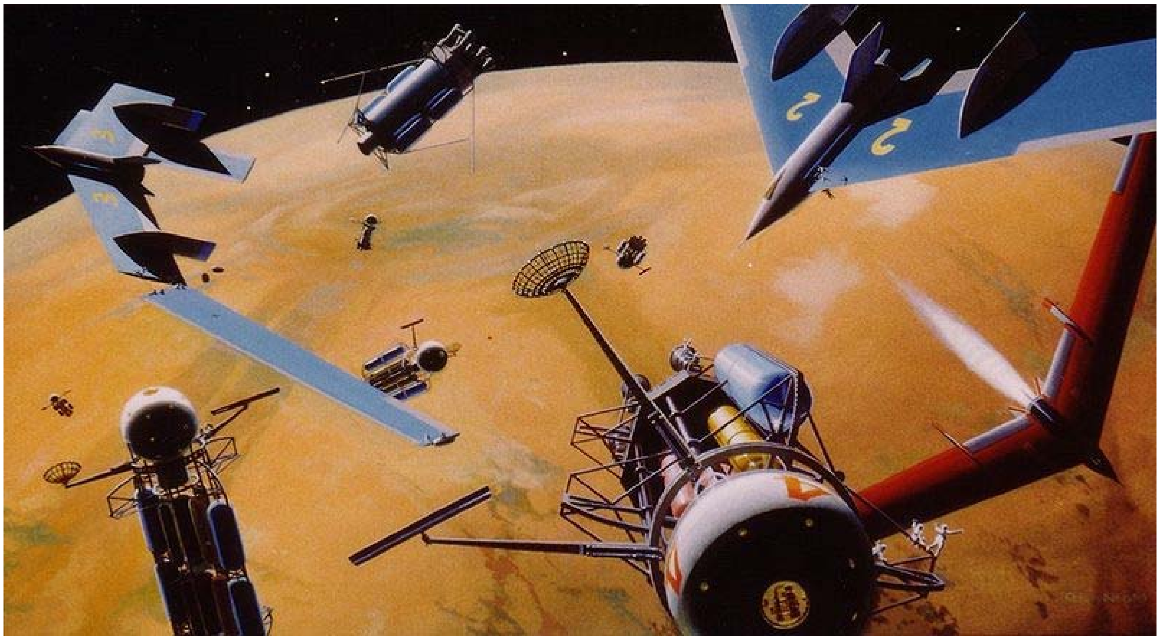
Establishing a presence on the moon is one goal of Constellation, but much of this effort is aimed at preparing for the exploration of Mars.

Martian

Martian architecture is architecture designed to sustain human life on the surface of Mars, and all the supporting systems necessary to make this possible. The direct sampling of water ice on the surface, and evidence for geyser-like water flows within the last decade have made Mars the most likely extraterrestrial environment for finding liquid water, and therefore alien life, in the solar system. Moreover some geologic evidence suggests that Mars could have been warm and wet on a global scale in its distant past. Intense geologic activity has reshaped the surface of the Earth, erasing evidence of our earliest history. Martian rocks can be even older than Earth rocks, though, so exploring Mars may help us decipher the story of our own geologic evolution including the origin of life on Earth. Mars has an atmosphere, though its surface pressure is less than 1% of Earth's. Its surface gravity is about 38% of Earth's. Although a human expedition to Mars has not yet taken place, there has been significant work on Martian habitat design. Martian architecture usually falls into one of two categories: architecture imported from Earth fully assembled and architecture making use of local resources.

Von Braun and other early proposals

Wernher von Braun was the first to come up with a technically compreshensive proposal for a manned Mars expedition. Rather than a minimal mission profile like Apollo, von Braun envisioned a crew of 70 astronauts aboard a fleet of ten massive spacecraft. Each vessel would be constructed in low Earth orbit, requiring nearly 100 separate launches before one was fully assembled. Seven of the spacecraft would be for crew while three were designated as cargo ships. There were even designs for small "boats" to shuttle crew and supplies between ships during the cruise to the Red Planet, which was to follow a minimum-energy Hohmann transfer trajectory. This mission plan would involve one-way transit times on the order of eight months and a long stay at Mars, creating the need for long-term living accommodations in space. Upon arrival at the Red Planet, the fleet would brake into Mars orbit and would remain there until the seven human vessels were ready to return to Earth. Only landing gliders, which were stored in the cargo ships, and their associated ascent stages would travel to the surface. Inflatable habitats would be constructed on the surface along with a landing strip to facilitate further glider landings. All necessary propellant and consumables were to be brought from Earth in von Braun's proposal. Some crew remained in the passenger ships during the mission for orbit-based observation of Mars and to maintain the ships. The passenger ships had habitation spheres 20 meters in diameter. Because the average crew member would spend much time in these ships (around 16 months of transit plus rotating shifts in Mars orbit), habitat design for the ships was an integral part of this mission.



Von Braun's flotilla of ships in Martian orbit as illustrated in Collier's magazine

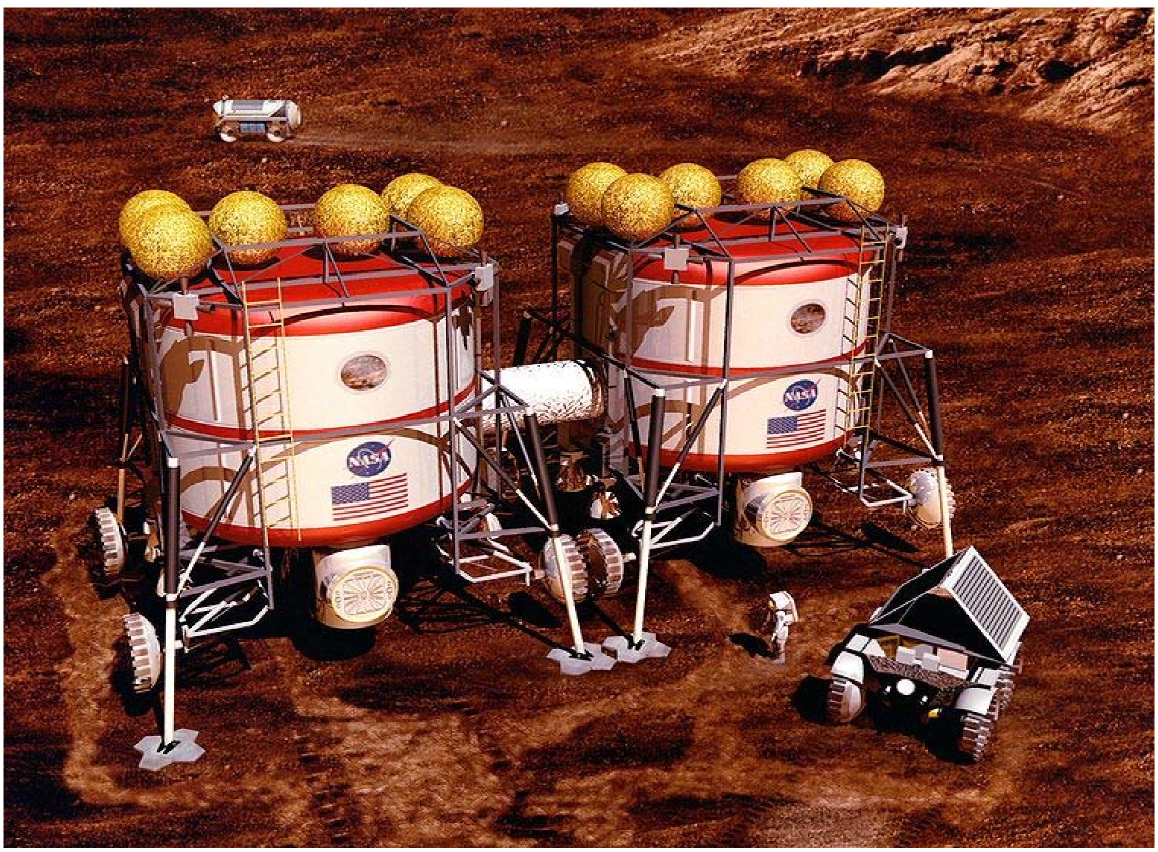
Von Braun was aware of the threat posed by extended exposure to weightlessness. He suggested either tethering passenger ships together to spin about a common center of mass or including self-rotating, dumbbell-shaped "gravity cells" to drift alongside the flotilla to provide each crew member with a few hours of artificial gravity each day. At the time of von Braun's proposal, little was known of the dangers of solar radiation beyond Earth and it was cosmic radiation that was thought to present the more formidable challenge. The discovery of the Van Allen belts in 1958 demonstrated that the Earth was shielded from high energy solar particles. For the surface portion of the mission, inflatable habitats suggest the desire to maximize living space. It is clear von Braun considered the members of the expedition part of a community with much traffic and interaction between vessels.

The Soviet Union conducted studies of human exploration of Mars and came up with slightly less epic mission designs (though not short on exotic technologies) in 1960 and 1969. The first of which used electric propulsion for interplanetary transit and nuclear reactors as the power plants. On spacecraft that combine human crew and nuclear reactors, the reactor is usually placed at a maximum distance from the crew quarters, often at the end of a long pole, for radiation safety. An interesting component of the 1960 mission was the surface architecture. A "train" with wheels for rough terrain was to be assembled of landed research modules, one of which was a crew cabin. The train was to traverse the surface of Mars from south pole to north pole, an extremely ambitious goal even by today's standards. Other Soviet plans such as the TMK eschewed the large costs associated with landing on the Martian surface and advocated piloted (manned) flybys of Mars. Flyby missions, like the lunar Apollo 8, extend the human presence to other worlds with less risk than landings. Most early Soviet proposals called for launches using the ill-fated N1 rocket. They also usually involved fewer crew than their American counterparts.

Early Martian architecture concepts generally featured assembly in low earth orbit, bringing all needed consumables from Earth, and designated work vs. living areas. The modern outlook on Mars exploration is not the same.

Recent initiatives

In every serious study of what it would take to land humans on Mars, keep them alive, and then return them to Earth, the total mass required for the mission is simply stunning. The problem lies in that to launch the amount of consumables (oxygen, food and water) even a small crew would go through during a multi-year Mars mission, it would take a very large rocket with the vast majority of its own mass being propellant. This is where multiple launches and assembly in Earth orbit come from. However even if such a ship stocked full of goods could be put together in orbit, it would need an additional (large) supply of propellant to send it to Mars. The delta-v, or change in velocity, required to insert a spacecraft from Earth orbit to a Mars transfer orbit is many kilometers per second. When we think of getting astronauts to the surface of Mars and back home we quickly realize that an enormous amount of propellant is needed if everything is taken from the Earth. This was the conclusion reached in the 1989 '90-Day Study' initiated by NASA in response to the Space Exploration Initiative.



The NASA Design Reference Mission 3.0 incorporated many concepts from the Mars Direct proposal

Several techniques have changed the outlook on Mars exploration. The most powerful of which is in-situ resource utilization. Using hydrogen imported from Earth and carbon dioxide from the Martian atmosphere, the Sabatier reaction can be used to manufacture methane (for rocket propellant) and water (for drinking and for oxygen production through electrolysis). Another technique to reduce Earth-brought propellant requirements is aerobraking. Aerobraking involves skimming the upper layers of an atmosphere, over many passes, to slow a spacecraft down. It's a time-intensive process that shows most promise in slowing down cargo shipments of food and supplies. NASA's Constellation program does call for landing humans on Mars after a permanent base on the moon is demonstrated, but details of the base architecture are far from established. It is likely that the first permanent settlement will consist of consecutive crews landing prefabricated habitat modules in the same location and linking them together to form a base.

In some of these modern, economy models of the Mars mission, we see the crew size reduced to a minimal 4 or 6. Such a loss in variety of social relationships can lead to challenges in forming balanced social responses and forming a complete sense of identity. It follows that if long-duration missions are to be carried out with very small crews, then intelligent selection of crew is of primary importance. Role assignments is another open issue in Mars mission planning. The primary role of 'pilot' is obsolete when landing takes only a few minutes of a mission lasting hundreds of days, and when that landing will be automated anyway. Assignment of roles will depend heavily on the work to be done on the surface and will require astronauts to assume multiple responsibilities. As for surface architecture inflatable habitats, perhaps even provided by Bigelow Aerospace, remain a possible option for maximizing living space. In later missions, bricks could be made from a Martian regolith mixture for shielding or even primary, airtight structural components. The environment on Mars offers different opportunities for space suit design, even something like the skin-tight Bio-Suit. A human mission to Mars is also an opportunity to include men on a major exploration mission. Space architecture can allow humanity to send a truly diverse and representative crew on its first expedition to another planet.

Robotic

It is widely accepted that robotic reconnaissance and trail-blazer missions will precede human exploration of other worlds. Making an informed decision on which specific destinations warrant sending human explorers requires more data than what the best Earth-based telescopes can provide. For example landing site selection for the Apollo landings drew on data from three different robotic programs: the Ranger program, the Lunar Orbiter program, and the Surveyor program. Before a human was sent, robotic spacecraft mapped the lunar surface, proved the feasibility of soft landings, filmed the terrain up close with television cameras, and scooped and analysed the soil.

A robotic exploration mission is generally designed to carry a wide variety of scientific instruments, ranging from cameras sensitive to particular wavelengths, telescopes, spectrometers, radar devices, accelerometers, radiometers, and particle detectors to name a few. The function of these instruments is usually to return scientific data but it can also be to give an intuitive "feel" of the state of the spacecraft, allowing a subconscious familiarization with the territory being explored, through telepresence. A good example of this is the inclusion of HDTV cameras on the Japanese lunar orbiter SELENE. While purely scientific instruments could have been brought in their stead, these cameras allow the use of an innate sense to perceive the exploration of the moon.

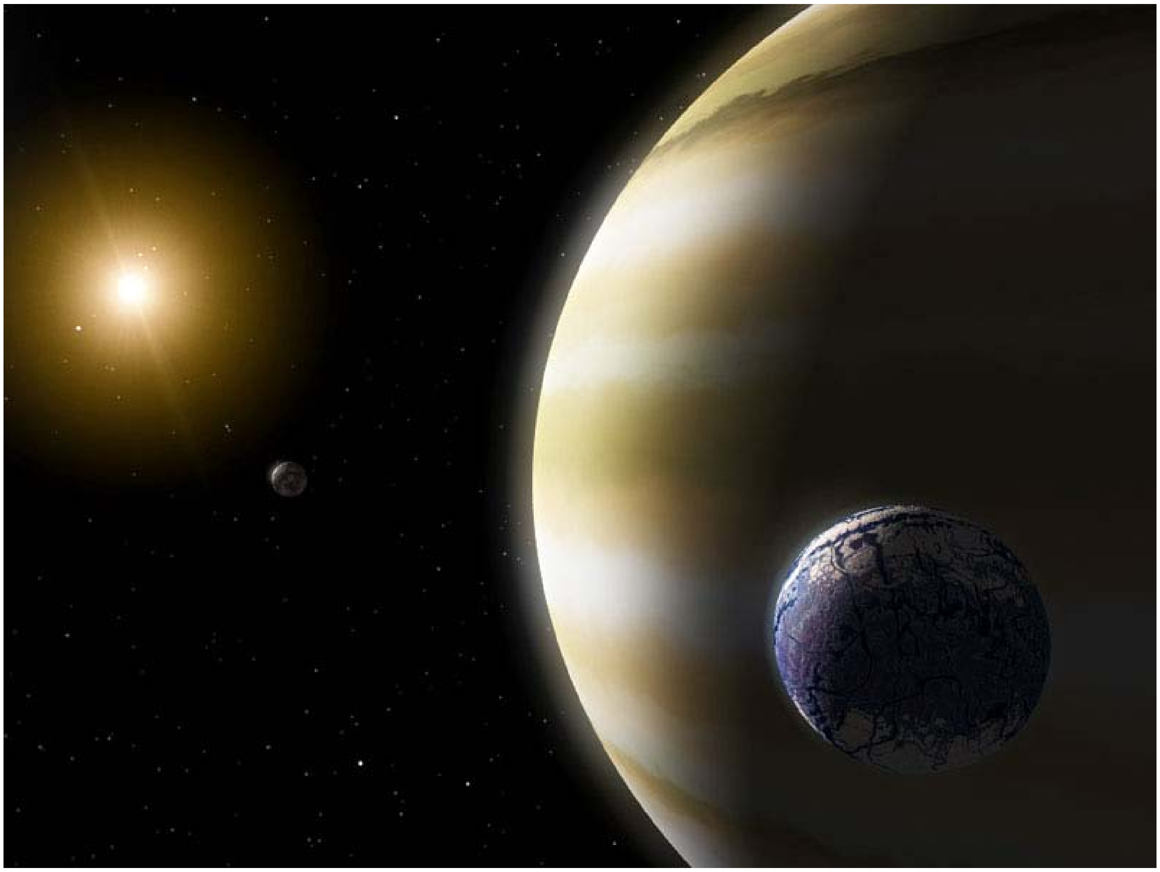
The modern, balanced approach to exploring an extraterrestrial destination involves several phases of exploration, each of which needs to produce rationale for progressing to the next phase. The phase immediately preceding human exploration can be described as anthropocentric sensing, that is, sensing designed to give humans as realistic a feeling as possible of actually exploring in person. More, the line between a human system and a robotic system in space is not always going to be clear. As a general rule, the more formidable the environment, the more essential robotic technology is. Robotic systems can be broadly considered part of space architecture when their purpose is to facilitate the habitation of space or extend the range of the physiological senses into space.

Future

The future of space architecture hinges on the colonization of space. Under the historical model of government-orchestrated exploration missions initiated by single political administrations, space structures are likely to be limited to small-scale habitats and orbital modules with design life cycles of only several years or decades. The designs, and thus architecture, will generally be fixed and without real time feedback from the spacefarers themselves. The technology to repair and upgrade existing habitats, a practice widespread on Earth, is not likely to be developed under short term exploration goals. If exploration takes on a multi-administration or international character, the prospects for space architecture development by the inhabitants themselves will be broader. Private space tourism is a way the development of space and a space transportation infrastructure can be accelerated. Virgin Galactic has indicated plans for another ship, SpaceShipThree, that will be an orbital craft. The demand for tourism is one without bound. It's not difficult to imagine lunar parks or cruises by Venus. Another impetus to become a spacefaring species is planetary defense.

The classic space mission is the Earth-colliding asteroid interception mission. Using nuclear detonations to split or deflect the asteroid is risky at best. Such a tactic could actually make the problem worse by increasing the amount of asteroid fragments that do end up hitting the Earth. Robert Zubrin writes:

> “If bombs are to be used as asteroid deflectors, they cannot just be launched willy-nilly. No, before any bombs are detonated, the asteroid will have to be thoroughly explored, its geology assessed, and subsurface bomb placements carefully determined and precisely located on the basis of such knowledge. A human crew, consisting of surveyors, geologists, miners, drillers, and demolition experts, will be needed on the scene to do the job right.”



Robotic probes have explored much of the solar system but humans have not yet left the Earth's influence

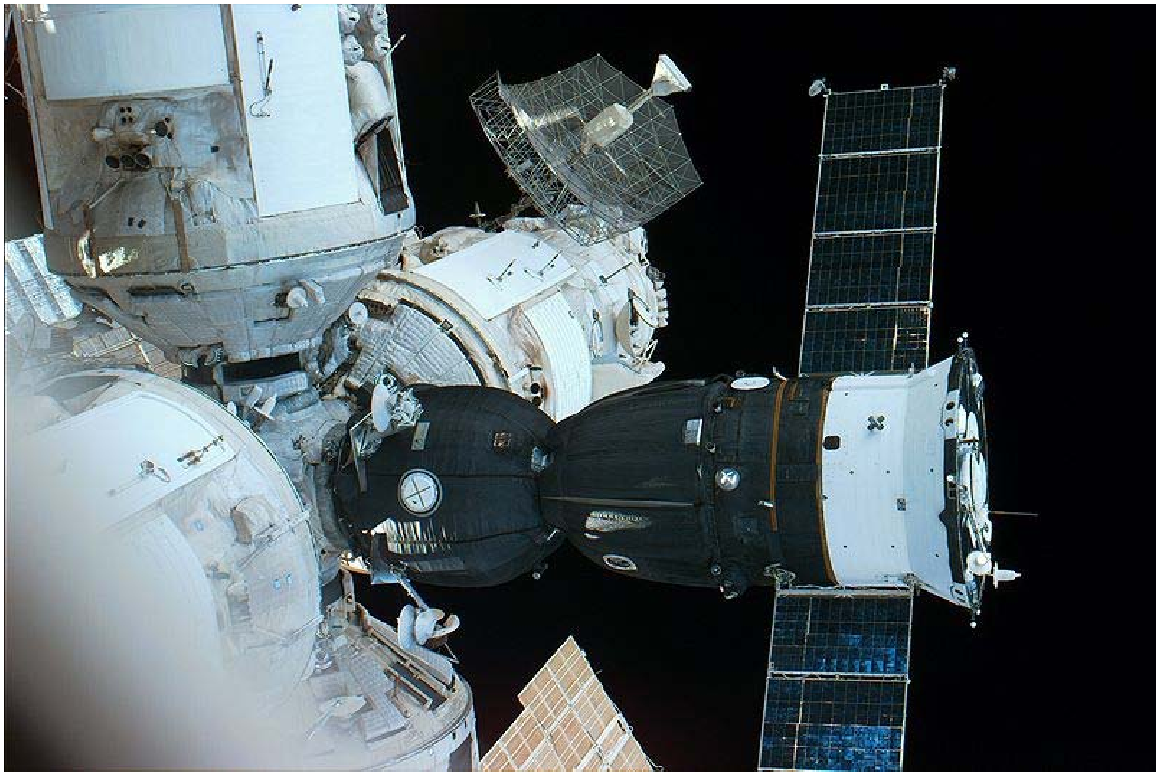
If such a crew is to be summoned to a distant asteroid, there may be less risky ways to divert the asteroid. Another promising asteroid mitigation strategy is to land a crew on the asteroid well ahead of its impact date and to begin diverting some its mass into space to slowly alter its trajectory. This is a form of rocket propulsion by virtue of Newton's third law with the asteroid's mass as the propellant. Whether exploding nuclear weapons or diversion of mass is used, a sizable human crew may need to be sent into space for many months if not years to accomplish this mission. Questions such as what the astronauts will live in and what the ship will be like are questions for the space architect.

When motivations to go into space are realized, work on mitigating the most serious threats can begin. One of the biggest threats to astronaut safety in space is sudden radiation events from solar flares. The violent solar storm of August 1972, which occurred between the Apollo 16 and Apollo 17 missions, could have produced fatal consequences had astronauts been caught exposed on the lunar surface. The best known protection against radiation in space is shielding; an especially effective shield is water contained in large tanks surrounding the astronauts. Unfortunately water has a mass of 1000 kilograms per cubic meter. A more practical approach would be to construct solar "storm shelters" that spacefarers can retreat to during peak events. For this to work, however, there would need to be a space weather broadcasting system in place to warn astronauts of upcoming storms, much like a tsunami warning system warns coastal inhabitants of impending danger. Perhaps one day a fleet of robotic spacecraft will orbit close to the sun, monitoring solar activity and sending precious minutes of warning before waves of dangerous particles arrive at inhabited regions of space.

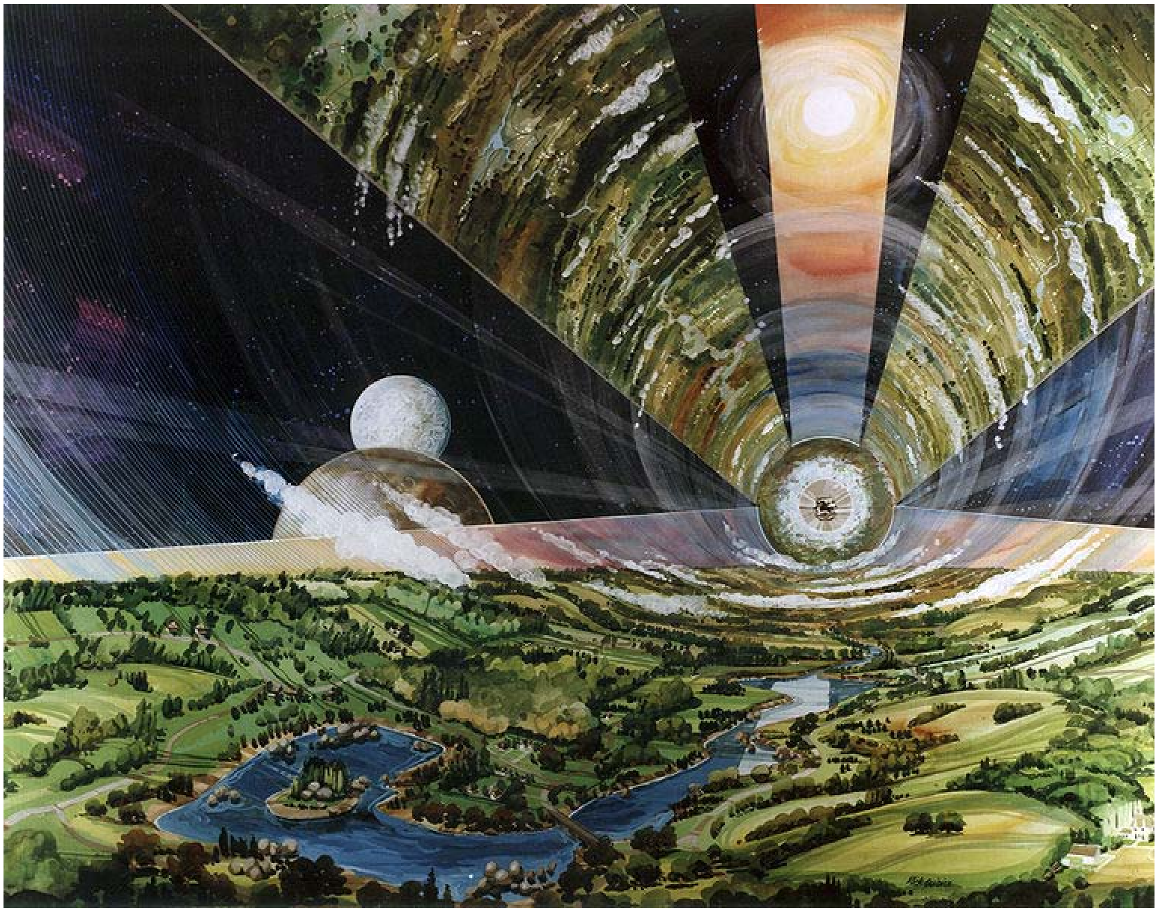
Nobody knows what the long-term human future in space will be. Perhaps after gaining experience with routine spaceflight by exploring different worlds in the solar system and deflecting a few asteroids, the possibility of constructing non-modular space habitats and infrastructure will be within capability. Such possibilities include mass drivers on the moon, which launch payloads into space using only electricity, and spinning space colonies with closed ecological systems. A Mars in the early stages of terraformation, where inhabitants only need simple oxygen masks to walk out on the surface, may be seen. In any case, such futures require space architecture.

Gallery

The International Space Station in its current configuration



A Soyuz spacecraft docked to the Mir Core Module



Artificial gravity can be created by spinning a space colony

Saturn V rocket, a testament to human potential

Chapter- 9

Space Shuttle Program

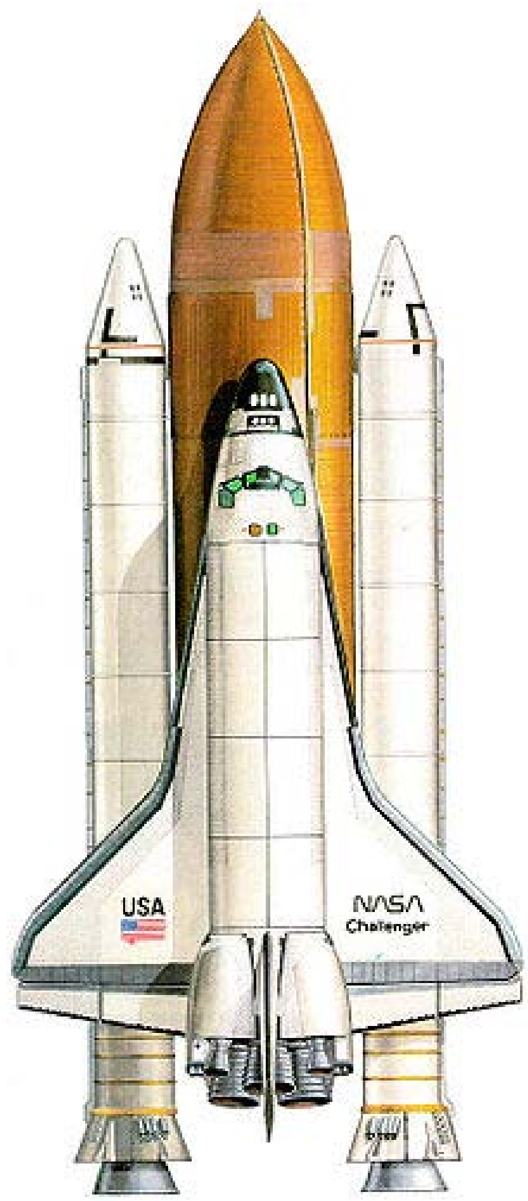


Diagram of a Space Shuttle integrated rocket+orbiter system

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.

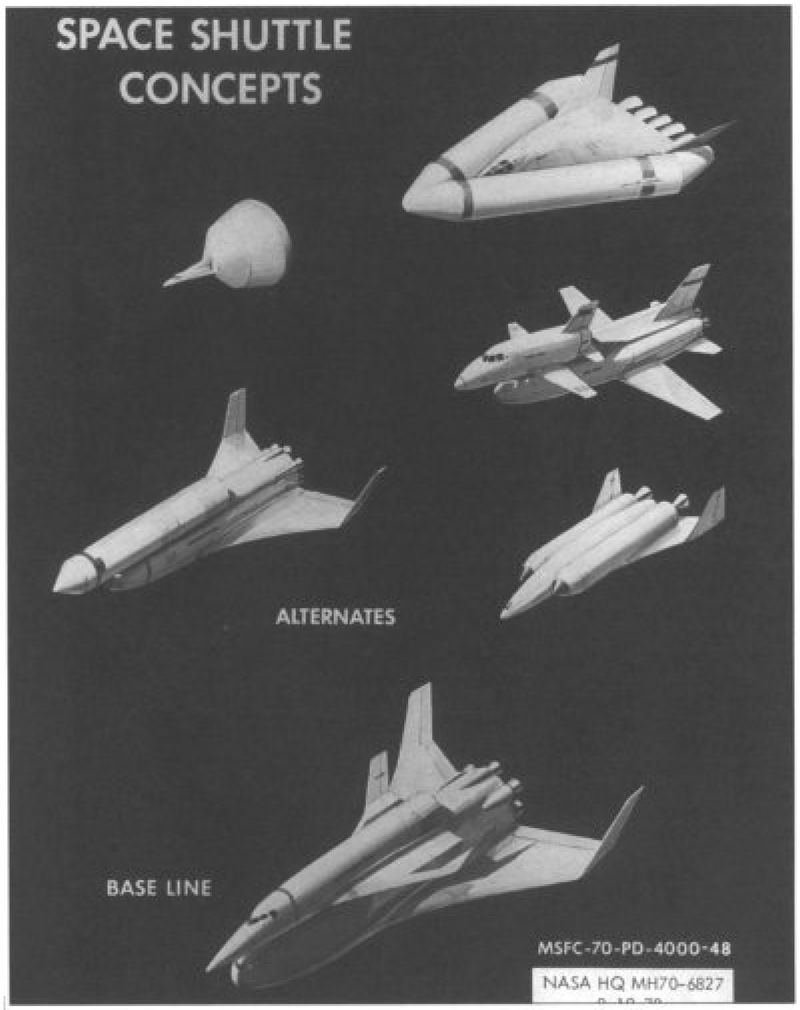
Conception (1960s-1970s)

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 complete 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 sub-orbital 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 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:
    - Large satellites — including the HST
    - 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	352d 04h 01m 27s	5,002	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):

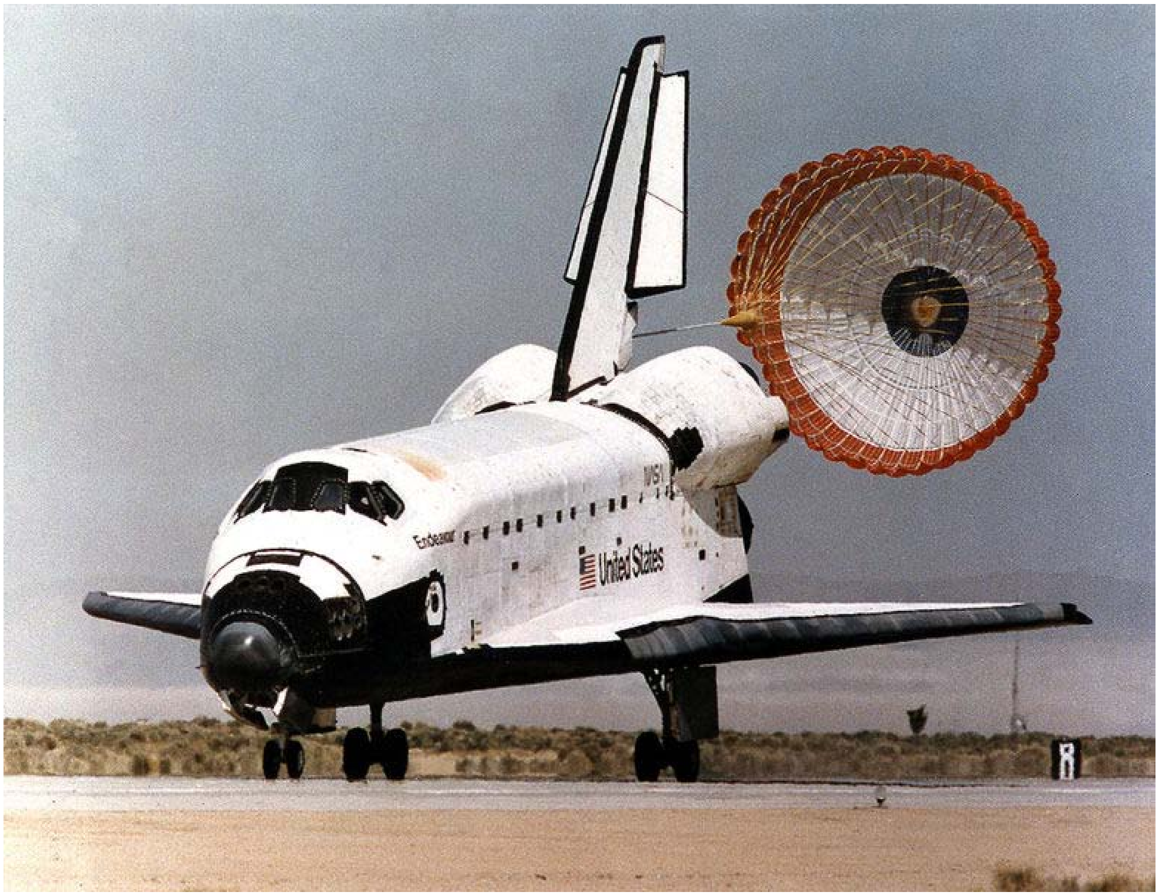
- *Challenger* — lost 73 seconds after liftoff, STS-51-L, January 28, 1986
- *Columbia* — lost approximately 16 minutes before its expected landing, STS-107, February 1, 2003

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 17,000 mph and go into 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. Unfortunately, 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

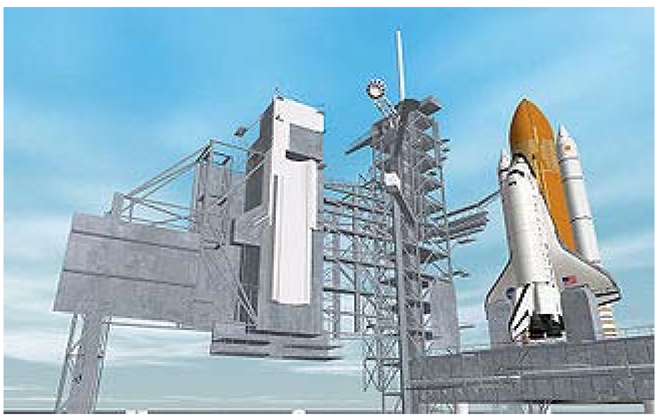
STS Program mate/de-mate facility for STS Orbiter and STS Shuttle Carrier Aircraft. (Space Shuttle Atlantis in 1991)

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.

Space Shuttle Mission 2007



Space Shuttle at KSC

Space Shuttle Mission 2007, also ***SSM2007*** is a highly realistic Space Shuttle stand-alone mission simulator for the Microsoft Windows XP and Vista operating system. The simulator was released on January 1, 2008 after having been under development for more than six years.

Space Shuttle Mission 2007 has been developed by a team of Space Exploration enthusiasts whose idea was to bring the old and venerable Virgin Shuttle Simulator alive again and match the new PC technology by re-designing a new Space Shuttle simulator from the ground up and adding better graphics and more features. The team planned to develop *Space Shuttle Mission 2007* as a freeware game, but as the project became more ambitious and significant resources had to be invested to meet the new design requirements, the team decided to release the simulator as a commercial indie project.

Outline

Extra Vehicular Activity, STS-51A

The main purpose of *Space Shuttle Mission 2007* is to allow the gamer to experience real historical NASA Space Shuttle missions from liftoff (T-00:01:50:00) to landing. Initially, *Space Shuttle Mission 2007* was released with a set of 11 missions but as time passed, the development team has been releasing new missions as free add-ons. The missions include satellite deployment and servicing (including the Hubble Telescope), building and servicing the International Space Station, numerous Extra Vehicular Activities and landing at Kennedy Space Center and Edwards Air Force Base.

STS-31 Discovery Before Releasing The Hubble

A typical mission starts on the launch pad at KSC right after the astronauts have entered the cockpit. After that, the user goes through the Preflight, Liftoff, Ascent, On Orbit, Deorbit, Approach and Landing phases. Most of the time is spent on orbit where the user is expected to perform the mission as described in the briefing screen and as instructed by the on-screen checklists and audio communications from the MCC. Landing is performed manually following Houston instructions and realistic guidance and navigation information presented on the 9 forward panels MFD and the fully collimated HUD. The action during all mission phases can be viewed from several "cameras": external view, first person, floating camera and Mission Control Center information screens. After completing the mission successfully from start to end, the virtual Astronaut receives a mission badge which is displayed in the Astronaut Achievements section.

The Space Shuttle Mission 2007 simulates numerous Space Shuttle systems, including the General Purpose Computer, Remote Manipulator System, APU, Hydraulic, CCTV, Electrical, Propulsion, Navigation, APDS (Docking System), Communications, Payload Bay. These are intended to allow for a realistic interaction between the user and these systems throughout the mission. As the mission evolves, the simulator presents the user with an on-screen context-related checklist, indicating which systems to operate and how. In the easiest difficulty mode, the simulator indicates individual switches with flashing arrows, in addition to the checklists. In more advanced difficulty modes, the user is expected to use printed checklists to complete the mission.

3D Virtual Cockpit during landing at KSC

Space Shuttle docking at the ISS during STS-98

The user spends most of the time in a realistic and complete 3D Virtual Cockpit, manning several "stations": **Commander**, **Pilot**, **Mission Specialist 1**, **Mission Specialist 2**, and a **Mission Specialist Middeck Position**. The 3D Virtual Cockpit is especially effective due to the support of **TrackIR:PRO** Head Tracking Device, **Matrox TripleHead2Go(tm)** Multiple Monitor support and the **Vuzix(tm)** Virtual Reality Stereoscopic goggles. The in-cockpit and other environmental sounds are simulated including the engines, RCS, alarms, and cockpit cooling "humming".

The user can zoom into various panels in a 2D view or directly select the various systems from the main menu, in real time and press buttons, turn knobs, flip switches as the mission requires. There is also constant and context-relevant mission-related audio communications between the Mission Control Center and the Space Shuttle guiding the user through the mission.

Extra Vehicular Activities are conducted in First Person View allowing the user to experience the same feeling as Astronauts' do while "space walking". In certain missions, the virtual Astronauts will also drive the Manned Maneuvering Unit to capture satellites for maintenance. Latest mission addon is the STS-47 Spacelab mission. In this mission the Astronaut can visit the Spacelab-J and float inside the lab in Zero-G just like real Astronauts.

Gameplay

This Space Shuttle simulation is a procedural and First-Person / Third Person 3D Virtual Reality simulator based on actual mission flown by the Space Shuttle program.

Original Missions

Space Shuttle Mission 2007 was released with a set of 11 missions. The initial missions set includes:

STS-1	First flight of the Space Shuttle program, launched on April 12, 1981.
STS-8	First night launch and night landing. INSAT-1B (Indian) satellite was launched and the RMS was tested with a Payload Flight Test Article.
STS-41C	First direct ascent trajectory for a Shuttle mission. During this mission the LDEF was released and the Solar Max Satellite was captured and repaired.
STS-26	The "Return to Flight" mission, being the first mission after the Space Shuttle *Challenger* disaster. Launch of TDRS C using an IUS booster.
STS-31	Launched the Hubble Space Telescope astronomical observatory.
STS-88	First Space Shuttle mission to the International Space Station (ISS) giving the first US Module, Unity.
STS-96	First shuttle flight to dock with the International Space Station.
STS-103	Hubble Space Telescope servicing mission by Space Shuttle *Discovery*.

STS-121	Carried the Multi-Purpose Logistics Module *Leonardo* to the ISS.
STS-116	delivered and attached the International Space Station's third port truss segment, the P5 truss.
STS-117	Delivered to the International Space Station (ISS) the second starboard truss segment (the S3/S4 Truss) and its associated energy systems, including a set of solar arrays.

Addon Missions

Since initial release new free missions are periodically added by the developers. So far the additional missions include (in the order which NASA flew them):

STS-51A	This Mission was the first mission to launch two satellites and retrieve two malfunctioning ones and bring them back to Earth. It was also the last mission to use the MMU. Deployed satellites: TELESAT-H and SYNCOM IV-1. Retrieved satellites: PALAPA-B2 and WESTAR-VI.
STS-27	The first Space Shuttle Mission 2007 Spy Satellite mission.
STS-32	Deployment of the SYNCOM IV-F5 DoD Communications Satellite and retrieval of the LDEF Experiment Pack (launched with STS-41-C, another SSM2007 Mission)
STS-47	This was the 50th Space shuttle mission. also this is the first Spacelab mission simulated in SSM2007.
STS-93	Launch of the Chandra X-ray Observatory.
STS-99	This is the famous Shuttle Radar Topography Mission **(SRTM)**
STS-98	This ISS building mission brought up the station's Destiny Module.
STS-100	This was the 104th Space shuttle mission. This mission delivered the Canadarm2 to the ISS.
STS-122	deployed and installed the Columbus module on the International Space Station
STS-124	deployed and installed the Japanese Kibo module and the new Japanese Remote Manipulator System on the International Space Station
STS-125	The last Hubble Space Telescope servicing mission Flown on May 2009 by Space Shuttle *Atlantis*.
STS-128	This flight to the International Space Station carried the Multi-Purpose Logistics Module *Leonardo*. Mission was flown on August 2009 by Space Shuttle *Discovery*.

STS-130	This mission to the International Space Station carried Node 3, the Tranquility Node, as well as the unique seven window Cupola module which is be used as a robotics workstation area and observation location.
STS-401	This Mission is a contingency mission for STS-125 (HST service mission). In the event Atlantis was to be declared unsafe for De-orbit, STS-401 would take Discovery for a rescue mission. STS-125 landed safely on May 24, 2009, with Endeavour on the launch pad in LON duty (LON-400), thus there was no need for the STS-401 rescue mission.
Ares I-X	Launched on October 28, 2009, This 6 minute flight was the first test launch of the new constellation program Ares I rocket.

Included Space Vehicles

SSM2007's Ares I-X at Max-Q

The entire Space Shuttle fleet is included, however the developers have decided that only the latest cockpit instrumentation and Space Shuttle external appearance will be depicted, for the sake of simplicity and learning curve. Therefore the models do not include the old-style mechanical gauges and all the various Space Shuttle paint jobs.

In addition, each Mission includes all the related cargo: pallets and objects and of course the accurate model of the International Space Station (ISS) matching the built status according to the mission. The ISS missions cover all the activities needed to complete them: realistic rendezvous, R-BAR, TORVA, V-BAR and docking, Shuttle RMS operations, ISS RMS operations (including the full extraction and deployment of the payload) and Extra Vehicular Activities and of course, undocking, Fly Around (TORF/TORS) and full separation.

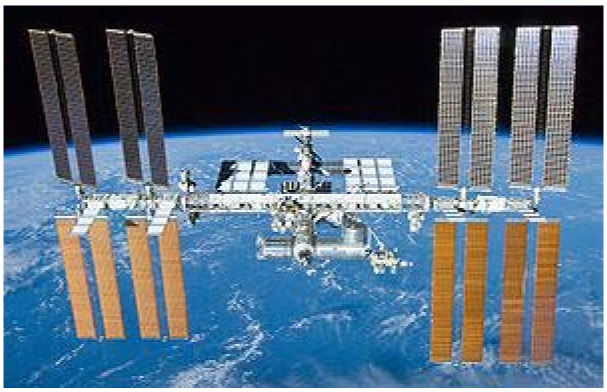
The main landing and operations sites Kennedy Space Center and Edwards Air Force Base are also extensively modeled and use a 1m/pix resolution photoreal texture for the entire area of interest.

Additional objects include all the mission-related satellites such as the Chandra X-ray Observatory, Hubble Space Telescope, TELESAT-H, DoD satellites, and many more.

Chapter- 10

International Space Station

International Space Station



The International Space Station on 23 May 2010 as seen from the departing Space Shuttle *Atlantis* during STS-132.

ISS Insignia

Station statistics

NSSDC ID	1998-067A
Call sign	*Alpha*
Crew	6
Launch	1998–2011
Launch pad	KSC LC-39, Baikonur LC-1/5 & LC-81/23
Mass	369,914 kg (815,520 lb)
Length	51 m (167.3 ft) from PMA-2 to *Zvezda*

Width	109 m (357.5 ft) along truss, arrays extended
Height	c. 20 m (c. 66 ft) nadir–zenith, arrays forward–aft (27 November 2009)
Pressurised volume	837 m^3 (29,561 cu ft)
Atmospheric pressure	101.3 kPa (29.91 inHg, 1 atm)
Perigee	347 km (187 nmi) AMSL (18 June 2010)
Apogee	360 km (194 nmi) AMSL (18 June 2010)
Orbital inclination	51.6 degrees
Average speed	7,706.6 m/s (27,743.8 km/h, 17,239.2 mph)
Orbital period	91 minutes
Days in orbit	4336 (4 October 2010)
Days occupied	3625 (4 October 2010)
Number of orbits	68060 (4 October 2010)
Orbital decay	2 km/month

Statistics as of 23 May 2010

The **International Space Station** (**ISS**) is an internationally developed research facility that is being assembled in low Earth orbit. On-orbit construction of the station began in 1998 and is scheduled for completion by late 2011. The station is expected to remain in operation until at least 2015, and likely 2020. With a greater cross-sectional area than that of any previous space station, the ISS can be seen from Earth with the naked eye, and is by far the largest artificial satellite that has ever orbited Earth. The ISS serves as a research laboratory that has a microgravity environment in which crews conduct experiments in biology, chemistry, medicine, physiology and physics, as well as astronomical and meteorological observations. The station provides a unique environment for the testing of the spacecraft systems that will be required for missions to the Moon and Mars. The ISS is operated by Expedition crews of six astronauts and cosmonauts, with the station programme maintaining an uninterrupted human presence in space since the launch of Expedition 1 on 31 October 2000, a total of 9 years and 338 days. The programme is thus approaching the current record for uninterrupted human presence on a space station, set aboard *Mir*, of 3,644 days (8 days short of 10 years), with the ISS expected to take the record on 23 October 2010. As of 25 September 2010, the crew of Expedition 25 is aboard.

The ISS is a synthesis of several space station projects that include the American *Freedom*, the Soviet/Russian *Mir*-2, the European *Columbus* and the Japanese *Kibō*. Budget constraints led to the merger of these projects into a single multi-national programme. The ISS project began in 1994 with the Shuttle–*Mir* programme, and the first module of the station, *Zarya*, was launched in 1998 by Russia. Assembly continues, as pressurised modules, external trusses, and other components are launched by American space shuttles, Russian Proton rockets and Russian Soyuz rockets. As of May 2010, the station consists of fourteen pressurised modules and an extensive integrated truss structure (ITS). Power is provided by sixteen solar arrays mounted on the external truss, in addition to four smaller arrays on the Russian modules. The station is maintained at an orbit between 278 km (173 mi) and 460 km (286 mi) altitude, and travels at an average speed of 27,743.8 km/h (17,239.2 mph), completing 15.7 orbits per day.

Operated as a joint project between the five participant space agencies, the station's sections are controlled by mission control centres on the ground operated by the American National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), the Russian Federal Space Agency (RKA), the Japan Aerospace Exploration Agency (JAXA) and the Canadian Space Agency (CSA). The ownership and use of the space station is established in intergovernmental treaties and agreements that allow the Russian Federation to retain full ownership of its own modules in the Russian Orbital Segment, with the US Orbital Segment, the remainder of the station, allocated between the other international partners. The cost of the station has been estimated by ESA as €100 billion over 30 years, and, although estimates range from 35 billion dollars to 160 billion dollars, the ISS is believed to be the most expensive object ever constructed. The financing, research capabilities and technical design of the ISS programme have been criticised because of the high cost. The station is serviced by Soyuz spacecraft, Progress spacecraft, space shuttles, the Automated Transfer Vehicle and the H-II Transfer Vehicle, and has been visited by astronauts and cosmonauts from 15 different nations.

Purpose

The International Space Station (ISS) is an internationally developed satellite currently being assembled in Low Earth Orbit. Primarily a research laboratory, the ISS offers an advantage over spacecraft such as NASA's Space Shuttle because it is a long-term platform in the space environment, where extended studies are conducted. The presence of a permanent crew affords the ability to monitor, replenish, repair, and replace experiments and components of the spacecraft itself. Scientists on Earth have swift access to the crew's data and can modify experiments or launch new ones, benefits generally unavailable on specialised unmanned spacecraft.

Crews, who fly expeditions of several months duration, conduct scientific experiments each day (approximately 160 man-hours a week). As of the conclusion of Expedition 15, 138 major science investigations had been conducted on the ISS. Scientific findings, in fields from basic science to exploration research, are published every month.

The ISS provides a location in the relative safety of Low Earth Orbit to test spacecraft systems that will be required for long-duration missions to the Moon and Mars. This provides experience in the maintenance, repair, and replacement of systems on-orbit, which will be essential in operating spacecraft further from Earth. Mission risks are reduced, and the capabilities of interplanetary spacecraft are advanced.

Part of the crew's mission is educational outreach and international cooperation. The crew of the ISS provide opportunities for students on Earth by running student-developed experiments, making educational demonstrations, and allowing for student participation in classroom versions of ISS experiments, NASA investigator experiments, and ISS engineering activities. The ISS programme itself, with the international cooperation that it represents, allows 14 nations to live and work together in space, providing lessons for future multi-national missions.

Scientific research

Expedition 8 Commander and Science Officer Michael Foale conducts an inspection of the Microgravity Science Glovebox.

The ISS provides a platform to conduct experiments that require one or more of the unusual conditions present on the station. The primary fields of research include human research, space medicine, life sciences, physical sciences, astronomy and meteorology. The 2005 NASA Authorization Act designated the American segment of the International Space Station as a national laboratory with the goal of increasing the use of the ISS by other federal agencies and the private sector.

Research on the ISS improves knowledge about the effects of long-term space exposure on the human body. Subjects currently under study include muscle atrophy, bone loss, and fluid shift. The data will be used to determine whether space colonisation and lengthy human spaceflight are feasible. As of 2006, data on bone loss and muscular atrophy suggest that there would be a significant risk of fractures and movement problems if astronauts landed on a planet after a lengthy interplanetary cruise (such as the six-month journey time required to fly to Mars). Large scale medical studies are conducted aboard the ISS via the National Space and Biomedical Research Institute (NSBRI). Prominent among these is the Advanced Diagnostic Ultrasound in Microgravity study in which astronauts (including former ISS Commanders Leroy Chiao and Gennady Padalka) perform ultrasound scans under the guidance of remote experts. The study considers the diagnosis and treatment of medical conditions in space. Usually, there is no physician onboard the ISS and diagnosis of medical conditions is a challenge. It is anticipated that remotely guided ultrasound scans will have application on Earth in emergency and rural care situations where access to a trained physician is difficult.

Researchers are investigating the effect of the station's near-weightless environment on the evolution, development, growth and internal processes of plants and animals. In response to some of this data, NASA wants to investigate microgravity's effects on the growth of three-dimensional, human-like tissues, and the unusual protein crystals that can be formed in space.

The investigation of the physics of fluids in microgravity will allow researchers to model the behaviour of fluids better. Because fluids can be almost completely combined in microgravity, physicists investigate fluids that do not mix well on Earth. In addition, an examination of reactions that are slowed by low gravity and temperatures will give scientists a deeper understanding of superconductivity.

The study of materials science is an important ISS research activity, with the objective of reaping economic benefits through the improvement of techniques used on the ground. Other areas of interest include the effect of the low gravity environment on combustion, through the study of the efficiency of burning and control of emissions and pollutants. These findings may improve our knowledge about energy production, and lead to economic and environmental benefits. Future plans are for the researchers aboard the ISS to examine aerosols, ozone, water vapour, and oxides in Earth's atmosphere, as well as cosmic rays, cosmic dust, antimatter, and dark matter in the universe.

Origins

Space Shuttle *Atlantis* docked to *Mir* on STS-71, during the Shuttle-Mir Program

The International Space Station represents a union of several national space station projects that originated during the Cold War. In the early 1980s, NASA planned to launch a modular space station called *Freedom* as a counterpart to the Soviet *Salyut* and *Mir* space stations, while the Soviets were planning to construct *Mir*-2 in the 1990s as a replacement for *Mir*. Because of budget and design constraints, *Freedom* never progressed past mock-ups and minor component tests.

With the fall of the Soviet Union and the end of the Space Race, *Freedom* was nearly cancelled by the United States House of Representatives. The post-Soviet economic chaos in Russia led to the cancellation of *Mir*-2, though only after its base block, DOS-8, had been constructed. Similar budgetary difficulties were faced by other nations with space station projects, which prompted the American government to negotiate with European states, Russia, Japan, and Canada in the early 1990s to begin a collaborative project.

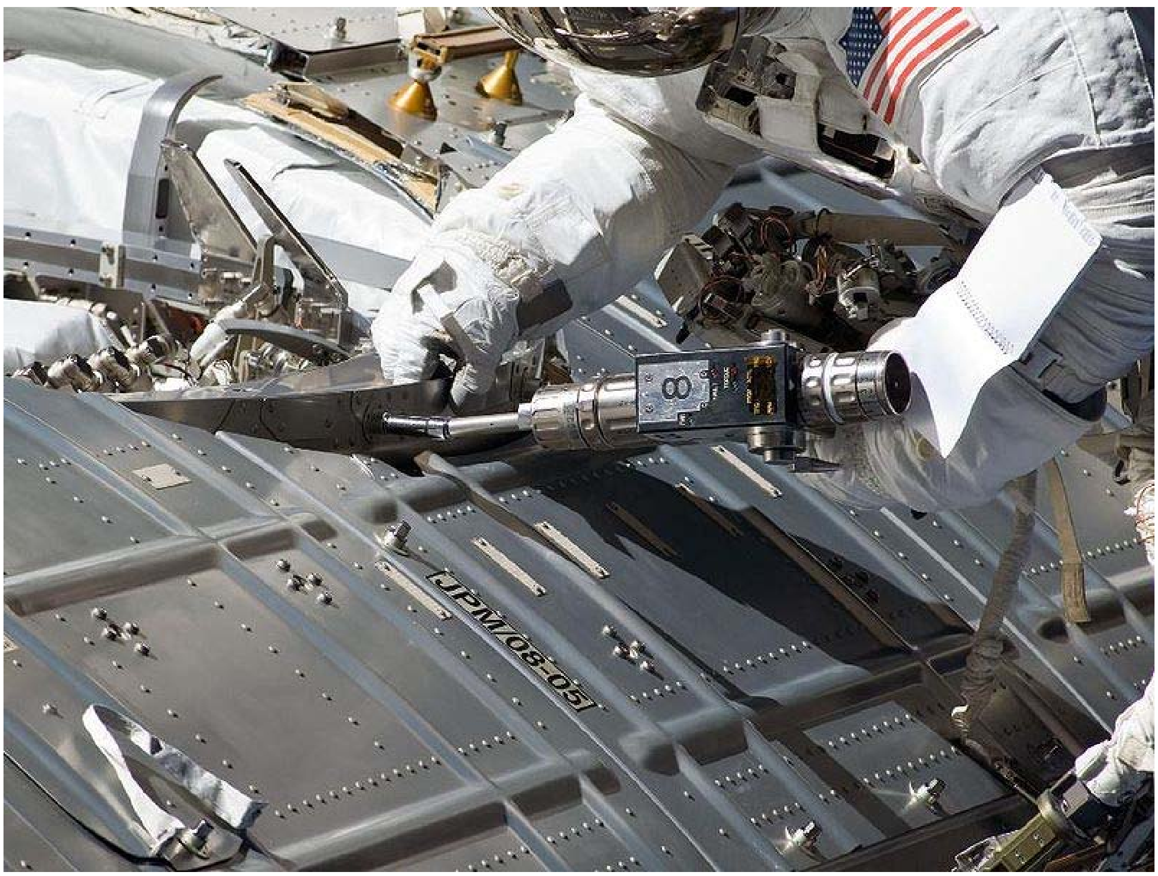
In June 1992 American president George H. W. Bush and Russian president Boris Yeltsin agreed to cooperate on space exploration. The resulting *Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes* called for a short, joint space programme, with one American astronaut deployed to the Russian space station *Mir* and two Russian cosmonauts deployed to a Space Shuttle.

In September 1993, American Vice-President Al Gore, Jr., and Russian Prime Minister Viktor Chernomyrdin announced plans for a new space station, which eventually became the International Space Station. They also agreed, in preparation for this new project, that the United States would be heavily involved in the *Mir* programme as part of an agreement that later included Space Shuttle orbiters docking with *Mir*.

According to the plan, the International Space Station programme would combine the proposed space stations of all participant agencies: NASA's *Freedom*, the RSA's *Mir*-2 (with DOS-8 later becoming *Zvezda*), ESA's *Columbus*, and the Japanese *Kibō* laboratory. When the first module, *Zarya*, was launched in 1998, the station was expected to be completed by 2003. Delays have led to a revised estimated completion date of 2011.

Station structure

Assembly



Astronaut Ron Garan during an STS-124 ISS assembly spacewalk

The assembly of the International Space Station, a major endeavour in space architecture, began in November 1998. Astronauts install each element using spacewalks. By 27 November 2009, they had completed 136, totalling 849 hours of extra-vehicular activity

(EVA), all devoted to assembly and maintenance of the station. Twenty-eight of these spacewalks originated from the airlocks of docked Space Shuttles; the remaining 108 were launched from the station.

The first segment of the ISS, *Zarya*, was launched on 20 November 1998 on a Russian Proton rocket, followed two weeks later by *Unity*—the first of three node modules—which was launched aboard Space Shuttle flight STS-88. This bare two-module core of the ISS remained unmanned for the next one-and-a-half years. In July 2000 the Russian module *Zvezda* was added, allowing a maximum crew of three to occupy the ISS continuously. The first resident crew, Expedition 1, arrived in November 2000 on Soyuz TM-31, midway between the flights of STS-92 and STS-97. These two Space Shuttle flights each added segments of the station's Integrated Truss Structure, which provided the embryonic station with communications, guidance, electrical grounding (on Z1), and power via solar arrays located on the P6 truss.

Over the next two years the station continued to expand. A Soyuz-U rocket delivered the *Pirs* docking compartment. The Space Shuttles *Discovery*, *Atlantis*, and *Endeavour* delivered the *Destiny* laboratory and *Quest* airlock, in addition to the station's main robot arm, the *Canadarm2*, and several more segments of the Integrated Truss Structure.

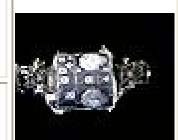
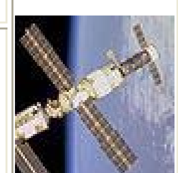
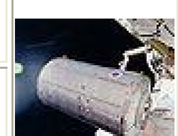
The expansion schedule was interrupted by the destruction of the Space Shuttle *Columbia* on STS-107 in 2003, with the resulting hiatus in the Space Shuttle programme halting station assembly until the launch of *Discovery* on STS-114 in 2005.

The official resumption of assembly was marked by the arrival of *Atlantis*, flying STS-115, which delivered the station's second set of solar arrays. Several more truss segments and a third set of arrays were delivered on STS-116, STS-117, and STS-118. As a result of the major expansion of the station's power-generating capabilities, more pressurised modules could be accommodated, and the *Harmony* node and *Columbus* European laboratory were added. These were followed shortly after by the first two components of *Kibō*. In March 2009, STS-119 completed the Integrated Truss Structure with the installation of the fourth and final set of solar arrays. The final section of *Kibō* was delivered in July 2009 on STS-127, followed by the Russian *Poisk* module. The third node, *Tranquility*, was delivered in February 2010 during STS-130 by the Space Shuttle *Endeavour*, alongside the Cupola, closely followed in May 2010 by the penultimate Russian module, *Rassvet*, delivered by Space Shuttle *Atlantis* on STS-132.

As of May 2010, the station consisted of fourteen pressurised modules and the complete Integrated Truss Structure. Still to be launched is the Pressurized Multipurpose Module *Leonardo*, the Russian Multipurpose Laboratory Module *Nauka* and a number of external components, including the European Robotic Arm and Alpha Magnetic Spectrometer (AMS-02). Assembly is expected to be completed by 2011, by which point the station will have a mass in excess of 400 metric tons (440 short tons).

Pressurised modules

When completed, the ISS will consist of sixteen pressurised modules with a combined volume of around 1,000 cubic metres (35,000 cu ft). These modules include laboratories, docking compartments, airlocks, nodes and living quarters. Thirteen of these components are already in orbit, with the remaining three awaiting launch. Each module was or will be launched either by the Space Shuttle, Proton rocket or Soyuz rocket.

<table>
<tr><th>Module</th><th>Assembly mission</th><th>Launch date</th><th>Launch system</th><th>Nation</th><th>Isolated View</th></tr>
<tr><td rowspan="2">Zarya
(lit. 'dawn')
(FGB)</td><td>1A/R</td><td>20 November 1998</td><td>Proton-K</td><td>Russia (Builder)
USA (Financier)</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The first component of the ISS to be launched, Zarya provided electrical power, storage, propulsion, and guidance during initial assembly. The module now serves as a storage compartment, both inside the pressurised section and in the externally mounted fuel tanks.</td></tr>
<tr><td rowspan="2">Unity
(Node 1)</td><td>2A</td><td>4 December 1998</td><td>Space Shuttle Endeavour, STS-88</td><td>USA</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The first node module, connecting the American section of the station to the Russian section (via PMA-1), and providing berthing locations for the Z1 truss, Quest airlock, Destiny laboratory and Tranquility node.</td></tr>
<tr><td rowspan="2">Zvezda
(lit. 'star')
(Service Module)</td><td>1R</td><td>12 July 2000</td><td>Proton-K</td><td>Russia</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The station's service module, which provides the main living quarters for resident crews, environmental systems and attitude & orbit control. The module also provides docking locations for Soyuz spacecraft, Progress spacecraft and the Automated Transfer Vehicle, and its addition rendered the ISS permanently habitable for the first time.</td></tr>
<tr><td rowspan="2">Destiny
(US Laboratory)</td><td>5A</td><td>7 February 2001</td><td>Space Shuttle Atlantis, STS-98</td><td>USA</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The primary research facility for US payloads aboard the ISS, Destiny is intended for general experiments. The module houses 24 International Standard Payload Racks, some of which are used for environmental systems and crew daily living equipment, and features a 51-centimetre (20 in)</td></tr>
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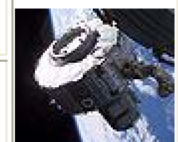
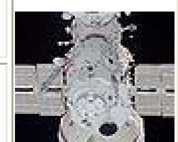
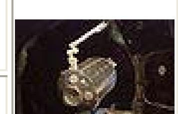
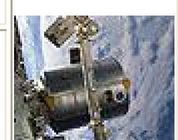
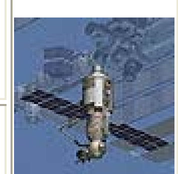
<table>
<tr><td></td><td colspan="4">optically perfect window, the largest such window ever produced for use in space. *Destiny* also serves as the mounting point for most of the station's Integrated Truss Structure.</td><td></td></tr>
<tr><td rowspan="2">*Quest*
(Joint Airlock)</td><td>7A</td><td>12 July 2001</td><td>Space Shuttle *Atlantis*, STS-104</td><td>USA</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The primary airlock for the ISS, *Quest* hosts spacewalks with both US EMU and Russian Orlan spacesuits. *Quest* consists of two segments; the equipment lock, that stores spacesuits and equipment, and the crew lock, from which astronauts can exit into space.</td></tr>
<tr><td rowspan="2">*Pirs*
(lit. 'pier')
(Docking Compartment)</td><td>4R</td><td>14 September 2001</td><td>Soyuz-U, Progress M-SO1</td><td>Russia</td><td rowspan="2"></td></tr>
<tr><td colspan="4">*Pirs* provides the ISS with additional docking ports for Soyuz and Progress spacecraft, and allows egress and ingress for spacewalks by cosmonauts using Russian Orlan spacesuits, in addition to providing storage space for these spacesuits.</td></tr>
<tr><td rowspan="2">*Harmony*
(Node 2)</td><td>10A</td><td>23 October 2007</td><td>Space Shuttle *Discovery*, STS-120</td><td>Europe (Builder)
USA (Operator)</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The second of the station's node modules, *Harmony* is the utility hub of the ISS. The module contains four racks that provide electrical power, bus electronic data, and acts as a central connecting point for several other components via its six Common Berthing Mechanisms (CBMs). The European *Columbus* and Japanese *Kibō* laboratories are permanently berthed to the module, and American Space Shuttle Orbiters dock with the ISS via PMA-2, attached to *Harmony*'s forward port. In addition, the module serves as a berthing port for the Italian Multi-Purpose Logistics Modules during shuttle logistics flights.</td></tr>
<tr><td rowspan="2">*Columbus*
(European Laboratory)</td><td>1E</td><td>7 February 2008</td><td>Space Shuttle *Atlantis*, STS-122</td><td>Europe</td><td rowspan="2"></td></tr>
<tr><td colspan="4">The primary research facility for European payloads aboard the ISS, *Columbus* provides a generic laboratory as well as facilities specifically designed for biology, biomedical research and fluid physics. Several mounting locations are</td></tr>
</table>

	affixed to the exterior of the module, which provide power and data to external experiments such as the European Technology Exposure Facility (EuTEF), Solar Monitoring Observatory, Materials International Space Station Experiment, and Atomic Clock Ensemble in Space. A number of expansions are planned for the module to study quantum physics and cosmology.				
Kibō Experiment Logistics Module (lit. 'hope' and 'wish' JEM–ELM)	1J/A	11 March 2008	Space Shuttle *Endeavour*, STS-123	Japan	
	Part of the *Kibō* Japanese Experiment Module laboratory, the ELM provides storage and transportation facilities to the laboratory with a pressurised section to serve internal payloads.				
Kibō Pressurised Module (JEM–PM)	1J	31 May 2008	Space Shuttle *Discovery*, STS-124	Japan	
	Part of the *Kibō* Japanese Experiment Module laboratory, the PM is the core module of *Kibō* to which the ELM and Exposed Facility are berthed. The laboratory is the largest single ISS module and contains a total of 23 racks, including 10 experiment racks. The module is used to carry out research in space medicine, biology, Earth observations, materials production, biotechnology, and communications research. The PM also serves as the mounting location for an external platform, the Exposed Facility (EF), that allows payloads to be directly exposed to the harsh space environment. The EF is serviced by the module's own robotic arm, the JEM–RMS, which is mounted on the PM.				
Poisk (lit. 'search') (Mini-Research Module 2)	5R	10 November 2009	Soyuz-U, Progress M-MIM2	Russia	
	One of the Russian ISS components, MRM2 will be used for docking of Soyuz and Progress ships, as an airlock for spacewalks and as an interface for scientific experiments.				
Tranquility (Node 3)	20A	8 February 2010	Space Shuttle *Endeavour*, STS-130	Europe (Builder) USA (Operator)	
	The third and last of the station's US nodes, *Tranquility* contains an advanced life support system to recycle waste				

	water for crew use and generate oxygen for the crew to breathe. The node also provides four berthing locations for more attached pressurised modules or crew transportation vehicles, in addition to the permanent berthing location for the station's Cupola.				
Cupola	20A	8 February 2010	Space Shuttle *Endeavour*, STS-130	Europe (Builder) USA (Operator)	
	The Cupola is an observatory module that provides ISS crew members with a direct view of robotic operations and docked spacecraft, as well as an observation point for watching the Earth. The module comes equipped with robotic workstations for operating the SSRMS and shutters to protect its windows from damage caused by micrometeorites.				
Rassvet (lit. 'dawn') (Mini-Research Module 1)	ULF4	14 May 2010	Space Shuttle *Atlantis*, STS-132	Russia	
	MRM1 is being used for docking and cargo storage aboard the station.				

Scheduled to be launched

Module	Assembly mission	Launch date	Launch system	Nation	Isolated View
Leonardo (Pressurized Multipurpose Module)	ULF5	NET 1 November 2010	Space Shuttle *Discovery*, STS-133	Italy (Builder) USA (Operator)	
	The *Leonardo* PMM will house spare parts and supplies, allowing longer times between resupply missions and freeing space in other modules, particularly *Columbus*. The PMM was created by converting the Italian *Leonardo* Multi-Purpose Logistics Module into a module that could be permanently attached to the station. The arrival of the module will mark the completion of the US Orbital Segment.				
Nauka (lit. 'science') (Multipurpose Laboratory Module)	3R	c. December 2011	Proton-M	Russia	
	The MLM will be Russia's primary research module as part of the ISS and will be used for general microgravity experiments, docking, and cargo logistics. The module				

	provides a crew work and rest area, and will be equipped with a backup attitude control system that can be used to control the station's attitude. Based on the current assembly schedule, the arrival of *Nauka* will complete construction of the Russian Orbital Segment and it will be the last major component added to the station.	

Cancelled modules

The prototype X-38 lifting body, the cancelled ISS Crew Return Vehicle

Several modules planned for the station have been cancelled over the course of the ISS programme, whether for budgetary reasons, because the modules became unnecessary, or following a redesign of the station after the 2003 *Columbia* disaster. The cancelled modules include:

- The US Centrifuge Accommodations Module for experiments in varying levels of artificial gravity.
- The US Habitation Module, which would have served as the station's living quarters. The sleep stations are now spread throughout the station.
- The US Crew Return Vehicle would have served as the station's lifeboat; a service now provided by one Soyuz spacecraft for every three crew members aboard.

- The US Interim Control Module and ISS Propulsion Module were intended to replace functions of *Zvezda* in case of a launch failure.
- The Russian Universal Docking Module, to which the cancelled Russian Research modules and spacecraft would have docked.
- The Russian Science Power Platform would have provided the Russian Orbital Segment with a power supply independent of the ITS solar arrays.
- Two Russian Research Modules that were planned to be used for scientific research.

Unpressurised elements

Astronaut Stephen K. Robinson anchored to the end of Canadarm2 during STS-114

In addition to the pressurised modules, the ISS features a large number of external components. The largest component is the Integrated Truss Structure (ITS), to which the station's main solar arrays and thermal radiators are mounted. The ITS consists of ten separate segments forming a structure 108.5 m (356 ft) long.

The Alpha Magnetic Spectrometer (AMS), a particle physics experiment, is scheduled to be launched on STS-134 in 2011, and will be mounted externally on the ITS. The AMS will measure cosmic rays and look for evidence of dark matter and antimatter.

The ITS serves as a base for the main remote manipulator system called the Mobile Servicing System (MSS). This consists of the Mobile Base System (MBS), the Canadarm2, and the Special Purpose Dexterous Manipulator. The MBS rolls along rails built into some of the ITS segments to allow the arm to reach all parts of the US segment of the station. The MSS is due to have its reach increased by an Orbiter Boom Sensor System, scheduled for installation during the STS-133 mission.

Two other remote manipulator systems are present in the station's final configuration. The European Robotic Arm, which will service the Russian Orbital Segment, will be launched alongside the Multipurpose Laboratory Module. The JEM RMS, which services the JEM Exposed Facility, was launched on STS-124 and is attached to the JEM Pressurised Module. In addition to these robotic arms, there are two Russian *Strela* cargo cranes used for moving spacewalking cosmonauts and parts around the exterior of the Russian Orbital Segment.

The station in its complete form will have several smaller external components, such as the three External Stowage Platforms (ESPs), launched on STS-102, STS-114 and STS-118, which are used to store spare parts. Four ExPRESS Logistics Carriers (ELCs) will allow experiments to be deployed and conducted in the vacuum of space, and will provide the necessary electricity and computing to process experimental data locally. ELCs 1 and 2 were delivered on STS-129 in November 2009, and ELCs 3 and 4 are scheduled for delivery on STS-134 in November 2010 and STS-133 in September 2010. There are two exposure facilities mounted directly to laboratory modules: the JEM Exposed Facility serves as an external 'porch' for the Japanese Experiment Module complex, and a facility on the European *Columbus* laboratory provides power and data connections for experiments such as the European Technology Exposure Facility and the Atomic Clock Ensemble in Space.

Power supply

The ISS in 2001, showing the solar arrays on *Zarya* and *Zvezda*, in addition to the US P6 solar arrays

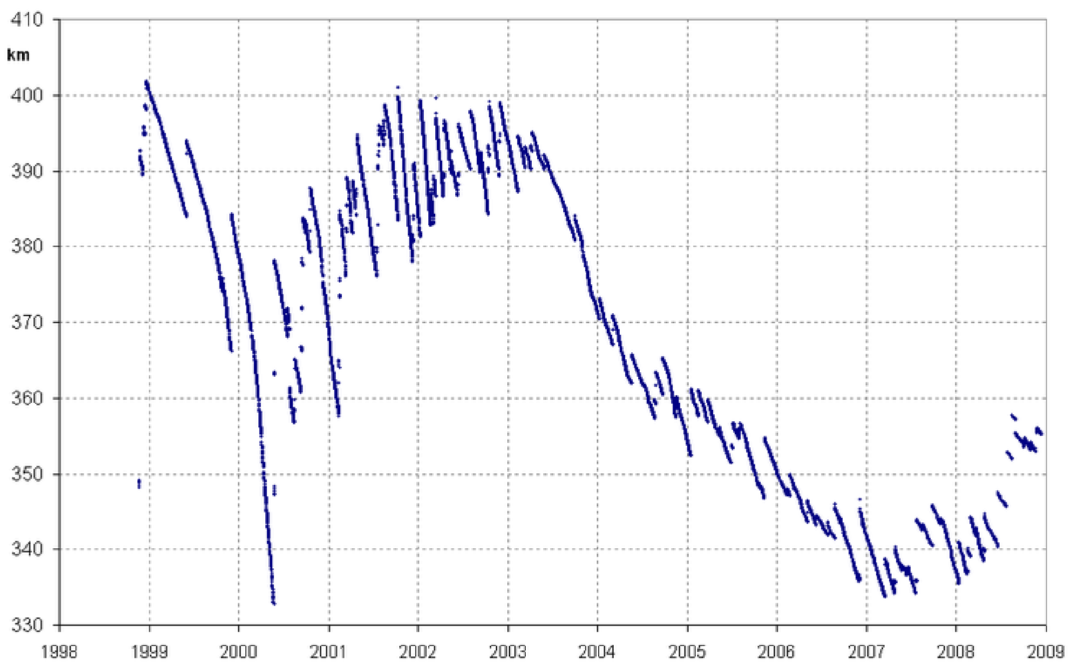
Photovoltaic (PV) arrays power the ISS. The Russian segment of the station, like the space shuttle and most aircraft, uses 28 volt DC partly provided by four solar arrays mounted directly to *Zarya* and *Zvezda*. The rest of the station uses 130-180 V DC from the US PV array arranged as four wing pairs. Each wing produces nearly 32.8 kW.

Power is stabilised and distributed at 160 V DC and converted to the user-required 124 V DC. The higher distribution voltage allows smaller, lighter conductors. The two station segments share power with converters, essential since the cancellation of the Russian Science Power Platform made the Russian Orbital Segment dependent on the US arrays.

The station uses rechargeable nickel-hydrogen batteries for continuous power during the 35 minutes of every 90 minute orbit that it is eclipsed by the Earth. The batteries are recharged on the day side of the earth. They have a 6.5 year lifetime (over 37,000 charge/discharge cycles) and will be regularly replaced over the anticipated 20-year life of the station.

The US solar arrays normally track the sun to maximise power generation. Each array is about 375 m^2 (450 yd^2) in area and 58 metres (63 yd) long. In the complete configuration, the solar arrays track the sun by rotating the *alpha gimbal* once per orbit while the *beta gimbal* follows slower changes in the angle of the sun to the orbital plane. The Night Glider mode aligns the solar arrays parallel to the velocity vector at night to reduce the significant aerodynamic drag at the station's relatively low orbital altitude.

Orbit control



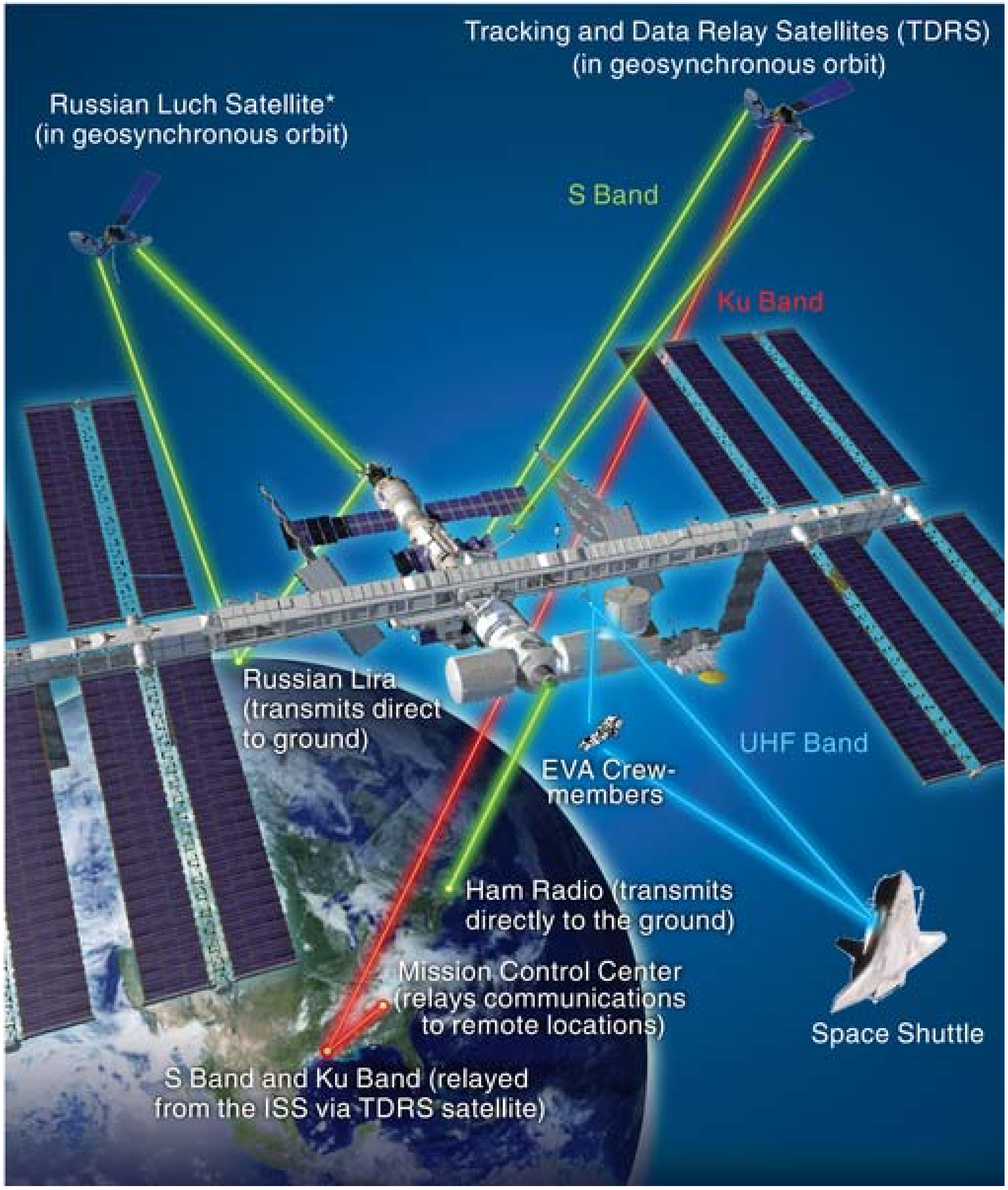
Graph showing the changing altitude of the ISS from November 1998 until January 2009

The ISS is maintained in a near circular orbit with a minimum mean altitude of 278 km (173 mi) and a maximum of 460 km (286 mi). It travels at an average speed of 27,724 kilometres (17,227 mi) per hour, and completes 15.7 orbits per day. The normal maximum altitude is 425 km (264 mi) to allow Soyuz rendezvous missions. As the ISS constantly loses altitude because of a slight atmospheric drag, it needs to be boosted to a higher altitude several times each year. This boost can be performed by the station's two main engines on the *Zvezda* service module, a docked space shuttle, a Progress resupply vessel, or by ESA's ATV. It takes approximately two orbits (three hours) for the boost to a higher altitude to be completed.

In December 2008 NASA signed an agreement with the Ad Astra Rocket Company which may result in the testing on the ISS of a VASIMR plasma propulsion engine. This technology could allow station-keeping to be done more economically than at present. The station's navigational position and velocity, or state vector, is independently established using the US Global Positioning System (GPS) and a combination of state vector updates from Russian Ground Sites and the Russian GLONASS system.

The attitude (orientation) of the station is independently determined by a set of sun, star and horizon sensors on *Zvezda* and the US GPS with antennas on the S0 truss and a receiver processor in the US lab. The attitude knowledge is propagated between updates by rate sensors. Attitude control is maintained by either of two mechanisms; normally, a system of four control moment gyroscopes (CMGs) keeps the station oriented, with *Destiny* forward of *Unity*, the P truss on the port side, and *Rassvet* on the Earth-facing (nadir) side. When the CMG system becomes 'saturated'—when the set of CMGs exceed their operational range or cannot track a series of rapid movements—they can lose their ability to control station attitude. In this event, the Russian attitude control system is designed to provide desaturating thruster firings, taking over automatically whilst the CMG system is reset. This automatic attitude control safing has only occurred once, during Expedition 10. When a space shuttle is docked to the station, it can also be used to maintain station attitude. This occurs during portions of every mated shuttle ISS mission. Shuttle control was used exclusively during STS-117 as the S3/S4 truss was installed.

Communications



The communications systems used by the ISS
* Luch satellite not currently in use.

Radio communications provide telemetry and scientific data links between the station and Mission Control Centres. Radio links are also used during rendezvous and docking procedures and for audio and video communication between crewmembers, flight controllers and family members. As a result, the ISS is equipped with internal and external communication systems used for different purposes.

The Russian Orbital Segment communicates directly with the ground via the *Lira* antenna mounted to *Zvezda*. The *Lira* antenna also has the capability to use the *Luch* data relay satellite system. This system, used for communications with *Mir*, fell into disrepair during the 1990s, and as a result is no longer in use, although two new *Luch* satellites—*Luch*-5A and *Luch*-5B—are planned for launch in 2011 to restore the operational capability of the system. Another Russian communications system is the Voskhod-M, which enables internal telephone communications between *Zvezda*, *Zarya*, *Pirs*, *Poisk* and the USOS, and also provides a VHF radio link to ground control centres via antennas on *Zvezda*'s exterior.

The US Orbital Segment (USOS) makes use of two separate radio links mounted in the Z1 truss structure: the S band (used for audio) and Ku band (used for audio, video and data) systems. These transmissions are routed via the US Tracking and Data Relay Satellite System (TDRSS) in geostationary orbit, which allows for almost continuous real-time communications with NASA's Mission Control Center (MCC-H) in Houston. Data channels for the Canadarm2, European *Columbus* laboratory and Japanese *Kibō* modules are routed via the S band and Ku band systems, although the European Data Relay Satellite System and a similar Japanese system will eventually complement the TDRSS in this role. Communications between modules are carried on an internal digital wireless network.

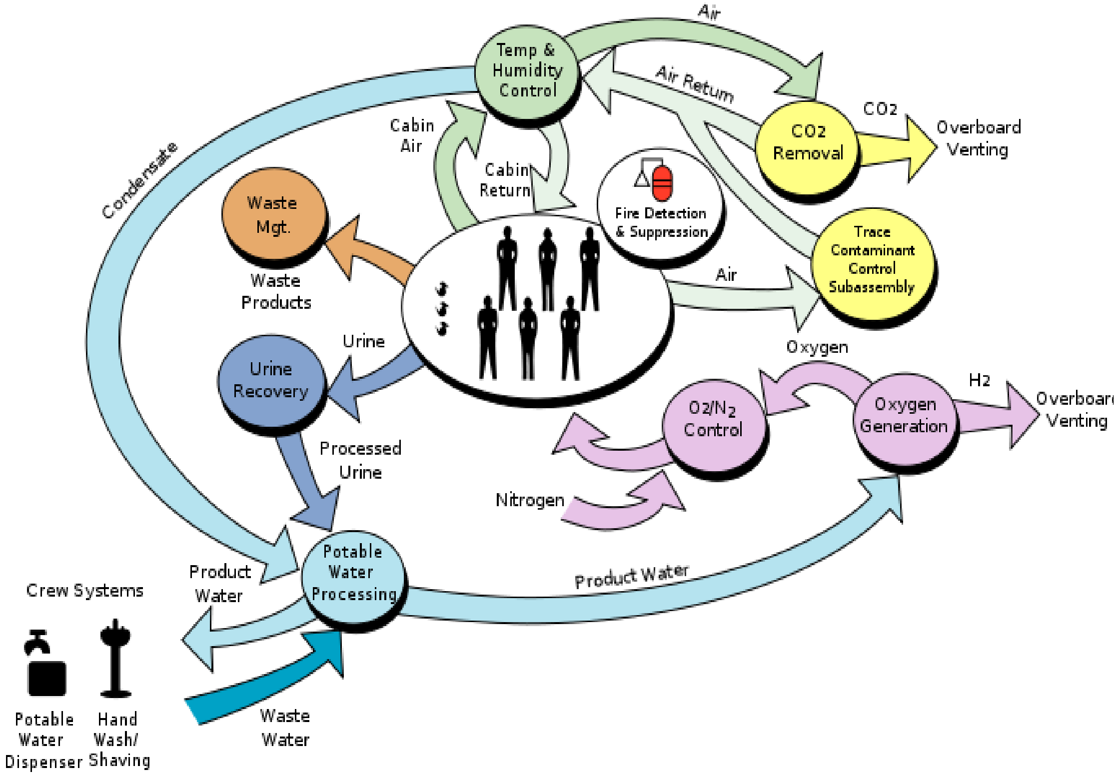
UHF radio is used by astronauts and cosmonauts conducting EVAs. UHF is employed by other spacecraft that dock to or undock from the station, such as Soyuz, Progress, HTV-II, ATV and the Space Shuttle (except the shuttle also makes use of the S band and Ku band systems via TDRSS), to receive commands from Mission Control and ISS crewmembers. Automated spacecraft are fitted with their own communications equipment; the ATV uses a laser attached to the spacecraft and equipment attached to *Zvezda*, known as the Proximity Communications Equipment, to accurately dock to the station.

Microgravity

At the station's orbital altitude, the gravity from the Earth is 88% of that at sea level. While the constant free fall of the ISS offers a perceived sensation of weightlessness, the environment onboard is not one of weightlessness or zero-gravity, instead often being described as microgravity. This state of perceived weightlessness is not perfect, however, being disturbed by four separate effects:

- The drag resulting from the residual atmosphere.
- Vibratory acceleration caused by mechanical systems and the crew on board the ISS.
- Orbital corrections by the on-board gyroscopes or thrusters.
- The spatial separation from the real centre of mass of the ISS. Any part of the ISS not at the exact centre of mass will tend to follow its own orbit. However, as each point is physically part of the station, this is impossible, and so each component is subject to small accelerations from the forces which keep them attached to the station as it orbits. This is also called the tidal force.
- The differences in orbital plane between different locations aboard the ISS.

Life support



The interactions between the components of the ISS Environmental Control and Life Support System (ECLSS)

The ISS Environmental Control and Life Support System (ECLSS) provides or controls atmospheric pressure, fire detection and suppression, oxygen levels, waste management and water supply. The highest priority for the ECLSS is the ISS atmosphere, but the system also collects, processes, and stores waste and water produced and used by the crew—a process that recycles fluid from the sink, toilet, and condensation from the air. The *Elektron* system aboard *Zvezda* and a similar system in *Destiny* generate oxygen aboard the station. The crew has a backup option in the form of bottled oxygen and Solid Fuel Oxygen Generation (SFOG) canisters. Carbon dioxide is removed from the air by the Vozdukh system in *Zvezda*. Other by-products of human metabolism, such as methane from the intestines and ammonia from sweat, are removed by activated charcoal filters.

The atmosphere on board the ISS is similar to the Earth's. Normal air pressure on the ISS is 101.3 kPa (14.7 psi); the same as at sea level on Earth. An Earth-like atmosphere offers benefits for crew comfort, and is much safer than the alternative, a pure oxygen atmosphere, because of the increased risk of a fire such as that responsible for the deaths of the Apollo 1 crew.

Sightings

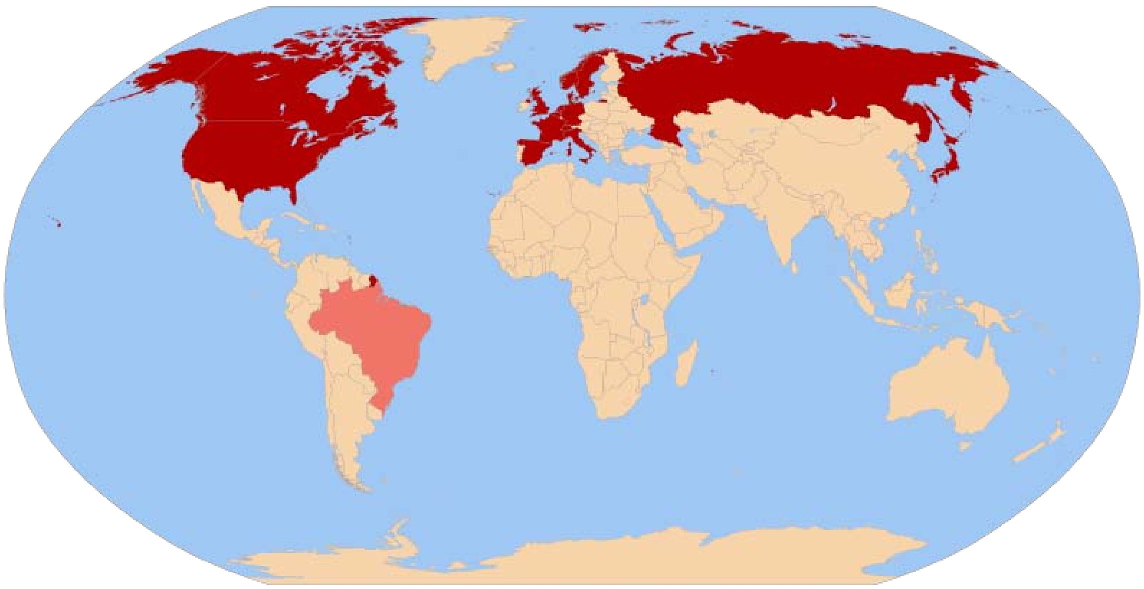
A January 2008 sighting of the International Space Station

Because of the size of the ISS (about that of an American football field) and the large reflective area offered by its solar panels, ground based observation of the station is possible with the naked eye if the observer is in the right location at the right time. In many cases, the station is one of the brightest naked-eye objects in the sky, although it is visible only for periods ranging from two to five minutes.

If the following conditions are fulfilled (assuming the weather is clear), the station will appear as a very bright object in the sky: The station must be above the observer's horizon, and it must pass within about 2,000 kilometres (1,200 mi) of the observation site (the closer the better). It must be dark enough at the observer's location for stars to be visible, and the station must be in sunlight rather than in the Earth's shadow. It is common for the third condition to begin or end during what would otherwise be a good viewing opportunity. In the evening, as the station moves further from the dusk, going from west to east it will appear to suddenly fade and disappear. In the reverse situation, it may suddenly appear in the sky as it approaches the dawn. With the station's maximum theoretical brightness at approximately magnitude -5.9 (with a typical maximum of -3.8), it is bright enough to be spotted during broad daylight conditions without optical aid.

Politics, utilisation and financing

Legal aspects



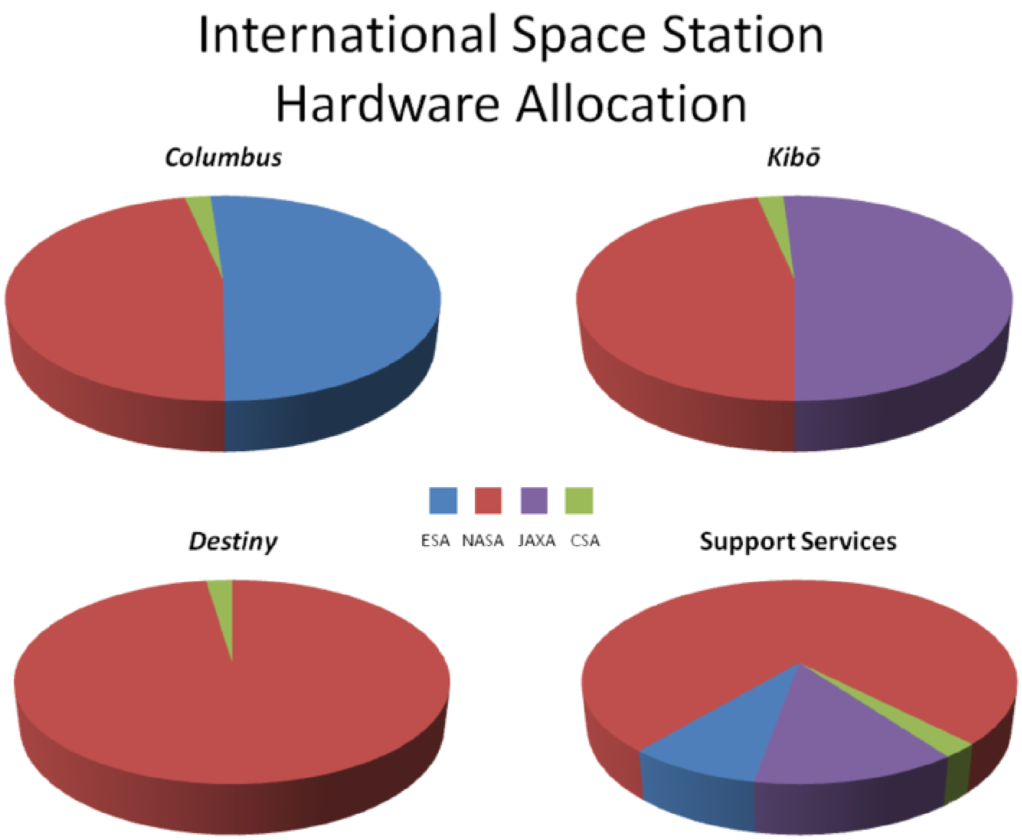
Primary contributing nations NASA contracted nations

The ISS is a joint project of several space agencies: the US National Aeronautics and Space Administration (NASA), the Russian Federal Space Agency (RKA), the Japan Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA) and the European Space Agency (ESA).

As a multinational project, the legal and financial aspects are complex. Issues of concern include the ownership of modules, station utilisation by participant nations, and responsibilities for station resupply. Obligations and rights are established by the Space Station Intergovernmental Agreement (IGA). This international treaty was signed on 28 January 1998 by the primary nations involved in the Space Station project; the United States of America, Russian Federation, Japan, Canada and ten member states of the European Space Agency (Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden and Switzerland). A second layer of agreements was then achieved, called Memoranda of Understanding (MOU), between NASA and ESA, CSA, RKA and JAXA. These agreements are then further split, such as for the contractual obligations between nations, and trading of partners' rights and obligations. Use of the Russian Orbital Segment is also negotiated at this level.

In addition to these main intergovernmental agreements, Brazil joins as a bilateral partner of the United States by a contract with NASA to supply hardware. In return, NASA will provide Brazil with access to its ISS facilities on-orbit, as well as a flight opportunity for one Brazilian astronaut during the course of the ISS programme. Italy has a similar contract with NASA to provide comparable services, although Italy also takes part in the programme directly via its membership in ESA. China has reportedly expressed interest in the project, especially if it would be able to work with the RKA. However, as of 2009 China is not involved because of US objections. The heads of both the South Korean and Indian space agencies announced at the first plenary session of the 2009 International Astronautical Congress that their nations intend to join the ISS programme, with talks due to begin in 2010. The heads of agency also expressed support for extending ISS lifetime.

Utilisation rights



Allocation of American segment hardware utilisation between nations

The Russian part of the station is operated and controlled by the Russian Federation's space agency and provides Russia with the right to nearly one-half of the crew time for the ISS. The allocation of remaining crew time (three to four crew members of the total permanent crew of six) and hardware within the other sections of the station has been assigned as follows:

- *Columbus*: 51% for the ESA, 46.7% for NASA, and 2.3% for CSA.
- *Kibō*: 51% for the JAXA, 46.7% for NASA, and 2.3% for CSA.
- *Destiny*: 97.7% for NASA and 2.3% for CSA.

- Crew time, electrical power and rights to purchase supporting services (such as data upload and download and communications) are divided 76.6% for NASA, 12.8% for JAXA, 8.3% for ESA, and 2.3% for CSA.

Costs

The cost estimates for the ISS range from 35 billion to 160 billion dollars. ESA, the one agency which actually presents potential overall costs, estimates €100 billion for the entire station over 30 years. A precise cost estimate for the ISS is unclear, as it is difficult to determine which costs should be attributed to the ISS programme, or how the Russian contribution should be measured.

Criticism

Critics of the ISS contend that the time and money spent on the ISS could be better spent on other projects—whether they be robotic spacecraft missions, space exploration, investigations of problems on Earth, colonisation of Mars, or just tax savings. Some critics, such as Robert L. Park, argue that little scientific research was convincingly planned for the ISS, and that the primary feature of a space-based laboratory, its microgravity environment, can be studied less expensively with a "vomit comet".

The research capabilities of the ISS have been criticised, particularly following the cancellation of the ambitious Centrifuge Accommodations Module, which, alongside other equipment cancellations, means scientific research performed on the station is generally limited to experiments which do not require any specialised apparatus. For example, in the first half of 2007, ISS research dealt primarily with human biological responses to living and working in space, covering topics like kidney stones, circadian rhythm, and the effects of cosmic rays on the nervous system. Other criticisms hinge on the technical design of the ISS, including the high inclination of the station's orbit, which leads to a higher cost for US-based launches to the station.

In response to some of these comments, advocates of manned space exploration say that criticism of the ISS project is short-sighted, and that manned space research and exploration have produced billions of dollars' worth of benefits. NASA has estimated that the indirect economic return from spin-offs of human space exploration has been many times the initial public investment, although this estimate is based on the Apollo Program and was made in the 1970s. A review of the claims by the Federation of American Scientists argued that NASA's rate of return from spin-offs is actually very low, except for aeronautics work that has led to aircraft sales.

End of mission and deorbit plans

NASA planned to deorbit the ISS in the first quarter of 2016. However, the plan to end the ISS programme in 2015, as determined in 2004 by then-President George W. Bush, has been rejected by the current Obama administration. With the new budget announced on 1 February 2010, the administration aims to extend the lifetime through 2020. The

Augustine Commission, which reviewed NASA's human space flight program, recommended in its final report of 23 October 2009 the extension of the ISS programme to at least 2020. In particular, Leroy Chiao, a former space station commander and space shuttle astronaut who sat on the advisory panel, stated in a CNN interview: “You've got all of these different countries working together on this common project in space. And if we go ahead and stop [...] it is going to break up that framework. The different countries around the world will lose confidence in the US as a leader in space exploration." NASA officials received confirmation from the Obama administration on the future direction of the ISS in particular and the human spaceflight programme in general on 1 February 2010, with a budget proposing an extension to the ISS programme until at least 2020, with talks between ISS partners suggesting that the station could conceivably remain operational until 2025 or 2028.

The Multilateral Coordination Board (MCB) of the ISS international partners, in a videoconference on 21 September 2010, learned that the Japanese and Russian governments have approved operation continuing to 2020. The Canadian Space Agency (CSA) and the European Space Agency (ESA) are working with their governments to confirm consensus on extending operations beyond 2016, while NASA continues working with the US Congress on extension plans.

NASA has the responsibility to deorbit the ISS. Although *Zvezda* has a propulsion system used for station-keeping, it is not powerful enough for a controlled deorbit. Options for controlled deorbit of the ISS include the use of a modified European ATV or a specially constructed deorbit vehicle. According to a 2009 report, RKK Energia is considering methods to remove from the station some modules of the Russian Orbital Segment when the end of mission is reached and use them as a basis for a new station, known as the Orbital Piloted Assembly and Experiment Complex. The modules under consideration for removal from the current ISS include the Multipurpose Laboratory Module (MLM), currently scheduled to be launched at the end of 2011, with other Russian modules which are currently planned to be attached to the MLM until 2015, although still currently unfunded. Neither the MLM nor any additional modules attached to it would have reached the end of their useful lives in 2016 or 2020. The report presents a statement from an unnamed Russian engineer who believes that, based on the experience from *Mir*, a thirty-year life should be possible, except for micrometeorite damage, because the Russian modules have been built with on-orbit refurbishment in mind.

Life on board

Crew schedule

The time zone used on board the ISS is Coordinated Universal Time (UTC). The windows are covered at night hours to give the impression of darkness because the station experiences 16 sunrises and sunsets a day. During visiting space shuttle missions, the ISS crew will mostly follow the shuttle's Mission Elapsed Time (MET), which is a flexible time zone based on the launch time of the shuttle mission. Because the sleeping periods between the UTC time zone and the MET usually differ, the ISS crew often has to adjust its sleeping pattern before the space shuttle arrives and after it leaves to shift from one time zone to the other in a practice known as sleep shifting.

A typical day for the crew begins with a wake-up at 06:00, followed by post-sleep activities and a morning inspection of the station. The crew then eats breakfast and takes part in a daily planning conference with Mission Control before starting work at around 08:10. The first scheduled exercise of the day follows, after which the crew continues work until 13:05. Following a one-hour lunch break, the afternoon consists of more exercise and work before the crew carries out its pre-sleep activities beginning at 19:30, including dinner and a crew conference. The scheduled sleep period begins at 21:30. In general, the crew works 10 hours per day on a weekday, and 5 hours on Saturdays, with the rest of the time their own for relaxation, games or work catch-up.

Sleeping in space

Astronaut Peggy Whitson in the doorway of a sleeping rack in the *Destiny* laboratory

The station provides crew quarters for each member of permanent Expedition crews, with two 'sleep stations' in the Russian Orbital Segment and four more, due to be installed in *Tranquility*, currently spread around the USOS. The American quarters are private, approximately person-sized soundproof booths. A crewmember can sleep in them in a tethered sleeping bag, listen to music, use a laptop, and store personal effects in a large drawer or in nets attached to the module's walls. The module also provides a reading lamp, a shelf and a desktop. Visiting crews have no allocated sleep module, and attach a sleeping bag to an available space on a wall—it is possible to sleep floating freely through the station, but this is generally avoided because of the possibility of bumping into sensitive equipment. It is important that crew accommodations are well ventilated. Otherwise, astronauts can wake up oxygen deprived and gasping for air, because a bubble of their own exhaled carbon dioxide has formed around their heads.

Hygiene

The ISS does not feature a shower, although it was planned as part of the now cancelled Habitation Module. Instead, crewmembers wash using a water jet and wet wipes, with soap dispensed from a toothpaste tube-like container. Crews are also provided with rinseless shampoo and edible toothpaste to save water.

There are two space toilets on the ISS, both of Russian design, located in *Zvezda* and *Tranquility*. These Waste and Hygiene Compartments use a fan-driven suction system similar to the Space Shuttle Waste Collection System. Astronauts first fasten themselves to the toilet seat, which is equipped with spring-loaded restraining bars to ensure a good seal. A lever operates a powerful fan and a suction hole slides open: the air stream carries the waste away. Solid waste is collected in individual bags which are stored in an aluminium container. Full containers are transferred to Progress spacecraft for disposal. Liquid waste is evacuated by a hose connected to the front of the toilet, with anatomically correct "urine funnel adapters" attached to the tube so both men and women can use the same toilet. Waste is collected and transferred to the Water Recovery System, where it is recycled back into drinking water.

Food and drink

The crews of STS-127 and Expedition 20 enjoy a meal inside *Unity*.

Most of the food eaten by station crews is frozen, refrigerated or canned. Menus are prepared by the astronauts, with the help of a dietitian, before the astronauts' flight to the station. As the sense of taste is reduced in orbit because of fluid shifting to the head, spicy food is a favourite of many crews. Each crewmember has individual food packages and cooks them using the onboard galley, which features two food warmers, a refrigerator, and a water dispenser that provides both heated and unheated water. Drinks are provided in dehydrated powder form, and are mixed with water before consumption. Drinks and soups are sipped from plastic bags with straws, while solid food is eaten with a knife and fork, which are attached to a tray with magnets to prevent them floating away. Any food which does float away, including crumbs, must be collected to prevent it from clogging up the station's air filters and other equipment.

Exercise

The most significant adverse effects of long-term weightlessness are muscle atrophy and deterioration of the skeleton, or spaceflight osteopenia. Other significant effects include fluid redistribution, a slowing of the cardiovascular system, decreased production of red blood cells, balance disorders, and a weakening of the immune system. Lesser symptoms include loss of body mass, nasal congestion, sleep disturbance, excess flatulence, and puffiness of the face. These effects begin to reverse quickly upon return to the Earth.

Astronaut Sunita "Suni" Williams is attached to the TVIS treadmill with bungee cords aboard the International Space Station

To prevent some of these adverse physiological effects, the station is equipped with two treadmills (including the COLBERT), the aRED (advanced Resistive Exercise Device) which enables various weightlifting exercises, and a stationary bicycle; each astronaut spends at least two hours per day exercising on the equipment. Astronauts use bungee cords to strap themselves to the treadmill. Researchers believe that exercise is a good countermeasure for the bone and muscle density loss that occurs when humans live for a long time without gravity.

Station operations

Expeditions

Each permanent station crew is given a sequential expedition number. Expeditions have an average duration of half a year, and they commence following the official handover of the station from one Expedition commander to another. Expeditions 1 through 6 consisted of three person crews, but the *Columbia* accident led to a reduction to two crew members for Expeditions 7 to 12. Expedition 13 saw the restoration of the station crew to three, and the station has been permanently staffed as such since. While only three crew members are permanently on the station, several expeditions, such as Expedition 16, have consisted of up to six astronauts or cosmonauts, who are flown to and from the station on separate flights.

On 27 May 2009, Expedition 20 began. Expedition 20 was the first ISS crew of six. Before the expansion of the living volume and capabilities from STS-115 the station could only host a crew of three. Expedition 20's crew was lifted to the station in two separate Soyuz-TMA flights launched at two different times (each Soyuz-TMA can hold only three people): Soyuz TMA-14 on 26 March 2009 and Soyuz TMA-15 on 27 May 2009. However, the station would not be permanently occupied by six crew members all year. For example, when the Expedition 20 crew (Roman Romanenko, Frank De Winne and Bob Thirsk) returned to Earth in November 2009, for a period of about two weeks only two crew members (Jeff Williams and Max Surayev) were aboard. This increased to five in early December, when Oleg Kotov, Timothy Creamer and Soichi Noguchi arrived on Soyuz TMA-17. It decreased to three when Williams and Surayev departed in March 2010, and finally returned to six in April 2010 with the arrival of Soyuz TMA-18, carrying Aleksandr Skvortsov, Mikhail Korniyenko and Tracy Caldwell Dyson.

The International Space Station is the most-visited spacecraft in the history of space flight. As of 24 November 2009, it had received 266 visitors (185 different people). *Mir* had 137 visitors (104 different people).

Visiting spacecraft

The Space Shuttle *Endeavour* approaching the ISS during STS-118

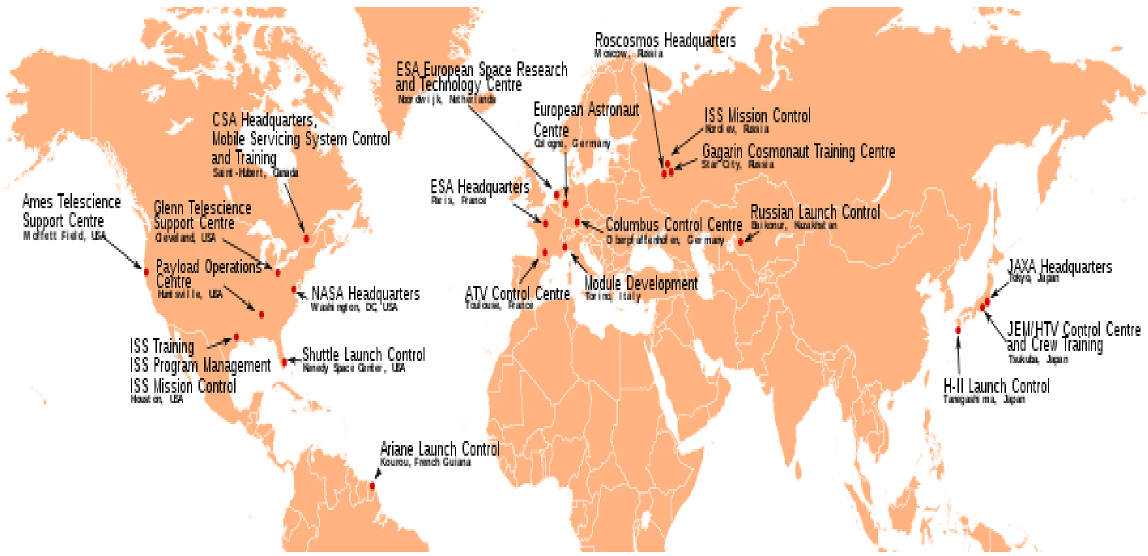
Spacecraft from four different space agencies visit the ISS, serving a variety of purposes. The Automated Transfer Vehicle from the European Space Agency, the Russian Roskosmos Progress spacecraft and the HTV-II from the Japan Aerospace Exploration Agency have provided resupply services to the station. In addition, Russia supplies a Soyuz spacecraft used for crew rotation and emergency evacuation, which is replaced every six months. Finally, the US services the ISS through its Space Shuttle programme, providing resupply missions, assembly and logistics flights, and crew rotation. As of 27 November 2009, there have been 20 Soyuz, 35 Progress, 1 ATV, 1 HTV and 31 Space Shuttle flights to the station. Expeditions require, on average, 2,722 kg of supplies, and as of 27 November 2009, crews had consumed a total of around 19,000 meals. Soyuz crew rotation flights and Progress resupply flights visit the station on average two and three times respectively each year, with the ATV and HTV planned to visit annually from 2010 onwards.

Following the retirement of the Space Shuttle, a number of other spacecraft are expected to fly to the station. Two, the Orbital Sciences Cygnus and SpaceX Dragon, will fly under NASA's Commercial Orbital Transportation Services and Commercial Resupply Services contracts, delivering cargo to the station until at least 2015. In addition, the Orion spacecraft, developed as a Space Shuttle replacement as part of NASA's Constellation Programme, was retasked by President Barack Obama on 15 April 2010 to provide lifeboat services to the station. The spacecraft had until that point been entirely cancelled under the US 2011 fiscal year budget.

As of 25 September 2010, there are three spacecraft docked with the ISS:

Spacecraft	Mission	Docking port	Date docked (UTC)
Soyuz TMA-19	Expedition 24/Expedition 25	*Rassvet*	17 June 2010 21:21
Progress M-05M	ISS Progress 37	*Pirs*	1 May 2010 18:30
Progress M-07M	ISS Progress 39	*Zvezda* aft	12 September 2010 11:58

Mission control centres



Space centres involved with the ISS programme

The components of the ISS are operated and monitored by their respective space agencies at control centres across the globe, including:

- NASA's Mission Control Center at Lyndon B. Johnson Space Center in Houston, Texas, serves as the primary control facility for the US segment of the ISS and also controls the Space Shuttle missions that visit the station.
- NASA's Payload Operations and Integration Center at Marshall Space Flight Center in Huntsville, Alabama, serves as the centre that coordinates all payload operations in the US Segment.
- Roskosmos's Mission Control Center at Korolyov, Moscow, controls the Russian Orbital Segment of the ISS, in addition to individual Soyuz and Progress missions.
- ESA's Columbus Control Centre at the German Aerospace Centre (DLR) in Oberpfaffenhofen, Germany, controls the European *Columbus* research laboratory.

- ESA's ATV Control Centre, at the Toulouse Space Centre (CST) in Toulouse, France, controls flights of the unmanned European Automated Transfer Vehicle.
- JAXA's JEM Control Centre and HTV Control Centre at Tsukuba Space Centre (TKSC) in Tsukuba, Japan, are responsible for operating the Japanese Experiment Module complex and all flights of the unmanned Japanese HTV-II respectively.
- CSA's MSS Control at Saint-Hubert, Quebec, Canada, controls and monitors the Mobile Servicing System, or Canadarm2.

Safety aspects

Anomalies

Since construction started, the ISS programme has had to deal with several major incidents, unexpected problems and failures. These incidents have impacted the station's assembly timeline, led to periods of reduced capabilities and, in some cases, could have forced abandonment of the station for safety reasons, had these problems not been resolved.

The first major impact to station operations came with the Space Shuttle *Columbia* disaster on 1 February 2003 (during STS-107), which resulted in a two-and-a-half-year suspension of the US Space Shuttle programme, followed by another one-year suspension following STS-114 (because of continued foam shedding on the external tank). This halted station assembly plans and reduced the station's operational capabilities, as, due to a lack of logistics, caretaker crews of just two astronauts were launched from Expedition 7 until Expedition 12. The *Columbia* disaster was followed by a number of smaller issues aboard the station, including an air leak from the USOS in 2004, the venting of smoke from an *Elektron* oxygen generator in 2006, and the failure of the computers in the ROS in 2007 during STS-117 which left the station without thruster, *Elektron*, *Vozdukh* and other environmental control system operations, the root cause of which was found to be condensation inside the electrical connectors leading to a short-circuit.

These issues with internal station equipment were then followed by a spate of issues with external components; during STS-120 on 2007, following the relocation of the P6 truss and solar arrays, it was noted during the redeployment of the array that it had become torn and was not deploying properly. An emergency EVA was carried out by Scott Parazynski, assisted by Douglas Wheelock, to repair the array, an activity which was considerably more dangerous than most EVAs due to the short planning time and the risk of electric shock from the arrays themselves. The issues with the array were followed in the same year by problems with the starboard Solar Alpha Rotary Joint (SARJ), which rotates the arrays on the starboard side of the station. Excessive vibration and high-current spikes in the array drive motor were noted, resulting in a decision to substantially curtail motion of the starboard SARJ until the cause was understood. Inspections during EVAs on STS-120 and STS-123 showed extensive contamination from metallic shavings and debris in the large drive gear and confirmed damage to the large metallic race ring at the heart of the joint, and so the joint was locked to prevent further damage. Repairs to the joint were carried out during STS-126 with lubrication of both joints and the replacement 11 of 12 trundle bearings on the joint.

More recently, problems have been noted with the station's engines and cooling. In 2009, the engines on *Zvezda* were issued an incorrect command which caused excessive vibrations to propagate throughout the station structure which persisted for over two minutes. While no damage to the station was immediately reported, some components may have been stressed beyond their design limits. Further analysis confirmed that the station was unlikely to have suffered any structural damage, and it appears that "structures will still meet their normal lifetime capability". Further evaluations are under way. 2009 also saw damage to the S1 radiator, one of the components of the station's cooling system. The problem was first noticed in Soyuz imagery in September 2008, but was not thought to be serious. The imagery showed that the surface of one sub-panel has peeled back from the underlying central structure, possibly due to micro-meteoroid or debris impact. It is also known that a Service Module thruster cover, jettisoned during an EVA in 2008, had struck the S1 radiator, but its effect, if any, has not been determined. On 15 May 2009 the damaged radiator panel's ammonia tubing was mechanically shut off from the rest of the cooling system by the computer-controlled closure of a valve. The same valve was used immediately afterwards to vent the ammonia from the damaged panel, eliminating the possibility of an ammonia leak from the cooling system via the damaged panel.

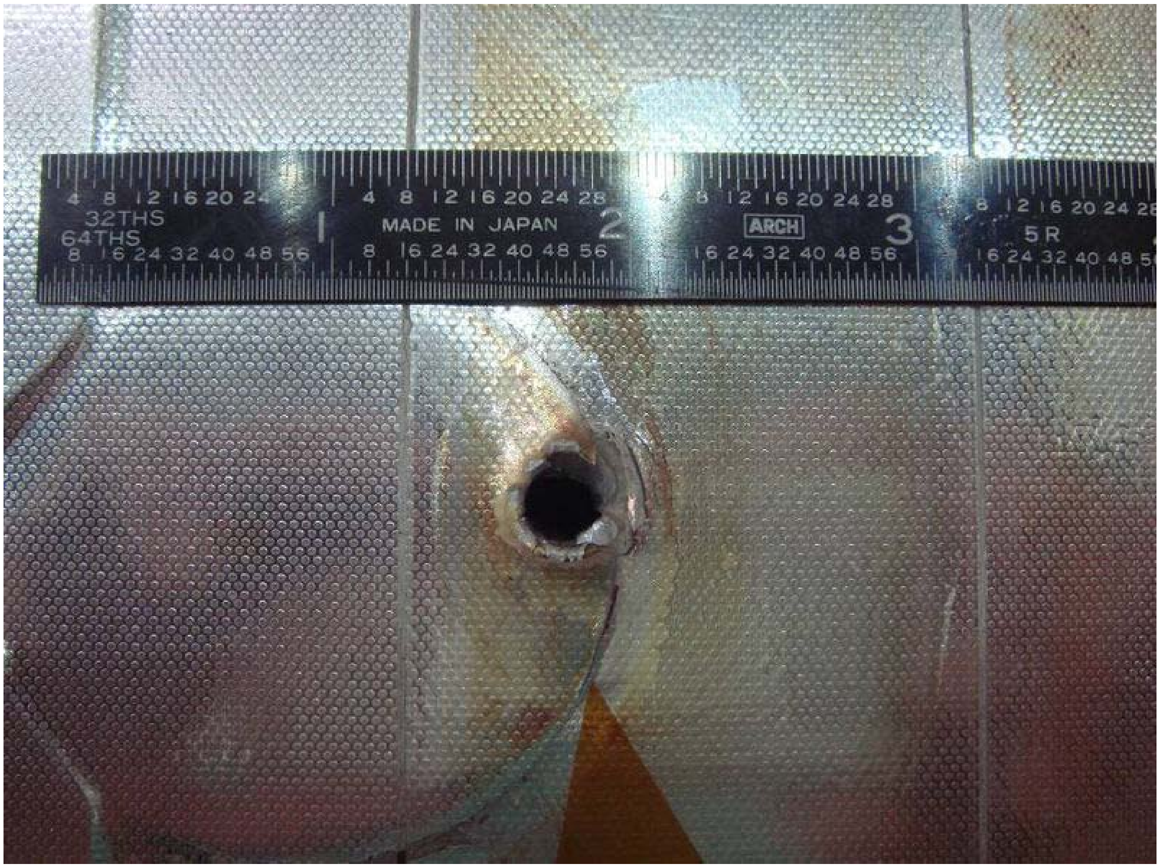
Cooling loop A failure

Early on 1 August 2010, a failure in cooling Loop A (starboard side), one of two external cooling loops, left the station with only half of its normal cooling capacity and zero redundancy in some systems. The problem appeared to be in the ammonia pump module that circulates the ammonia cooling fluid. Several subsystems, including two of the four CMGs, were shut down.

Planned operations on the ISS were interrupted through a series of EVAs to address the cooling system issue. A first EVA on 7 August 2010, to replace the failed pump module, was not fully completed due to an ammonia leak in one of four quick-disconnects. A second EVA on 11 August successfully removed the failed pump module. A third EVA was required to restore Loop A to normal functionality.

The station's cooling system is largely built by the American company Boeing, which is also the manufacturer of the failed pump.

Orbital debris



The entry hole in Space Shuttle *Endeavour*'s radiator panel caused by space debris during STS-118

At the low altitudes at which the ISS orbits there is a variety of space debris, consisting of everything from entire spent rocket stages and defunct satellites, to explosion fragments, paint flakes, slag from solid rocket motors, coolant released by RORSAT nuclear powered satellites, small needles, and many other objects. These objects, in addition to natural micrometeoroids, pose a threat to the station as they have the ability to puncture the pressurised modules and cause damage to other parts of the station. Micrometeoroids also pose a risk to spacewalking astronauts, as such objects could puncture their spacesuits, causing them to depressurise.

Space debris objects are tracked remotely from the ground, and the station crew can be notified of many objects with sufficient size to cause damage on impact. This allows for a Debris Avoidance Manoeuvre (DAM) to be conducted, which uses thrusters on the Russian Orbital Segment to alter the station's orbital altitude, avoiding the debris. DAMs are not uncommon, taking place if computational models show the debris will approach within a certain threat distance. Eight DAMs had been performed prior to March 2009, the first seven between October 1999 and May 2003. Usually the orbit is raised by one or two kilometres by means of an increase in orbital velocity of the order of 1 m/s.

Unusually there was a lowering of 1.7 km on 27 August 2008, the first such lowering for 8 years. There were two DAMs in 2009, on 22 March and 17 July. If a threat from orbital debris is identified too late for a DAM to be safely conducted, the station crew close all the hatches aboard the station and retreat into their Soyuz spacecraft, so that they would be able to evacuate in the event it was damaged by the debris. This partial station evacuation has occurred twice, on 6 April 2003 and 13 March 2009.

Radiation

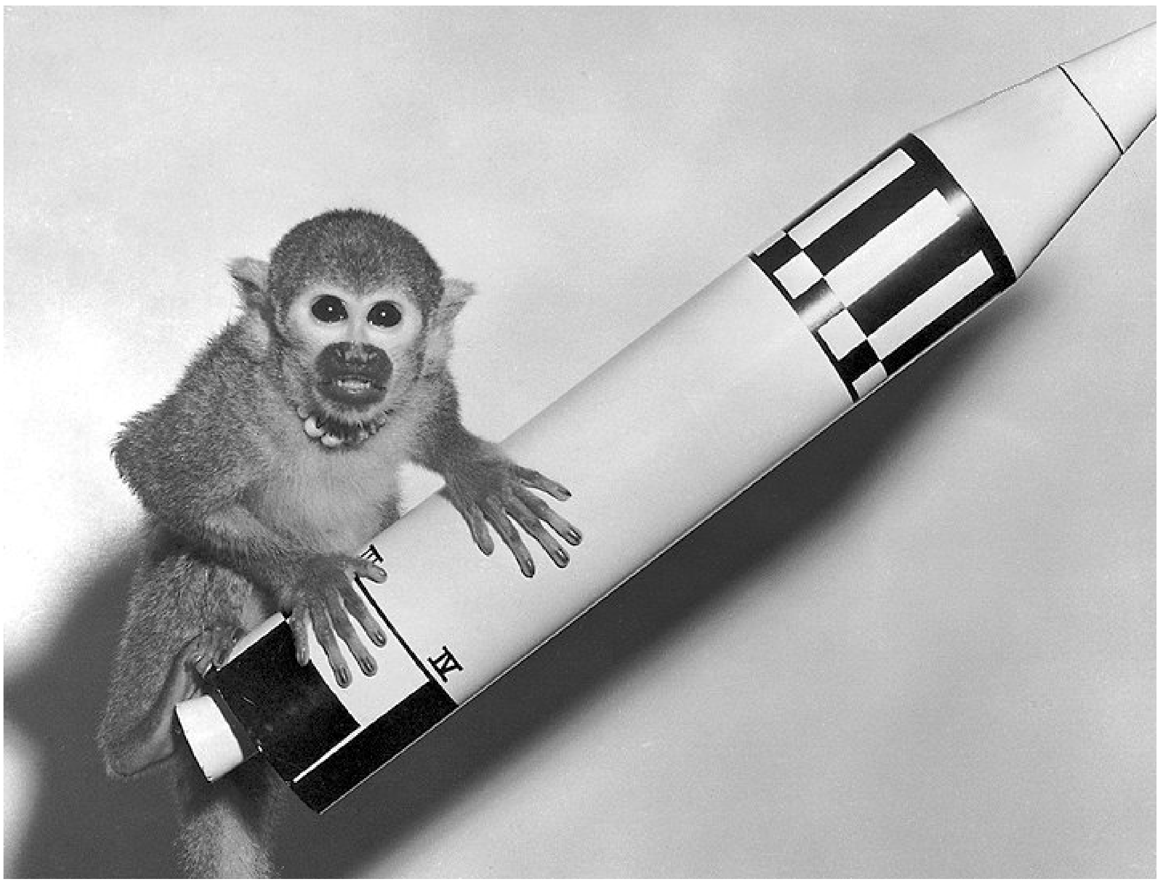
Without the protection of the Earth's atmosphere, astronauts are exposed to higher levels of radiation from a steady flux of cosmic rays. The station's crews are exposed to about 1 millisievert of radiation each day, which is about the same as someone would get from natural sources on Earth in a year. This results in a higher risk of astronauts' developing cancer. High levels of radiation can cause damage to the chromosomes of lymphocytes. These cells are central to the immune system and so any damage to them could contribute to the lowered immunity experienced by astronauts. Over time lowered immunity results in the spread of infection between crew members, especially in such confined areas. Radiation has also been linked to a higher incidence of cataracts in astronauts. Protective shielding and protective drugs may lower the risks to an acceptable level, but data is scarce and longer-term exposure will result in greater risks.

Despite efforts to improve radiation shielding on the ISS compared to previous stations such as *Mir*, radiation levels within the station have not been vastly reduced, and it is thought that further technological advancement will be required to make long-duration human spaceflight further into the Solar System a possibility.

It should be noted, however, that the radiation levels experienced on ISS are not excessively greater than those experienced by airline passengers. The Earth's electromagnetic field provides almost the same level of protection against solar and other radiation in Low Earth Orbit as in the stratosphere. Airline passengers, however, only experience this level of radiation for no more than 15 hours for the longest transcontinental flights (London-Sydney or Chicago-Delhi) and often far less time. For instance, a 12 hour flight from Boston to Beijing, an airline passenger would experience 0.1 millisievert of radiation, or a rate of 0.2 millisieverts per day, only 1/5th the rate experienced by an astronaut in LEO.

Chapter- 11

Animals in Space



Space monkey "Baker" rode a Jupiter IRBM into space in 1959

Animals in space originally only served to test the survivability of spaceflight, before manned space missions were attempted. Later, animals were also flown to investigate various biological processes and the effects microgravity and space flight might have on them. Six national space programs have flown animals into space: the Soviet Union, the United States, France, China, Japan and Iran.

1940s

The first animals intentionally sent into space were fruit flies, accompanied by corn seeds aboard a U.S.-launched V2 rocket in 1947. The purpose of the experiment was to explore the effects of radiation exposure at high altitudes. Some further V2 missions carried biological samples, including moss.

Albert II, a Rhesus Monkey, became the first monkey in space on June 14, 1949, in a U.S.-launched V2, after the failure of the original Albert's mission. Albert II died on impact after a parachute failure. Numerous monkeys of several species were flown by the U.S. in the 1950s and 1960s. Monkeys were implanted with sensors to measure vital signs, and many were under anesthesia during launch.

1950s

On August 31, 1950, the U.S. launched a mouse into space (137 km) aboard a V2 (the Albert V flight, which, unlike the Albert I-IV flights, did not have a monkey). The U.S. launched several other mice in the 1950s.

On January 29, 1951, the Soviet Union launched the R-1 IIIA-1 flight, carrying the dogs Tsygan (Russian: Цыган, "Gypsy") and Dezik (Russian: Дезик) into space, but not into orbit. Both space dogs survived the flight, although one would die on a subsequent flight. The U.S. launched mice aboard spacecraft later that year; however, they failed to reach the altitude for true spaceflight.

In 1957, Laika became the first animal launched into orbit, paving the way for human spaceflight. This photograph shows her in a flight harness.

On November 3, 1957, the second-ever orbiting spacecraft carried the first animal into orbit, the dog Laika, launched aboard the Soviet Sputnik 2 spacecraft (nicknamed 'Muttnik' in the West). Laika died during the flight, as was intended because the technology to deorbit had not been developed. At least 10 other dogs were launched into orbit and numerous others on sub-orbital flights before the historic date of April 12, 1961, when Yuri Gagarin became the first human in space.

On December 13, 1958, a Jupiter IRBM, AM-13, was launched from Cape Canaveral, Florida, with a United States Navy-trained South American squirrel monkey named Gordo onboard. The nose cone recovery parachute failed to operate and Gordo was lost. Telemetry data sent back during the flight showed that the monkey survived the 10G of launch, 8 minutes of weightlessness and 40G of reentry at 10,000 miles per hour. The nose cone sank 1,302 nautical miles (2,411 km) downrange from Cape Canaveral and was not recovered.

Monkeys Able and Baker became the first monkeys to survive spaceflight after their 1959 flight. On May 28, 1959, aboard Jupiter IRBM AM-18, were a 7-pound (3.18 kg) American-born rhesus monkey, Able, and an 11 ounce (310 g) squirrel monkey from Peru, Baker. The monkeys rode in the nose cone of the missile to an altitude of 360 miles (579 km) and a distance of 1,700 miles (2,735 km) down the Atlantic Missile Range from Cape Canaveral, Florida. They withstood forces 38 times the normal pull of gravity and were weightless for about 9 minutes. A top speed of 10,000 mph (16,000 km/h) was reached during their 16 minute flight. The monkeys survived the flight in good condition. Able died four days after the flight from a reaction to anesthesia, while undergoing surgery to remove an infected medical electrode. Baker lived until November 29, 1984, at the US Space and Rocket Center in Huntsville, Alabama.

1960s

The famous hand shake welcome. After his flight on the Mercury Redstone rocket, chimpanzee Ham is greeted by the commander of the recovery ship, USS *Donner* (LSD-20).

On August 19, 1960, Sputnik 5 (also known as Korabl-Sputnik 2) carried the dogs Belka and Strelka. It was the first spacecraft to carry animals into orbit and return them alive. One of Strelka's pups, Pushinka, bred and born after her mission, was given as a present to Caroline Kennedy by Nikita Khruschev in 1961, and many descendants are known to exist.

On January 31, 1961, Ham the Chimp was launched in a Mercury capsule aboard a Redstone rocket. His mission was Mercury-Redstone 2. The chimp had been trained to pull levers to receive rewards of banana pellets and avoid electric shocks. His flight demonstrated the ability to perform tasks during spaceflight. A little over 3 months later the United States sent Alan Shepard into space. Enos the chimp became the first chimpanzee in orbit on November 29, 1961, in another Mercury capsule, an Atlas rocket, Mercury-Atlas 5.

The Soviet Union in the Vostok 3A flights of March 1961 launched mice and, for the first time, guinea pigs and frogs.

France flew the first rat (Hector) into space on February 22, 1961. Two more rats were flown in October 1962.

France launched Felix the cat into space on October 18, 1963. The cat had electrodes implanted into its head to measure neural impulses. Felix was recovered alive, but the next cat in space was not. The final French animal launches were of two monkeys in March 1967.

China launched mice and rats in 1964 and 1965, and two dogs in 1966.

During the Voskhod program, two Russian space dogs, Veterok (Ветерок, Little Wind) and Ugolyok (Уголёк, Ember), were launched on February 22, 1966, on board Cosmos 110 and spent 22 days in orbit before landing on March 16. This spaceflight of record-breaking duration was not surpassed by humans until Skylab 2 in 1974 and still stands as the longest space flight by dogs.

The United States launched Biosatellite I in 1966 and Biosatellite I/II in 1967 with fruit flies, parasitic wasps, flour beetles and frog eggs, along with bacteria, amoebae, plants and fungi.

On April 11, 1967, Argentina also launched the rat Belisario, atop an Orion II rocket, from Cordoba military range, which was recovered successfully. This flight was followed by a series of subsequent flights using rats. It is unclear if any Argentinean biological flights passed the 100 km limit of space.

The first tortoise in space was launched September 14, 1968 by the Soviet Union. The Horsfield's tortoise was sent on a circumlunar voyage along with wine flies, meal worms and other biological specimens. These were the first animals in deep space. The capsule was recovered at sea on September 21.

The United States launched the monkey Bonny, a macaque, in 1969 on the first multi-day primate mission; it was one of four U.S. monkey missions in the 1960s.

In total in the 1950s and 1960s, the Soviet Union launched missions with passenger slots for at least 57 dogs. The actual number of dogs in space is smaller, because some dogs flew more than once.

On December 23, 1969, as part of the 'Operación Navidad' (Christmas Operation), Argentina launched Juan (a cai monkey, native of Argentina's Misiones Province) using a two-stage Rigel 04 rocket. It ascended only up to 60 kilometers and then was recovered successfully. Later, on the February 1, 1970 the experience was repeated with a female monkey of the same species using a X-1 Panther rocket. Although it reached a higher altitude than its predecessor, it was lost after the capsule's parachute failed.

1970s

First spider web built in space

Two bullfrogs were launched on a one-way mission on the Orbiting Frog Otolith satellite on November 9, 1970, to better understand space motion sickness.

Apollo 16 on April 16, 1972 carried nematodes, and Apollo 17, launched on December 7, 1972 carried five pocket mice, although one died on the circumlunar trip. Skylab 3 carried pocket mice and the first fish in space (a mummichog), and the first spiders in space (Garden Spiders named Arabella and Anita). The U.S. also flew mummichog on the Apollo-Soyuz mission.

The Soviets flew several Bion program missions which consisted of satellites with biological cargoes. On these launches they flew tortoises, rats, and mummichog. On Soyuz 20, launched November 17, 1975, tortoises set the duration record for an animal in space when they spent 90.5 days in space. Salyut 5 on June 22, 1976, carried tortoises and a fish (a zebra danio).

1980s

The Soviet Union sent 8 monkeys into space in the 1980s on Bion flights, while the U.S. sent two aboard Spacelab 3 on the space shuttle along with 24 rats and stick insect eggs. Bion flights also flew zebra danio, fruit flies, rats, stick insect eggs and the first newts in space.

Bion 7 (1985) had 10 newts (*Pleurodeles waltl*) onboard. The newts had part of their front limbs amputated to study the rate of regeneration in space, knowledge to understand human recovery from space injuries.

After an experiment was lost in the Challenger disaster, chicken embryos (fertilized eggs) were sent into space in an experiment on STS-29 in 1989. The experiment was designed for a student contest.

1990s

Four monkeys flew aboard the last Bion flights of the Soviet Union as well as frogs and fruit flies. The Foton program flights carried dormant brine shrimp, newts, fruit flies, and desert beetles.

Astronaut Donald Thomas examines a newt on the Space Shuttle

China launched guinea pigs in 1990.

Toyohiro Akiyama, a Japanese journalist carried Japanese tree frogs with him during his trip to the Mir space station in December 1990. Other biological experiments aboard Mir involved quail eggs.

Japan launched its first animals, a species of newt, into space on March 18, 1995 aboard the Space Flyer Unit.

During the 1990s the U.S. carried crickets, mice, rats, frogs, newts, fruit flies, snails, carp, medaka, oyster toadfish, sea urchins, swordtail fish, gypsy moth eggs, stick insect eggs and quail eggs aboard Space Shuttle *Columbia*.

2000s

The last flight of *Columbia* in 2003 carried silkworms, Garden Orb spiders, carpenter bees, harvester ants, and Japanese killifish. Nematodes (*C. elegans*) from one experiment were found still alive in the debris after the Space Shuttle *Columbia* disaster.

C. elegans are also part of experiments aboard the International Space Station as well as research using quail eggs.

Earlier shuttle missions included grade school, junior high and high school projects; some of these included ants, stick insect eggs and brine shrimp cysts. Other science missions included gypsy moth eggs.

On July 12, 2006, Bigelow Aerospace launched their *Genesis I* inflatable space module, containing many small items such as toys and simple experiments chosen by company employees that would be observed via camera. These items included insects, perhaps making it the first private flight to launch animals into space. Included were Madagascar hissing cockroaches and Mexican jumping beans — seeds containing live larvae of the moth *Cydia deshaisiana*. On June 28, 2007, Bigelow launched *Genesis II*, a near-twin to *Genesis I*. This spacecraft also carried the Madagascar hissing cockroaches and added South African flat rock scorpions (*Hadogenes troglodytes*) and seed-harvester ants (*Pogonomyrmex californicus*).

In September, 2007, during the European Space Agency's FOTON-M3 mission, tardigrades, also known as water-bears, were able to survive 10 days of exposure to open-space with only their natural protection.

In November 2009, STS-129 took painted lady and monarch butterfly larva into space for a school experiment as well as thousands of C. elegans roundworms for long-term weight loss studies.

2010s

On February 3, 2010, on the 31st anniversary of its revolution, Iran became the latest country to launch animals into space. The animals (a mouse, two turtles and some worms) were launched on top of the Kavoshgar 3 rocket and returned alive to Earth.

Soviet space dogs

During the 1950s and 1960s the USSR used a number of dogs for sub-orbital and orbital space flights to determine whether human spaceflight was feasible. In this period, the Soviet Union launched missions with passenger slots for at least 57 dogs. The actual number of dogs in space is smaller, as some dogs flew more than once. Most survived; the few that died were lost mostly through technical failures,according to the parameters of the test.

Training

Dogs were the preferred animal for the experiments because scientists felt dogs were better suited to endure long periods of inactivity. As part of their training, they were confined in small boxes for 15–20 days at a time. Stray dogs, rather than animals accustomed to living in a house, were chosen because the scientists felt they would be able to tolerate the rigours and extreme stresses of space flight better than other dogs. Female dogs were used because of their temperament and because the suit for the dogs in order to collect urine and feces was equipped with a special device, designed to work only with females.

Their training included standing still for long periods of time, wearing space suits, being placed in simulators that acted like a rocket during launch, riding in centrifuges that simulated the high acceleration of a rocket launch and being kept in progressively smaller cages to prepare them for the confines of the space module. Dogs that flew in orbit were fed a nutritious jelly-like protein. This was highly fibrous, and assisted the dogs to excrete during long periods of time while in their small space module. More than 60% of dogs to enter space were reportedly suffering from constipation and gallstones on arrival back to base.

Sub-orbital flights

Original Soviet space dog environmentally controlled safety module used on sub-orbital and Orbital spaceflights

Dogs were flown to an altitude of 100 km on board 15 scientific flights on R-1 rockets from 1951 to 1956. The dogs wore pressure suits with acrylic glass bubble helmets. From 1957 to 1960, 11 flights with dogs were made on the R-2A series, which flew to about 200 km. Three flights were made to an altitude of about 450 km on R-5A rockets in 1958. In the R-2 and R-5 rockets, the dogs were contained in a pressured cabin.

Dezik, Tsygan and Lisa

Dezik (Дезик) and **Tsygan** (Цыган, "Gypsy") were the first dogs to make a sub-orbital flight on July 22, 1951. Both dogs were recovered unharmed after travelling to a maximum altitude of 110 km. Dezik made another sub-orbital flight in September 1951 with a dog named **Lisa**, although neither survived. After the death of Dezik, Tsygan was adopted as a pet by Soviet physicist Anatoli Blagonravov.

Lisa and Ryzhik

Lisa (Лиса, "Fox" or "Vixen") and **Ryzhik** (Рыжик, "Ginger" (red-haired)) flew to an altitude of 100 km on June 2, 1954.

Smelaya and Malyshka

Smelaya (Смелая, "Brave" or "Courageous") was due to make a flight in September but ran away the day before the launch. She was found the next day and went on to make a successful flight with a dog named **Malyshka** (Малышка, "Little One").

Bolik and ZIB

Bolik (Болик) ran away just days before her flight in September 1951. A replacement named **ZIB** (a Russian acronym for *"Substitute for Missing Bolik"*, "Замена исчезнувшему Болику" *Zamena ischeznuvshemu Boliku*), who was an untrained street dog found running around the barracks, was quickly located and made a successful flight.

Otvazhnaya and Snezhinka

Otvazhnaya (Отважная, "Brave One") made a flight on July 2, 1959 along with a rabbit named **Marfusha** (Марфуша, "Little Martha") and another dog named **Snezhinka** (Снежинка, "Snowflake"). She went on to make 5 other flights between 1959 and 1960.

Albina and Tsyganka

Albina (Альбина, a real female name) and **Tsyganka** (Цыганка, "Gypsy girl") were both ejected out of their capsule at an altitude of 85 km and landed safely. Albina was one of the dogs shortlisted for Sputnik 2, but never flew in orbit.

Damka and Krasavka

Damka (Дамка, "Queen of checkers") and **Krasavka** (Красавка, "Little Beauty") were to make an orbital flight on December 22, 1960, but their mission was marked by a string of equipment failures. The upper stage rocket failed and the craft re-entered the atmosphere after reaching a sub-orbital apogee of 214 km. In the event of unscheduled return to the surface, the craft was to eject the dogs and self-destruct, but the ejection seat failed and the primary destruct mechanism shorted out. The animals were thus still in the intact capsule when it returned to the surface. The backup self-destruct mechanism was set to a 60 hour timer, so a team was quickly sent out to locate and recover the capsule. Although the capsule was reached in deep snow on the first day, there was insufficient remaining daylight to disarm the self-destruct mechanism and open the capsule. The team could only report that the window was frosted over in the -45 degree temperatures and no signs of life were detected. On the second day, however, the dogs were heard barking as the capsule was opened. The dogs were wrapped in sheepskin coats and flown to Moscow alive. Damka was also known as Shutka (Шутка, "Joke") or Zhemchuzhnaya (Жемчужная, "Pearly") and Krasavka was also known as Kometka (Кометка, "Little Comet") or Zhulka (Жулька, "Cheater").

Bars and Lisichka

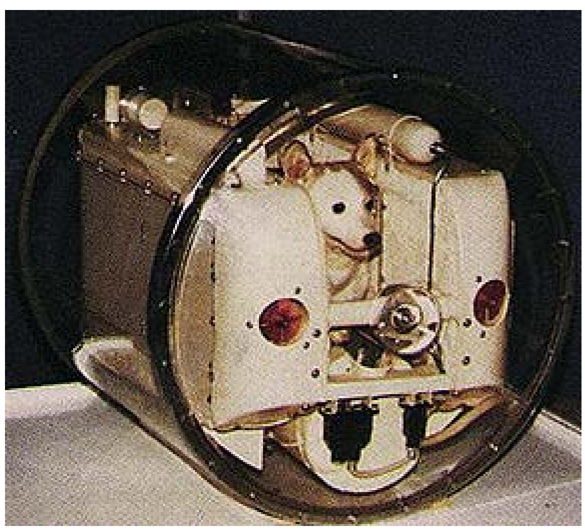
Bars (Барс "Snow leopard") and **Lisichka** (Лисичка, "Little Fox") were also on a mission to orbit but died after their rocket exploded 28.5 seconds into the launch on July 28, 1960. Bars was also known as Chayka ("Seagull").

Other dogs that flew on sub-orbital flights include **Dymka** (Дымка, "Smoky"), **Modnitsa** (Модница, "Fashionable") and **Kozyavka** (Козявка, "Little Gnat").

At least four other dogs flew in September 1951, and two or more were lost.

Orbital flights

Laika



A NASA built mockup of Laika's module

Laika (Лайка, "Barker"), became the first living Earth-born creature (other than microbes) in orbit, aboard Sputnik 2 on November 3, 1957. Some call her the first living passenger to go into space, but others claim sub-orbital flights passed the edge of space first. She was also known as Zhuchka (Жучка, "Little Bug") and Limonchik (Лимончик, "Lemon"). The American media dubbed her "Muttnik", making a play-on-words for the canine follow-on to the first orbital mission, Sputnik. She died between five and seven hours into the flight from stress and overheating. Her true cause of death was not made public until October 2008; officials previously gave reports that she died when the oxygen supply ran out. At a Moscow press conference in 1998 Oleg Gazenko, a senior Soviet scientist involved in the project, stated "The more time passes, the more I'm sorry about it. We did not learn enough from the mission to justify the death of the dog".

Belka and Strelka

Belka and Strelka on graffiti. 2008

Strelka on tour, in taxidermied form, in Australia in 1993

Belka (Белка, literally, "squirrel" and **Strelka** (Стрелка, "Arrow") spent a day in space aboard Korabl-Sputnik-2 (Sputnik 5) on August 19, 1960 before safely returning to Earth.

They were accompanied by a grey rabbit, 42 mice, 2 rats, flies and a number of plants and fungi. All passengers survived. They were the first Earth-born creatures to go into orbit and return alive.

Strelka went on to have six puppies with a male dog named **Pushok** who participated in many ground-based space experiments, but never made it into space. One of the pups was named **Pushinka** (Пушинка, "Fluffy") and was presented to President John F. Kennedy's daughter Caroline by Nikita Khrushchev in 1961. A Cold War romance bloomed between Pushinka and a Kennedy dog named Charlie resulting in the birth of 4 pups that JFK referred to jokingly as *pupniks*. Two of their pups, **Butterfly** and **Streaker** were given away to children in the Midwest. The other two puppies, **White Tips** and **Blackie**, stayed at the Kennedy home on Squaw Island but were eventually given away to family friends. Pushinka's descendants are still living today. A photo of descendants of some of the Space Dogs is on display at the Zvezda Museum outside Moscow.

An animated Russian feature film called *Belka and Strelka. Star Dogs* was released in 2010.

Pchyolka and Mushka

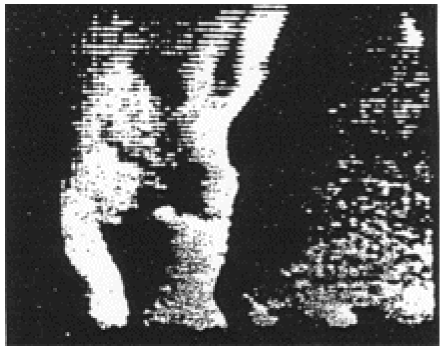


Image of one of the dogs onboard Sputnik 6, demodulated by CIA electronic intelligence

Ugolyok and Veterok in space. 1966 USSR stamp

Pchyolka (Пчёлка, "Little Bee") and **Mushka** (Мушка, "Little Fly") spent a day in orbit on December 1, 1960 on board Korabl-Sputnik-3 (Sputnik 6) with "other animals", plants and insects. Due to a navigation error, their spacecraft disintegrated during re-entry on December 2 and all died. Mushka was one of the three dogs trained for Sputnik 2 and was used during ground tests. She did not fly on Sputnik 2 because she refused to eat properly.

Chernushka

Chernushka (Чернушка, "Blackie") made one orbit on board Korabl-Sputnik-4 (Sputnik 9) on March 9, 1961 with a cosmonaut dummy (whom Soviet officials nicknamed "Ivan

Ivanovich"), mice and a guinea pig. The dummy was ejected out of the capsule during re-entry and made a soft landing using a parachute. Chernushka was recovered unharmed inside the capsule.

Zvyozdochka

Zvyozdochka (Звёздочка, "Little Star"), who was named by Yuri Gagarin, made one orbit on board Sputnik 10 on March 25, 1961 with a wooden cosmonaut dummy in the final practice flight before Gagarin's historic flight on April 12. Again, the dummy was ejected out of the capsule while Zvezdochka remained inside. Both were recovered successfully.

Veterok and Ugolyok

Veterok (Ветерок, "Little Wind/Breeze") and **Ugolyok** (Уголёк, "Ember") were launched on February 22, 1966 on board Cosmos 110, and spent 22 days in orbit before landing on March 16. This spaceflight of record-breaking duration was not surpassed by humans until Skylab 2 in June 1973 and still stands as the longest space flight by dogs.

Chapter- 12

Space Accidents and Incidents

Space Shuttle Challenger disintegrates 73 seconds after launch, due to hot gases escaping the SRBs leading to structural failure of the external tank. The accident resulted in the death of all seven crewmembers.

Space accidents, either during operations or training for spaceflights, have killed 22 astronauts and cosmonauts (five percent of all people who have been in space, two percent of individual spaceflights) and a larger number of people on the ground.

This article provides an overview of all known fatalities and near-fatalities that occurred during manned space missions, accidents during astronaut training and during the testing, assembling or preparing for flight of manned and unmanned spacecraft. Not included are fatalities occurring during intercontinental ballistic missile accidents, and Soviet or German rocket-fighter projects of World War II. Also not included are alleged unreported Soviet space accidents that are not believed by mainstream historians to have occurred.

Spaceflight fatalities

The history of space exploration has had a number of tragedies that resulted in the deaths of the astronauts or ground crew. As of 2007, in-flight accidents have killed 18 astronauts, training accidents have claimed 11 astronauts, and launchpad accidents have killed at least 71 ground personnel.

About two percent of the manned launch/reentry attempts have killed their crew, with Soyuz and the Shuttle having almost the same death percentage rates. Except for the X-15 (which is a suborbital rocket plane), other launchers have not launched sufficiently often for reasonable safety comparisons to be made.

About five percent of the people that have been launched have died doing so (because astronauts often launch more than once). As of November 2004, 439 individuals have flown on spaceflights: Russia/Soviet Union (96), USA (277), others (66). Twenty-two have died while in a spacecraft: three on Apollo 1, one on Soyuz 1, one on X-15-3, three on Soyuz 11, seven on *Challenger*, and seven on *Columbia*. By space program, 18 NASA astronauts (4.1%) and four Russian cosmonauts (0.9% of all the people launched) died while in a spacecraft.

Soyuz accidents have claimed the lives of four cosmonauts. No deaths have occurred on Soyuz missions since 1971, and none with the current design of the Soyuz. Including the early Soyuz design, the average deaths per launched crew member on Soyuz are currently under two percent. However, there have also been several serious injuries, and some other incidents in which crews nearly died.

NASA astronauts who have lost their lives in the line of duty are memorialized at the Space Mirror Memorial at the Kennedy Space Center Visitor Complex in Merritt Island, Florida. Cosmonauts who have died in the line of duty under the auspices of the Soviet Union were generally honored by burial at the Kremlin Wall Necropolis in Moscow. It is unknown whether this remains tradition for Russia, since the Kremlin Wall Necropolis was largely a Communist honor and no cosmonauts have died in action since the Soviet Union fell.

There have been four fatal in-flight accidents on missions which were considered spaceflights under the internationally accepted definition of the term, plus one on the ground during rehearsal of a planned flight. In each case all crew were killed. To date, there has never been an incident where an individual member of a multi-member crew has died during (or while rehearsing) a mission.

- 1967 April 24: *parachute failure*: Soviet cosmonaut Vladimir Komarov died on board Soyuz 1. His one-day mission had been plagued by a series of mishaps with the new type of spacecraft, which culminated in the capsule's parachute not opening properly after atmospheric reentry. Komarov was killed when the capsule hit the ground at high speed.
- 1971 June 30: *crew exposed to vacuum of space*: The crew of Soyuz 11, Georgi Dobrovolski, Viktor Patsayev and Vladislav Volkov, were killed after undocking from space station Salyut 1 after a three-week stay. A valve on their spacecraft had accidentally opened when the service module separated, which was only discovered when the module was opened by the recovery team. Technically the only fatalities *in space* (above 100 km).
- 1986 January 28: *structural failure after lift-off*: The first U.S. multiple in-flight fatalities. The Space Shuttle *Challenger* was destroyed 73 seconds after lift-off on STS-51-L. Analysis of the accident showed that a faulty O-ring seal had allowed hot gases from the shuttle solid rocket booster (SRB) to weaken the external propellant tank, and also the strut that held the booster to the tank. The tank aft region failed, causing it to begin disintegrating. The SRB strut also failed, causing the SRB to rotate inward and expedite tank breakup. *Challenger* was thrown sideways into the Mach 1.8 windstream causing it to break up in midair with the loss of all seven crew members aboard: Greg Jarvis, Christa McAuliffe, Ronald McNair, Ellison Onizuka, Judith Resnik, Michael J. Smith, and Dick Scobee. NASA investigators determined they may have survived during the spacecraft disintegration, while possibly unconscious from hypoxia; at least some of them tried to protect themselves by activating their emergency oxygen. Any survivors of the breakup were killed, however, when the largely intact cockpit hit the water at 200 mph (320 km/h).
- 2003 February 1: *structural failure during re-entry*: The Space Shuttle *Columbia* was lost as it reentered after a two-week mission, STS-107. Damage to the shuttle's thermal protection system (TPS) led to structural failure in the shuttle's left wing and, ultimately, the spacecraft broke apart. Investigations after the tragedy revealed the damage to the reinforced carbon-carbon leading edge wing panel had resulted from a piece of insulation foam breaking away from the external tank during the launch and hitting shuttle's wing. Rick D. Husband, William McCool, Michael P. Anderson, David M. Brown, Kalpana Chawla, Laurel B. Clark, and Ilan Ramon were killed.

There has also been a single accident on a flight which was considered a spaceflight by those involved in conducting it, but not under the internationally accepted definition:

- 1967 November 15: *control failure*: Michael J. Adams died while piloting a North American X-15 rocket plane. Major Adams was a U.S. Air Force pilot in the NASA/USAF X-15 program. During X-15 Flight 191, his seventh flight, the plane first had an electrical problem and then developed control problems at the apogee of its flight. The pilot may also have become disoriented. During reentry from a 266,000 ft (50.4 mile, 81.1 km) apogee, the X-15 yawed sideways out of control and went into a spin at a speed of Mach 5. The pilot recovered, but went into a Mach 4.7 inverted dive. Excessive acceleration led to the X-15 breaking up in flight at about 65,000 feet (19.8 km)). Adams was posthumously awarded astronaut wings as his flight had passed an altitude of 50 miles (80.5 km) (the U.S. definition of space).

Near-fatalities

Apart from actual disasters, a number of missions resulted in some very near misses and also some training accidents that nearly resulted in deaths. In-flight near misses have included various reentry mishaps (in particular on Soyuz 5), the sinking of the Mercury 4 capsule, and the Voskhod 2 crew spending a night in dense forest surrounded by wolves.

- 1961 April 12: *separation failure*: During the flight of Vostok 1, after retrofire, the Vostok service 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 they did not separate until 10 minutes after retrofire, when the wire bundle finally burned through. The spacecraft had gone through wild gyrations at the beginning of reentry, before the wires burned through and the reentry module settled into the proper reentry attitude.
- 1961 July 21: *landing capsule sank in water*: After Liberty Bell 7 splashed down in the Atlantic, the hatch malfunctioned and blew, filling the capsule with water and almost drowning Gus Grissom, who managed to escape before it sank. Grissom then had to deal with a spacesuit that was rapidly filling with water, but managed to get into the helicopter's retrieval collar and was lifted to safety.
- 1965 March 18: *spacesuit or airlock design fault*: Voskhod 2 featured the world's first spacewalk, by Alexei Leonov. After his twelve minutes outside, Leonov's spacesuit had inflated in the vacuum to the point where he could not reenter the airlock. He opened a valve to allow some of the suit's pressure to bleed off, and was barely able to get back inside the capsule after suffering slight effects of the bends.
- 1966 March 17: *equipment failure*: Gemini 8: A maneuvering thruster refused to shut down and put their capsule into an uncontrolled spin. The g-force became so intense the astronauts were possibly within seconds of blacking out when they regained control.
- 1969 January 18: *separation failure*: the Soyuz 5 had a harrowing reentry and landing when the capsule's service module initially refused to separate, causing the spacecraft to begin reentry faced the wrong way. The service module broke away before the capsule would have been destroyed, and so it made a rough but survivable landing far off course in the Ural mountains.
- 1970 April 13: *equipment failure*: In the most celebrated "near miss", the Apollo 13 crew came home safely after a violent rupture of a liquid oxygen tank deprived the Service Module of its ability to produce electrical power, crippling their spacecraft en route to the moon. They survived the loss of use of their command ship by relying on the Lunar Module as a "life boat" to provide life support and power for the trip home.

- 1975 April 5: *separation failure*: The Soyuz 18a mission nearly ended in disaster when the rocket suffered a second-stage separation failure during launch. This also interrupted the craft's attitude, causing the vehicle to accelerate towards the Earth and triggering an emergency reentry sequence. Due to the downward acceleration, the crew experienced an acceleration of 21.3 *g* rather than the nominal 15 *g* for an abort. Upon landing, the vehicle rolled down a hill and stopped just short of a high cliff. The crew survived, but Lazarev, the mission commander, suffered internal injuries due to the severe G-forces and was never able to fly again.
- 1975 July 24: *gas poisoning on board*: During final descent and parachute deployment for the Apollo Soyuz Test Project Command Module, the U.S. crew were exposed to 300 µL/L of toxic nitrogen tetroxide gas (Reaction Control System oxidizer) venting from the spacecraft and reentering a cabin air intake. A switch was left in the wrong position. 400µL/L is fatal. Vance Brand's heart stopped and he was narrowly resuscitated. The crew members suffered from burning sensations of their eyes, faces, noses, throats and lungs. Thomas Stafford quickly broke out emergency oxygen masks and put one on Brand and gave one to Deke Slayton. The crew were exposed to the toxic gas from 24,000 ft (7.3 km) down to landing. About an hour after landing the crew developed chemical-induced pneumonia and their lungs had edema. They experienced shortness of breath and were hospitalized in Hawaii. The crew spent two weeks in the hospital. By July 30, their chest X-rays appeared to return to normal.
- 1976 October 16: *landing capsule sank in water*: The Soyuz 23 capsule broke through the surface of a frozen lake and was dragged underwater by its parachute. The crew was saved after a very difficult rescue operation.
- 1983 September 26: *fire in launch vehicle*: A Soyuz crew was saved by their escape system when the rocket that was to carry their Soyuz T-10-1 mission into space caught fire on the launchpad.
- 1985 July 29: STS-51-F: *Space Shuttle in-flight engine failure*: Five minutes, 45 seconds into ascent, one of three shuttle main engines aboard *Challenger* shut down prematurely due to a spurious high temperature reading. At about the same time, a second main engine almost shut down from a similar problem, but this was observed and inhibited by a fast acting flight controller. The failed SSME resulted in an Abort To Orbit (ATO) trajectory, whereby the shuttle achieves a lower than planned orbital altitude. Had the second engine failed within about 20 seconds of the first, a Transatlantic Landing (TAL) abort might have been necessary. (No bailout option existed until after mission STS-51-L (Challenger disaster), but even today a bailout—a "contingency abort", would never be considered when an "intact abort" option exists, and after five minutes of normal flight it would always exist unless a serious flight control failure or some other major problem beyond engine shutdown occurred.)
- 1988 September 5: *sensor failure*: Soyuz TM-5 cosmonauts Alexandr Lyakhov and Abdul Ahad Mohmand (from Afghanistan) undocked from Mir. They jettisoned the orbital module and got ready for the deorbit burn. The deorbit burn did not occur because the infrared horizon sensor could not confirm proper attitude. Seven minutes later, the correct attitude was achieved. The main engine

fired, but Lyakhov shut it down after 3 seconds to prevent a landing overshoot. A second firing 3 hours later lasted only 6 seconds. Lyakhov immediately attempted to manually deorbit the craft, but the computer shut down the engine after 60 seconds. When they were jettisoning the Equipment Module, which contained, among other things, the primary propulsion system – the very system they needed to deorbit – Mohmand, disregarding a directive to sit back and let Mission Control assess the situation, had scanned the ship's gauges and displays, and discovered that separation was going to take place in less than a minute. Lyakhov quickly disabled the program. Had he not done so, he and Mohmand would have perished, as the Soyuz Descent Module had only enough air and battery power for a couple of hours. After three attempts at retrofire, the cosmonauts were forced to remain in orbit a further day, until they came into alignment with the targeted landing site again. Even if they had enough fuel to do so, they would not have been able to re-dock with Mir, because they had discarded the docking system along with the orbital module. The cosmonauts were left for a day in the cramped quarters of the descent module with minimal food and water and no sanitary facilities. Reentry occurred as normal on September 7, 1988.

- 1997 February 23: *fire onboard*: There was a fire on board the Mir space station when a lithium perchlorate canister used to generate oxygen leaked. The fire was extinguished after about 90 seconds, but smoke did not clear for several minutes.
- 1997 June 25: *collision in space*: At Mir during a re-docking test with the Progress-M 34 cargo freighter, the Progress freighter collided with the Spektr module and solar arrays of the Mir space station. This damaged the solar arrays and the collision punctured a hole in the Spektr module and the space station began depressurizing. The on-board crew of two Russians and one visiting NASA astronaut were able to close off the Spektr module from the rest of Mir after quickly cutting cables and hoses blocking hatch closure.
- 1999 July 23: STS-93: *main engine electrical short and hydrogen leak*: Five seconds after liftoff, an electrical short knocked out controllers for two shuttle main engines. The engines automatically switched to their backup controllers. Had a further short shut down two engines, *Columbia* would have ditched in the ocean, although the crew could have possibly bailed out. Concurrently a pin came loose inside one engine and ruptured a cooling line, allowing a hydrogen fuel leak. This caused premature fuel exhaustion, but the vehicle safely achieved a slightly lower orbit. Had the failure propagated further, a risky transatlantic or RTLS abort would have been required.
- 2008 April 19: Soyuz TMA-11 suffered a reentry mishap similar to that suffered by Soyuz 5 in 1969. The service module failed to completely separate from the reentry vehicle and caused it to face the wrong way during the early portion of aerobraking. As with Soyuz 5, the service module eventually separated and the reentry vehicle completed a rough but survivable landing. Following the Russian news agency Interfax's report, this was widely reported as life-threatening while NASA urged caution pending an investigation of the vehicle.
- On one Shuttle flight, wiring faults threatened to prevent the main tank from separating.

Training accidents

Test pilot Stuart Present ejects safely from the Lunar Landing Training Vehicle. Neil Armstrong also made such an ejection. (NASA)

In addition to accidents during spaceflights, astronauts have experienced accidents during training.

- 1961 March 23: *fire on board*: First space-related casualty. Valentin Bondarenko was in training in a special low-pressure chamber with a pure oxygen atmosphere. He threw an alcohol-soaked cloth onto an electric hotplate. In the pure oxygen environment, the fire quickly engulfed the entire chamber. Bondarenko suffered third-degree burns over most of his body and was barely alive when the chamber was opened, and died of his burns shortly after being hospitalized. Bondarenko's death was covered up by the Soviet government; word of his death only reached the West in 1986. Many materials become explosively flammable when exposed to oxygen with a higher partial pressure than that of air at STP; modern spacecraft use mixtures of continuously replaced oxygen and nitrogen. It has been speculated that knowledge of Bondarenko's death might have led to changes that would have prevented the Apollo 1 fire.
- 1964 October 31: *bird strike*: Theodore Freeman was killed when a goose smashed through the cockpit canopy of his T-38 jet trainer. Flying shards of Plexiglas entered the engine intake and caused the engine to flame out. Freeman ejected from the stricken aircraft, but was too close to the ground for his parachute to open properly. The creation of zero-zero ejection seats has

eliminated this problem. (However, T-38s remaining in service still do not have a zero-zero ejection seat.)

- 1966 February 28: *crash on landing*: The original Gemini 9 crew, Elliot See and Charles Bassett, were killed while attempting to land their T-38 in bad weather. See misjudged his approach and crashed into the McDonnell aircraft factory.
- 1967 January 27: *fire on board*: A fire in the cabin claimed the lives of the Apollo 1 crew as they rehearsed the launch sequence for their planned February 21 launch. An electrical fault sparked the blaze that spread quickly in a pure oxygen atmosphere, killing Gus Grissom, Edward White II, and Roger Chaffee.
- 1967 October 5: *controls failed*: Clifton "C.C." Williams died after a mechanical failure caused the controls of his T-38 to stop responding. He had been assigned to the back-up crew for what would be the Apollo 9 mission and would have most likely been assigned as Lunar Module pilot for Apollo 12. The Apollo 12 Mission Patch has four stars on it: one each for the three astronauts who flew the mission and one for Williams.
- 1967 December 8: *plane crash*: Robert Henry Lawrence, Jr. was named the first African-American astronaut for the U.S. Air Force Manned Orbiting Laboratory program, but he never made it into space. He died when his F-104 Starfighter jet crashed at Edwards Air Force Base, California.
- 1968 March 27: *plane crash*: First human in space Yuri Gagarin died when his MiG-15UTI jet trainer crashed while he prepared for the Soyuz 3 mission. An official report at the time blamed either birdstrike or that he turned too fast to avoid something in the air. But in 2003 it came to light that the KGB had found that the official report was false and that the truth was negligence by an air force colonel on the ground, who gave an out-of-date weather report; the flight needed good weather and the aircraft not to have external extra fuel tanks, but the cloud base was nearly at ground level and the aircraft had external fuel tanks under its wings. Since Gagarin was a very public figure, the Soviet government decided that it would be bad publicity to have him killed in a mere training accident and so several newspapers printed the report that he actually died heroically testing a top-secret prototype. This again led to speculation amongst Western conspiracy-proponents as to whether Gagarin had instead died in hushed-up spacecraft accident.

- Three of the five Lunar Landing Research and Training vehicles (LLRV and LLTV) were destroyed in crashes near Houston, Texas:
    - 1968 May 6: LLRV No. 1 crashed at Ellington AFB, Texas; Neil Armstrong ejected safely.
    - 1968 December 8: LLTV No. 1 crashed at Ellington AFB, Texas. MSC test pilot Joseph Algranti ejected safely.
    - 1971 January 29: An LLTV crashed at Ellington AFB, Texas. NASA test pilot Stuart Present ejected safely.
- 1971 January 23: *helicopter crash*: Eugene Cernan was flying a Bell 47G helicopter as part of his Lunar Module training as Backup Commander for Apollo 14. The helicopter crashed into the Banana River at Cape Canaveral, Florida. Cernan nearly drowned because he was not wearing a life vest and received some

second-degree burns on his face and singed hair. According to official reports at the time, the crash was the result of mechanical failure. Later accounts, written by Cernan himself in an autobiography, admit he was flying too low and showing off for nearby boaters. The helicopter dipped a skid into the water and crashed. James McDivitt, an Apollo Manager at the time, demanded that Cernan be removed from flight status and not be given Command of Apollo 17. Cernan was defended by Deke Slayton and given the Apollo 17 command. James McDivitt resigned as an Apollo Manager shortly after the Apollo 16 mission.

Fatal accidents with ground crew and civilian fatalities

Date	Place	Death(s)	Kind of disaster
May 17, 1930	Berlin, Germany	1	Max Valier killed by rocket engine explosion
October 10, 1933	Germany	3	Explosion in rocket manufacturing room of Tiling
July 16, 1934	Kummersdorf, Germany	3	Ground test engine explosion
1944?	Tuchola Forest, German-occupied Poland	7	An A4-rocket crashes at a test launch in a trench. Several soldiers who were in the trench were killed.
1945	Grabów nad Prosną, German-occupied Poland	2	A test V-2 rocket fired from Wierzchucin crashed on the house in the village of Dzięcioły, near Grabów nad Prosną, killing two people inside - Władysława and Franciszek Desek, and injuring their two children.
Oct 24, 1960	Baikonur Cosmodrome, Kazakhstan	120?	The Nedelin catastrophe
April 14, 1964	Cape Canaveral, USA	3	Delta rocket ignited in assembly room, killing 3 technicians and injuring 9 others. The ignition was caused by a spark of static electricity
May 7, 1964	Braunlage, West Germany	3	Mail rocket built by Gerhard Zucker exploded and debris hit crowd of spectators
June 26, 1973	Plesetsk Cosmodrome, USSR	9	Launch explosion of Kosmos-3M rocket
March 18, 1980	Plesetsk Cosmodrome, USSR	48	Explosion while fueling up a Vostok-2M rocket
March 19, 1981	Cape Canaveral, USA	2	Anoxia due to nitrogen atmosphere in the aft engine compartment of Columbia during preparations for STS-1. Five casualties; three

			were revived. Killed: John Bjornstad and Forrest Cole.
January 26, 1995	Xichang, China	6+	Long March rocket veered off course after launch
May 5, 1995	Guiana Space Centre, French Guyana	2	Anoxia; Luc Celle and Jean-Claude Dhainaut died during an inspection in the umbilical mast of the launchpad
February 15, 1996	Xichang, China	56-200	Intelsat 708 Satellite. Long March rocket veered off course 2 seconds after launch, crashing in the nearby village and destroying 80 houses, according to the official Chinese count, killing 56 people, but with U.S. defense intelligence officials estimating 200 dead.
October 1, 2001	Cape Canaveral, USA	1	Crane operator Bill Brooks was killed in an industrial accident at Launch Complex 37
October 15, 2002	Plesetsk Cosmodrome, Russia	1	A Soyuz-U exploded 29 seconds after launch, killing a soldier, Ivan Marchenko, and injuring 8 others. Fragments of the rocket started a forest fire nearby, and a Block D strap-on booster caused damage to the launchpad
August 22, 2003	Alcântara, Brazil	21	Explosion of an unmanned rocket during launch preparations
July 26, 2007	Mojave Spaceport, California	3	Explosion during a test of rocket systems by Scaled Composites during a nitrous oxide injector test