Recent and Future Development of

Space Exploration

(Development and Applications)

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Asian Space Race

The **Asian space race** is a purported race among several Asian countries to achieve scientific and technological advancements in space. The exploration of Outer space is of strategic concern to a growing number of countries worldwide. Earth's orbit and Manned spaceflight are becoming the main battleground to ensure national security. In past and recent years, a number of Asian nations have become serious contenders in the "race" to control space.

Asian space powers

Of the nine (or eleven if one counts Russia and Ukraine separate from the Soviet Union) countries that have successfully launched a satellite independently into orbit, five are Asian countries: Japan, China, India, Israel and Iran.

Kazakhstan does not have its own rocket technology and hosts the Baikonur Cosmodrome launch facility which is used by Russia under a lease agreement of $150 million annually. Iraq developed and tested the Tammouz space launch vehicle without a satellite on 5 December 1989. According to a press release by the Iraqi News Agency the warhead completed 6 orbits, but this was not confirmed by international observers. North Korea has also claimed to have launched satellites Kwangmyŏngsŏng by its own launchers twice (in 31 August 1988 and in 5 April 2009), however according to international observers, those rockets fell into the North Pacific without deploying any satellites in orbit. South Korea plans to enter the Asian space club in 2009 and Indonesia, Taiwan, Pakistan, Malaysia, Turkey are claimed to have some kind of space program as well.

China's first manned spacecraft entered orbit in October 2003, making China the first Asian nation and the third after Soviet Union/Russia and the United States in the world to send a human into space independently.

India expects to demonstrate independent human spaceflight by 2015, and both Iran and Japan have plans for independent manned spaceflights around the year 2020.

While the achievements of space programs run by main Asian space players China, India and Japan are modest in comparison to the milestones set by the United States and the former Soviet Union in the first space race, some experts believe it may only be a matter of time before Asia leads the field. As for beginning of 21st century, China is the leader in Asia's space race. The first Chinese manned spaceflight in 2003 marked the beginning of a space race in the region. In the same time, the issue of a space race's existence in Asia is still debated. As example, China denies that there is an Asian Space Race.

Motivations

The motivations behind a new space race include national pride, national security and commercial development.

China, India, Iran, Japan have dual-purpose space programs - military and civilian. Because of external threats Israel, North Korea and the Republic of China (Taiwan) concentrate mainly on military space applications. The programs of South Korea, Malaysia and Thailand are mainly civilian. Indonesia, while initially focusing primarily on civil applications has begun moving into the dual-purpose arena following the development of Ballistic Missile capabilities in 2008. The Indian Space Program was mainly based on developing civilian space applications, but since the launch of its Defence Surveillance Satellite, Radar Imaging Satellite (RISAT-2) and Spy Satellites in 2009 has transformed into a dual-purpose space program.

Some examples: In January 2007 China became the first Asian military-space power to send an anti-satellite missile into orbit to destroy an aging Chinese Feng Yun 1C in polar orbit weather satellite. As conterpart, month later, Japan's space agency (JAXA) has launched an experimental communications satellite designed to enable super high-speed data transmission in remote areas which would make Japan as high-tech space leader. After successful achievement of geostationary technology, India has launched its first Chandrayaan-1 Moon mission. First Korean astronaut Yi So-yeon spent 11 days aboard the International Space Station in April 2008.

Apart from national pride, there are also commercial motivations. According to a report by the Space Frontier Foundation released in 2006, the "space economy" is estimated to be worth about $180 billion, with more than 60 percent of space-related economic activity coming from commercial goods and services. Now China and India widely propose the commercial launch service.

Asian national milestones

Big Three

China

China's space program has been in the spotlight since 2003, when it started manned space launches, becoming the first Asian country and the third overall to independently send a man into space. China successfully performed an EVA in September 2008. China has developed a sizable family of successful Long March rockets. It has launched two lunar orbiters, Chang'e 1 and Chang'e 2 and intends to land a rover on the moon and conduct a sample return mission. In 2011, China plans to embark on a program to established a manned space station starting with the launch of Tiangong 1. China also expects to send its first Mars probe in 2011. As well as national pride there are commercial drivers such as launching of satellites for communications, weather forecast and research of Earth's atmosphere.

It also has collaborative projects with Russia, ESA and Brazil and has launched commercial satellites for other countries.

Some analysts suggest that the Chinese space program is linked to the nation's efforts at developing advanced military technology. In 2007, China used an anti-satellite missile to destroy a defunct weather satellite, the Feng Yun 1-C, orbiting 528 miles (850 km) above Earth. The resulting explosion sent a wave of debris hurtling through space at more than 6 miles per second. On 21 February 2008 the US Navy destroyed a disabled spy satellite USA 193. The US denied the destruction of the satellite was a response to an anti-satellite test carried out by China in 2007.

India

India's interest in space travel had a modest beginning in the early 1960s, when scientists launched a small rocket above Kerala. Now India has its own space launch vehicles, has launched several satellites, sent a probe to the moon and demonstrated re-entry technology. Initially India's space program was not taken as a geopolitical weapon of pride but under Vikram Sarabhai focussed on practical uses of space in increasing standards of living. Thus the impetus was on putting remote sensing and communications satellites into orbit. This has changed in the recent past. The main shifts took place under two administrations. The first was that of Indira Gandhi, when India sent its first human in space, Rakesh Sharma, through Soviet Intercosmos Program. Then there was a long gap before the second shift, which was during the administration in India under Atal Behari Vajpayee. Just a few days after China said that it would send a human into orbit in the second half of 2003, Indian Prime Minister Atal Behari Vajpayee publicly urged his country's scientists to work towards sending a man to the Moon. Chandrayaan-1, India's first unmanned lunar mission was launched on October 2008. The Indian Space Research Organisation (ISRO) is planning its 2nd moon mission, Chandrayaan-2, in 2013. India expects a manned space mission by 2015 that will make the country a fourth space power.The Indian Space Research Organisation had begun preparations for a mission to Mars.

Japan

The H-IIA F11 launch vehicle lifts off from Tanegashima Space Center in Japan.

Japan has been cooperating with the United States on missile defence since 1999. North Korean nuclear and Chinese military programs represent a serious issue for Japan's foreign relations. Japan is now working on military and civilian space technologies, developing missile defence systems, new generations of military spy satellites, and planning for manned stations on the Moon. Japan started to construct spy satellites after North Korea test fired a Taepodong missile over Japan in 1998, although the North Korean government claimed the missile was merely launching a satellite to space accusing Japan of causing an arms race. The Japanese constitution adopted after World War II limits military activities to defensive operations. On May 2007 Prime Minister Shinzo Abe called for a bold review of the Japanese Constitution to allow the country to take a larger role in global security and foster a revival of national pride. Japan has not yet developed its own manned spacecraft and has not adopted acting program of developing of one. Some time ago project of Japan space shuttle HOPE-X launched by conventional space launcher H-II was developed during several years but was postponed. Then the more simple manned capsule Fuji was proposed but not adopted. Pioneer projects of single-stage to orbit, reusable launch vehicle horizontal takeoff and landing ASSTS and vertical takeoff and landing Kankoh-maru also exists but have not been adopted. More conservative new (JAXA manned spacecraft) project is expected to launch by 2025 as part of Japanese plans of manned missions to Moon. Some science journalists are doubtful about the Japanese manned moon project and expect the project is a euphemism for participation in the American Constellation program, same as the Japanese manned space program such as ISS. On the other hand, JAXA planned to send a Humanoid robot (such as ASIMO) as an astronaut to the moon.

Other nations

Indonesia was one of the first Asian countries that began operate their own application (communication) satellite purchased abroad and now intends to join the Asian space powers by developing and starting of use of the own small space launch vehicle Pengorbitan (RPS-420) in 2012-2014.

Iran has developed its own satellite launch vehicle based on the Shahab series of IRBM's, and named the Safir SLV. On February 2, 2009, Iranian state television reported that Iran's first domestically made satellite Omid (from the Persian امید, meaning "Hope") had been successfully launched into LEO by a version of Iran's Safir rocket, the Safir-2. The launch was made to coincide with the 30th anniversary of the Iranian Revolution. Iran is presently working on the Omid series of indigenous satellites among others. The Iranian Space Agency has also disclosed its plans for a manned space program intending to put humans in space by 2021.

Israel became the eighth country in the world to build its own satellite and launch it with its own launcher when on September 19, 1988, Israel launched its first satellite, Ofeq-1, using an Israeli-built Shavit three-stage launch vehicle. Since then, local universities, research institutes and private industry, backed by the Israel Space Agency, have made progress in space technology. At the time, the launching was the high point of a process that had begun in 1983, with the establishment of the Israel Space Agency under the aegis of the Ministry of Science. Space research by university-based scientists had already begun in the 1960s, providing a ready-made pool of experts for Israel's foray into space. The agency's role is stated to be for supporting "private and academic space projects, coordinate their efforts, initiate and develop international relations and projects, head integrative projects involving different bodies, and create public awareness for the importance of space development."

North Korea has long-durated experience of rocket technology and years before proliferated it to Pakistan, Iran etc. On 12 March 2009 North Korea signed the Outer Space Treaty and the Registration Convention, after a previous declaration of preparations for a new satellite launch. DPRK twicely announced that launched satellites Kwangmyŏngsŏng-1 at August 31, 1998 and Kwangmyŏngsŏng-2 at April 5, 2009. This claims both times not confirmed in the world, but USA and South Korea estimated ones as tests of military ballistic missile. DPRK has Korean Committee of Space Technology space agency of North Korea, operates the Musudan-ri (Tonghae Satellite Launching Ground) Pongdong-ri (Tongch'ang-dong Space Launch Center) rocket launching sites and developed Baekdusan-1 and Unha (Baekdusan-2) space launchers and Kwangmyŏngsŏng satellites. In 2009 DPRK announced more ambitious future space projects including own manned space flights and development of a manned partially reusable launch vehicle even.

In 1961, a team of Pakistani scientists launched a sounding rocket, named Rehbar-I from the Sonmiani Rocket Range. The launching of the Rehbar-I made Pakistan the third country in Asia and only the tenth in the world in carrying out such a launch. In 1986, Pakistani scientist launched Pakistan's first satellites, called Badr-1 and Badr-B aboard Chinese and Russian rockets. Pakistan currently has one satellite in space PAKSAT-1 which was launched originally by United States for Indonesia and is currently out of service. The Pakistani Space Agency, SUPARCO, is planning its new upgraded communication satellite PAKSAT-IR, which is expected to be launched by 2012 by Chinese.

South Korea is a newer player in the Asian space race. In August 2006 South Korea launched its first military communications satellite, the Mugunghwa-5 satellite. The satellite was placed in geosynchronous orbit and is able to collect surveillance information on North Korea. The South Korean government is spending hundreds of millions of dollars in space technology and is due to launch its first space launcher KSR in 2008. South Korea's space program is justified by its government in terms of long-term commercial benefits and national pride. Seoul has long seen North Korea's significantly longer missile range as a serious threat to its national security. With the nation's first astronaut launched into Space, Lee So-yeon, South Korea gained confidence of entering Asian space race. Currently, the country is completing the construction of Naro Space Center. Once operational, South Korea will be able to build satellites and missiles with local technology. South Korea is pursuing a space program that could defend the peninsula while lessening Seoul's dependency on the United States.

Other "young" space players are Malaysia and Turkey that announced multitask space programs in 2006 and 2007. They intends to develop own satellites and launchers in nearest future and manned space facilities in far future even.

Taiwan tries some space efforts including space launchers. Thailand, Vietnam and some other countries mainly engaged by satellites only.

In 2009, Bangladesh announced its plans to launch its first satellite into orbit by 2011. At a cost of $150 million, the communications satellite is part of a wider scheme to develop the country's telecommunications sector. Bangladesh's government has stressed that the country seeks an "entirely peaceful and commercial" role in space.

There have been reports of the two rising Asian powers, China and India's collaboration with EU to challenge American supremacy in space. In 2003 reports emerged that China will invest £140 million in the European Union's Galileo global satellite system and India will invest £210 million in the scheme. However, hopes of India and China working closely on Global Satellite Navigation System were thrashed when Government of India approved the Indian Regional Navigational Satellite System project and signed an agreement with Russia on future development of GLONASS. Also, NASA's involvement in India's lunar mission and several other space-related projects indicates growing collaboration between India and the United States in the field of space exploration.

Major Asian achievements

The Chinese manned spaceflight was a high-profile Asian space achievement. The advanced technology was caused by integration of many related technology experiences. Chinese space achievements are practical. Early Chinese satellites, FSW series, performed many atmospheric reentry tests. Other nations such as Japan and India have less reentry experiences, which cause a barrier to manned spaceflight yet. In 1990s, China also succeeded in commercial launches, which caused many launch experiences and high success average after 1990s later. These achievements followed on the manned spaceflight in 2003. Recently, China also aims scientific achievement such as solar system exploration. When Japan and Europe began interplanetary explorations with Halley Armada in 1980s, China was in depression and skipped solar system explorations at this time. But the first Asian Mars orbiter, Yinghuo 1, will be launched only in 2011.

India has gained significant expertise in space technologies and has successfully conducted many commercial launches. The most numerous satellites in simultaneous launch, 10, was achieved in 2008. The first probe designed for lunar impact in Asia was achieved in same year. GSLV MK III, planned to launch in 2010, is expected to be commercial competitive because of low-cost heavy launch vehicle. India is aiming to position itself as the second country to successfully execute an indigenous manned spaceflight in Asia.

Japan has many Asian space achievements especially in scientific field. There were some strange circumstances. Japanese first orbital launch was achieved by a university's institute, earlier than a national space agency. Therefore, most of early Japanese satellites were for scientific exploration and caused many scientific achievements. On the other hand, the national space agency had to catch the university in haste. So many American space technologies, such as geosynchronous launch and weather/communication satellites, were imported early on. Thereafter, strong yen and Super 301 made disadvantage of Japanese commercial launches. Japan lost launch chance and less experience caused deterioration of success average after 1990s later. Then most of Japanese indigenous launches except governmental satellites are limited to technology experiments and scientific satellites, which have to aim global achievements.

Solar System explorations

Solar System explorations are major space technology in the public eye as well as manned spaceflight. Since Sakigake, the first interplanetary probe in Asia, was launched in 1985, Japan has led Asian planetary explorations, but other nations are catching up now.

The Moon race

The Moon is thought to be rich in Helium-3, which could one day be used in nuclear fusion power plants to fuel future energy demands in Asia, which is one of the world's fastest-growing economies, and harbors over 60% of the world's population. All three main Asian space powers plans to send man to Moon in far future and sent lunar probes already and in nearest future.

Probing the moon

Japan is the first Asian country to launch a lunar probe. The Hiten (Japanese: "flying angel") spacecraft (known before the launch as Muses-A), built by the Institute of Space and Astronautical Science of Japan, was launched on January 24, 1990. The mission did not go as it was planned in many aspects. Kaguya, is the second Japanese lunar orbiter spacecraft and was launched on September 14, 2007.

China launched its first lunar probe named Chang'e-1 on October 24, 2007 and successfully entered lunar orbit on November 5, 2007.

India launched its first lunar probe Chandrayaan-1 on October 22, 2008 and successfully entered its final lunar orbit on November 2, 2008. The mission did not go as it was planned, and signal to the satellite was loss less than midway through the mission. However, it was able to successfully complete 95% of its objectives and is hence considered a major success.

Moon landings

The first confirmed moon landing in Asia was Hiten's additional mission in 1993. It was a intentional hard landing at end of mission and some pictures of lunar surface were taken until impact, but Hiten was not designed for moon lander and had few scientific instruments for lunar exploration. Japanese next moon landing program, except crash at end of mission, was LUNAR-A developed from 1992. Although the LUNAR-A orbiter was cancelled, its landers(penetrators) are integrated into Russian Luna-Glob program and scheduled to launch in 2011. The penetrators are "relatively" hard landers but they will not be destroyed at moon landing as same as soft landers.

The first achieved Asian probe specialized for moon landing was Indian Moon Impact Probe (MIP) released from Chandrayaan-1 in 2008. MIP was only a hard lander destroyed at landing such as Galileo's entry probe, but its instruments performed lunar observation within 25 min until impact and the landing test will be applied to future soft landings such as Chandrayaan-2 planned in 2012.

Chinese Chang'e-1 spacecraft also achieved systematical hard landing at end of mission in 2009 and China became 6th country reached at lunar surface. One of the landing purpose was pre-test of future soft landings as same as MIP. Chinese lunar soft lander is scheduled to achieve in Chang'e-3.

Asian on the Moon

Over four decades after Neil Armstrong has become the first man to walk on the Moon, Asia's major powers hurry in their own space ambitions to send the first Asian to the Moon. China, Japan, and India, which have already sent orbiters, all have plans to send a manned spacecraft to the Moon; the earliest schedules (China, India and Japan) would have the first manned lunar spaceflight in the 2020s, around the same time as the American Constellation program would return an American to the Moon.

Exploration of the major planets

Japanese interplanetary probes have been limited to Small Solar System bodies such as comets and asteroids. JAXA's Nozomi probe was launched in 1998, but contact was lost with the probe due to electrical failures before visiting the planet Mars. The second Japanese probe for the planet Venus, Akatsuki, was launched in 2010.

Chinese scientists expect that China will take 20 years to launch independent planetary probes. But China may reverse the disadvantage of 44 years total in comparison with Japan. The Russian Phobos Grunt mission will bring the Chinese Yinghuo-1 probe to Mars centric orbit and is planned to launch in 2011. If successful, China will become the first country in Asia and 4th country in the world to own a "Mars orbiter". Moreover, the Chinese manned Mars exploration program is planned for c. 2050 by Chinese Academy of Sciences.

India is also planning a Mars orbiter, which will be launched in 2013 at the earliest.

On the other hand, the first student planetary probe in the world may come from Asia. The PLANET-C probe is planned to bring the UNITEC-1 student spacecraft to Venus.

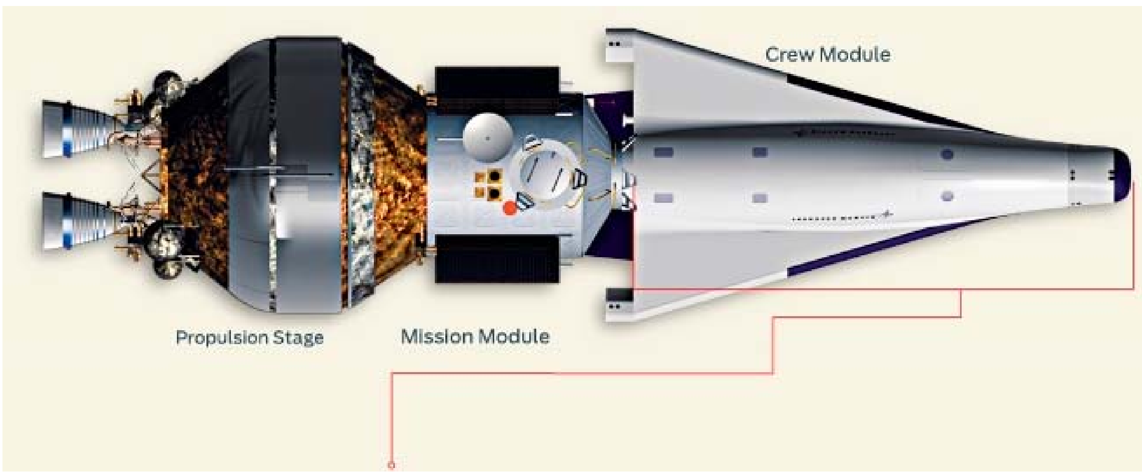
Asian space agencies and programs

- Bangladesh - Space Research and Remote Sensing Organization (SPARRSO)
- People's Republic of China - China National Space Administration (CNSA) (Chinese space program)
- India - Indian Space Research Organisation (ISRO)
- Indonesia - National Institute of Aeronautics and Space (LAPAN)
- Iran - Iranian Space Agency (ISA)
- Israel - Israeli Space Agency (ISA)
- Japan - Japan Aerospace Exploration Agency (JAXA)
- Malaysia - Malaysian National Space Agency (MNSA)
- North Korea - Korean Committee of Space Technology (KCST)
- Pakistan - Pakistan Space and Upper Atmosphere Research Commission (SUPARCO)
- Philippines - Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
- South Korea - Korea Aerospace Research Institute (KARI)
- Republic of China - National Space Organization (NSPO)

- Thailand - Geo-Informatics and Space Technology Development Agency (GISTDA)

Chapter- 2

Crew Exploration Vehicle



CEV initial concept in Lockheed Martin design, showing delta-wing crew module (*at right*), with a mission module and propulsion stage (with rocket engines) for interplanetary flight.

Orion (spacecraft), as a later design, after the initial plans for the **Crew Exploration Vehicle** led to development of the Orion.

The **Crew Exploration Vehicle** (or **CEV**) was the conceptual component of the U.S. NASA Vision for Space Exploration that later became known as the Orion spacecraft. The Orion CEV is part of NASA's Constellation Program to send human explorers back to the Moon, and then onward to Mars and other destinations in the solar system.

Official planning for the vehicle began in 2004, with the final Request For Proposal issued on March 1, 2005, to begin a design competition for the vehicle. For the later design and construction phases, see: Orion (spacecraft). NASA has posted project status notes at the NASA.gov website, under the name "Orion Crew Exploration Vehicle".

Competition

The concept for the vehicle was officially announced in a speech given by George W. Bush at NASA Headquarters on January 14, 2004. The Draft Statement of Work for the CEV was issued by NASA on December 9, 2004, and slightly more than one month later, on January 21, 2005, NASA issued a Draft Request For Proposal (RFP). The Final RFP was issued on March 1, 2005, with the potential bidders being asked to answer by May 2, 2005.

NASA had planned to have a suborbital or an Earth orbit fly-off called *Flight Application of Spacecraft Technologies* (FAST) between two teams' CEV designs before September 1, 2008. However, in order to permit an earlier date for the start of CEV operations, Administrator Michael Griffin had indicated that NASA would select one contractor for the CEV in 2006. From his perspective, this would both help eliminate the currently planned four-year gap between the retirement of the Shuttle in 2010 and the first manned flight of the CEV in 2014 (by allowing the CEV to fly earlier), and save over $1 billion for use in CEV development.

On June 13, 2005, NASA announced the selection of two consortia, Lockheed Martin Corp. and the team of Northrop Grumman Corp. and The Boeing Co. for further CEV development work. Each team had received a US$28 million contract to come up with a complete design for the CEV and its launch vehicle until August 2006, when NASA would award one of them the task of building the CEV. The teams would also have to develop a plan for their CEV to take part in the assembly of a lunar expedition, either with an Earth orbit rendezvous, a lunar orbit rendezvous, or with a direct ascent. The two teams were composed of:

- Northrop Grumman associated with Boeing as subcontractor for the Spiral One, Alenia Spazio, ARES Corporation, Draper Laboratory and United Space Alliance

- Lockheed Martin associated with EADS SPACE Transportation, United Space Alliance, Aerojet, Honeywell, Orbital Sciences, Hamilton Sundstrand, and Wyle Laboratories (awarded the contract August 31, 2006).

Each contractor-led team included subcontractors that provided the lunar expedition astronauts with equipment, life support, rocket engines, and onboard navigation systems. The planned orbital or suborbital fly-offs under FAST would have seen the competition of a CEV built by each team, or of a technology demonstrator incorporating CEV technologies. Under FAST, NASA would have chosen the winner to build the final CEV after actual demonstration of this hardware. Fly-offs are often used by the U.S. Air Force to select military aircraft; NASA has never used this approach in awarding contracts. However, as Administrator Griffin had indicated he would abandon the FAST approach, NASA pursued the more traditional approach of selecting a vehicle based on the contractors' proposals.

On August 31, 2006, NASA announced that the contract to design and develop the Orion was awarded to Lockheed Martin Corp. According to Bloomberg News, five analysts it surveyed prior to the award announcement tipped the Northrop team to win. Marco Caceres, a space industry analyst with Teal Group, had projected that Lockheed would lose, partly because of Lockheed Martin's earlier failure on the $912 million X-33 shuttle replacement program; after the contract award he suggested that Lockheed Martin's work on the X-33 gave it more recent research and development experience in propulsion and materials, which may have helped it win the contract. According to an Aerospace Daily & Defense Report summary of a NASA document explaining the rationale for the contract award, the Lockheed Martin proposal won on the basis of a superior technical approach, lower and more realistic cost estimates, and exceptional performance on Phase I of the CEV program.

Lockheed Martin plans to manufacture the manned spacecraft at facilities in Texas, Louisiana, and Florida. The program manager is Cleon Lacefield.

Proposals

Original designs

Lockheed's proposed craft was a small shuttle-shaped lifting-body design, big enough for six astronauts and their equipment. Its airplane-shaped design made it easier to navigate during high-speed returns to Earth than the capsule-shaped vehicles of the past, according to Lockheed Martin. According to the French daily *Le Figaro* and the publication *Aviation Week and Space Technology*, EADS SPACE Transportation would be in charge of the design and construction of the associated *Mission Module* (MM). The head of the Lockheed team was Cleon Lacefield. The Lockheed Martin design was quite similar to their OSP design, but has some slight changes, mainly the presence of the mission module.

The Lockheed Martin CEV design included several modules in the LEO (low earth orbit) and manned lunar versions of the spacecraft, plus an abort system. The abort system was an escape tower like that used in the Mercury, Apollo, Soyuz, and Shenzhou craft (Gemini, along with the Space Shuttles *Enterprise* and *Columbia* [until STS-4] used ejection seats). It would be capable of an abort during any part of the ascent phase of the mission. The crew would sit in the Rescue Module (RM) during launch. According to the publication *Aviation Week and Space Technology*, the RM would have an outer heat shield of reinforced carbon-carbon and a redundant layer of felt reusable surface insulation underneath in case of RCC failure. The RM comprised the top half of the Crew Module (CM), which comprised the RM and the rest of the lifting-body structure. The CM included living space for four crew members. In an emergency the RM separates from the rest of the CM. The RM would seat up to six crew members, with two to a row, and the CM has living space and provisions for four astronauts for 5–7 days. Extra-Vehicular Activities (EVAs) could be conducted from the CM, which could land on land or water and could be reused 5–10 times.

The mission module would be added to the bottom of the CEV for a lunar mission, and would be able to hold extra consumables and provide extra space for a mission of lunar duration. It would also provide extra power and communications capabilities, and include a docking port for the Lunar Surface Access Module (LSAM). On the bottom of the lunar CEV stack would be the Propulsion or Trans-Earth Injection Module (TEIM) which would provide for return to the Earth from the Moon. It would probably incorporate (according to Aviation Week) 2 Pratt & Whitney RL-10 engines. Together, the RM/CM, MM, and TEIM made up the Lockheed Martin lunar stack. The original idea was to launch the CM, MM, and TEIM on three separate Evolved Expendable Launch Vehicles (EELVs), with one component in each launch. This vehicle would need additional modules to reach lunar orbit and to land on the Moon. However, this plan was to be altered according to the CFI (Call for Improvements), described below.

Unlike the well-publicized Lockheed Martin CEV design, virtually no information was publicly available on the Boeing/Northrop Grumman CEV design. However, it is instructive to note that most publicly released Boeing designs for the canceled Orbital Space Plane (OSP) resembled the Apollo capsule. Given that Lockheed Martin's CEV design was in many ways a derivative of their OSP, it was possible that the Boeing CEV is a capsule rather than a lifting body or plane design.

Changes to original bids

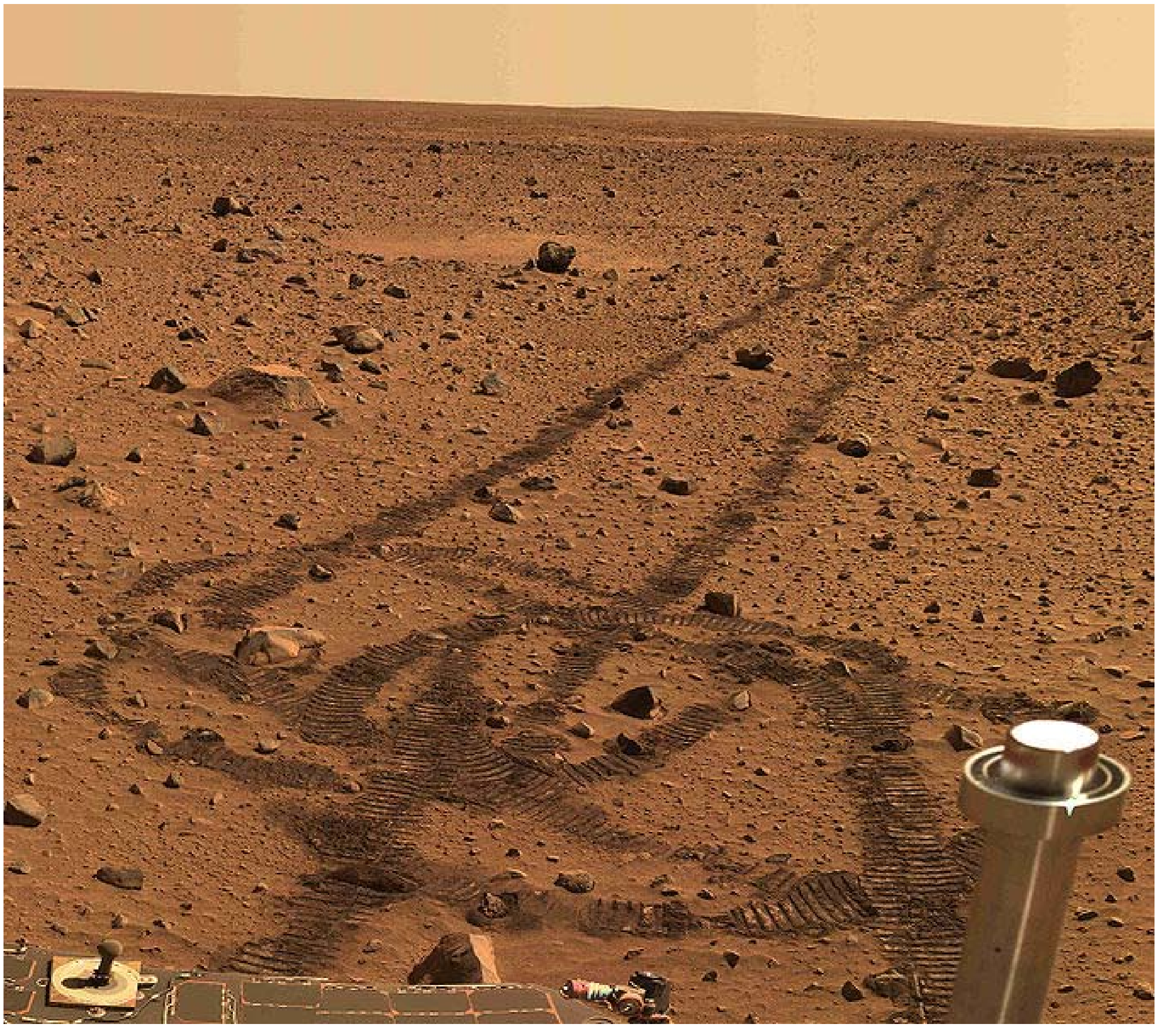
NASA Constellation officials announcing the selected Orion contractor Aug. 31, 2006, at NASA Headquarters

Sean O'Keefe's strategy would have seen the CEV development in two distinct phases. Phase I would have involved the design of the CEV and a demonstration by the potential contractors that they could safely and affordably develop the vehicle. Phase I would have run from bid submissions in 2005 to FAST and downselect to one contractor. Phase II would have begun after FAST and involved final design and construction of the CEV. However, this schedule was unacceptably slow to Mike Griffin, and the plan was changed such that NASA will issue a "Call for Improvements" (CFI) after the release of the ESAS for Lockheed Martin and Boeing to submit Phase II proposals. NASA chose Lockheed Martin's consortium as the winning consortium on August 31, 2006. Therefore, the CEV bids submitted and described above are not necessarily representative of the final CEV design, as they will be changed in accordance with the CFI and any findings of the ESAS that are put into the CFI.

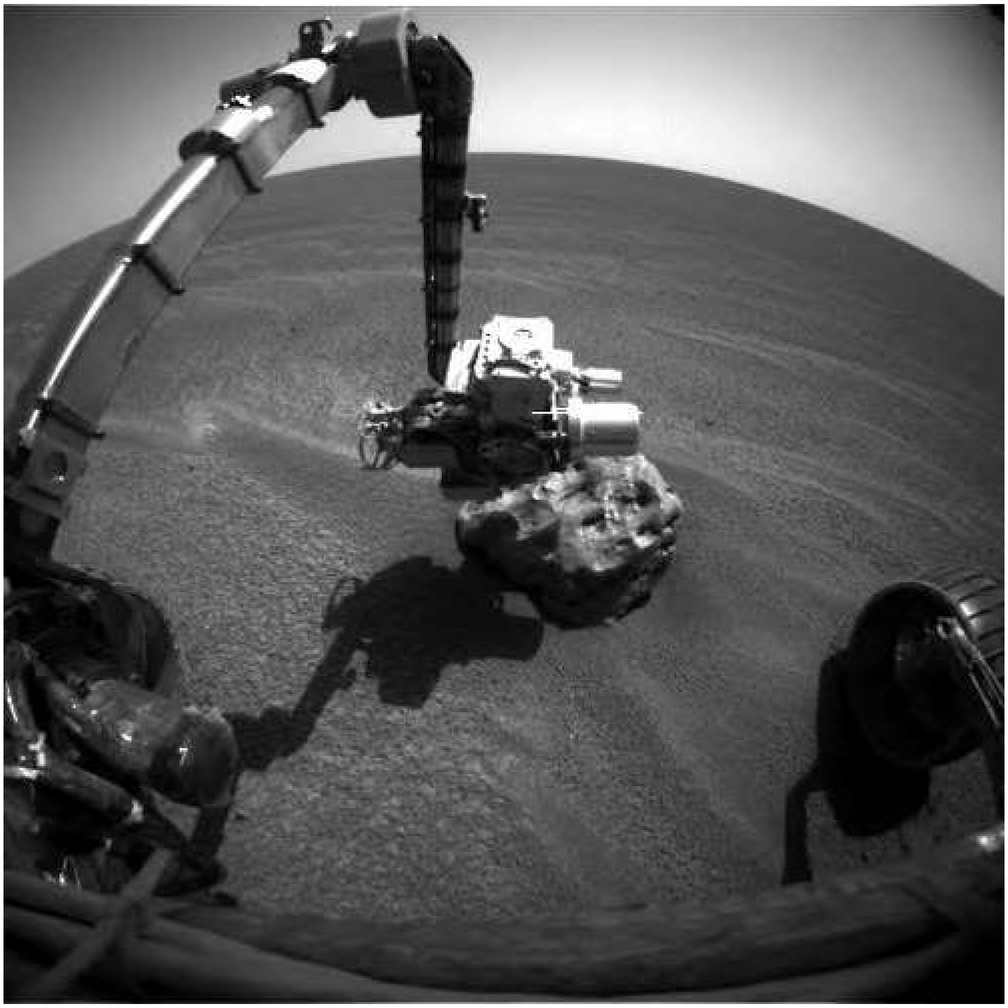
Chapter- 3

Exploration of Mars

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 2011, there is one functioning piece of equipment on the surface of Mars beaming signals back to Earth: 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 Exploration Joint 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:

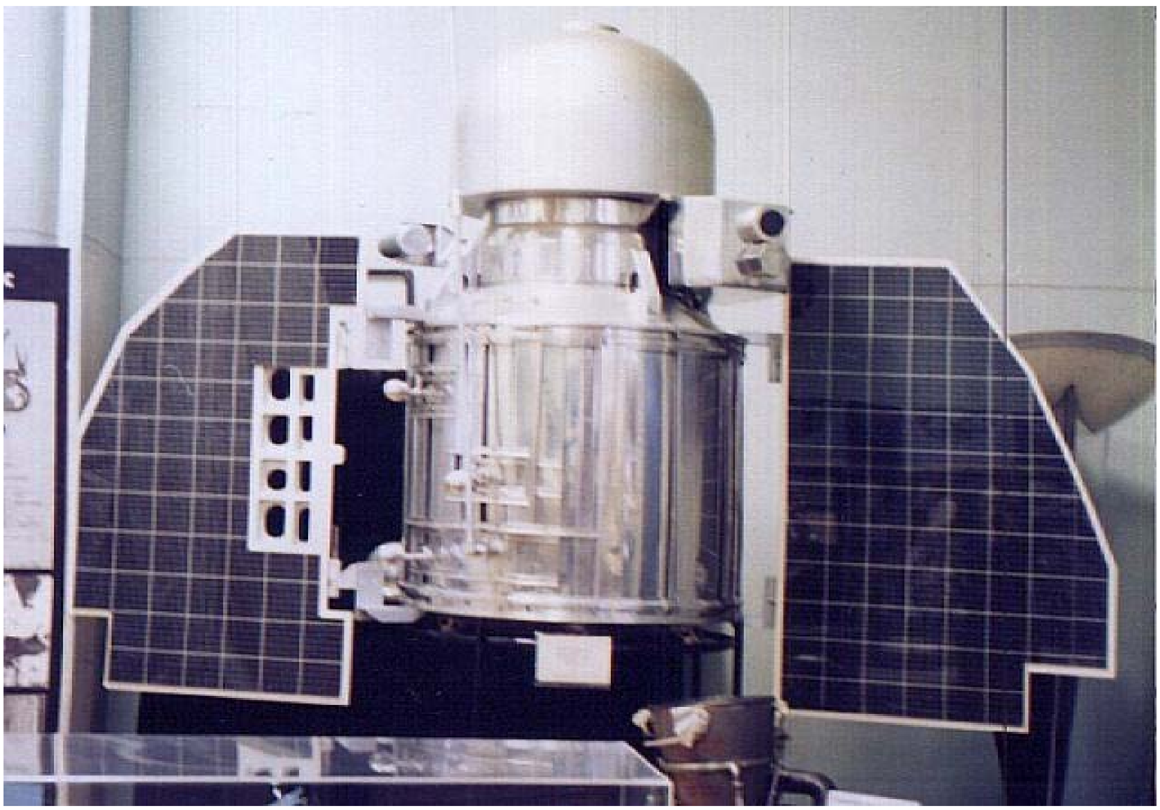
- 18 November 1996 (MJD 50405)
- 22 January 1999 (MJD 51200)
- 19 April 2001 (MJD 52018)
- 5 June 2003 (MJD 52795)
- 10 August 2005 (MJD 53592)
- 21 September 2007 (MJD 54364)
- 15 October 2009 (MJD 55119)
- 7 November 2011 (MJD 55872)
- 2 January 2014 (MJD 56659)

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



Mars 1M spacecraft

The Mars 1M program (sometimes dubbed Marsnik in Western media) was the first Soviet unmanned spacecraft interplanetary exploration program, which consisted of two flyby probes launched towards Mars in October 1960, Mars 1960A and Mars 1960B (also known as *Korabl 4* and *Korabl 5* respectively). After launch, the third stage pumps on both 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.

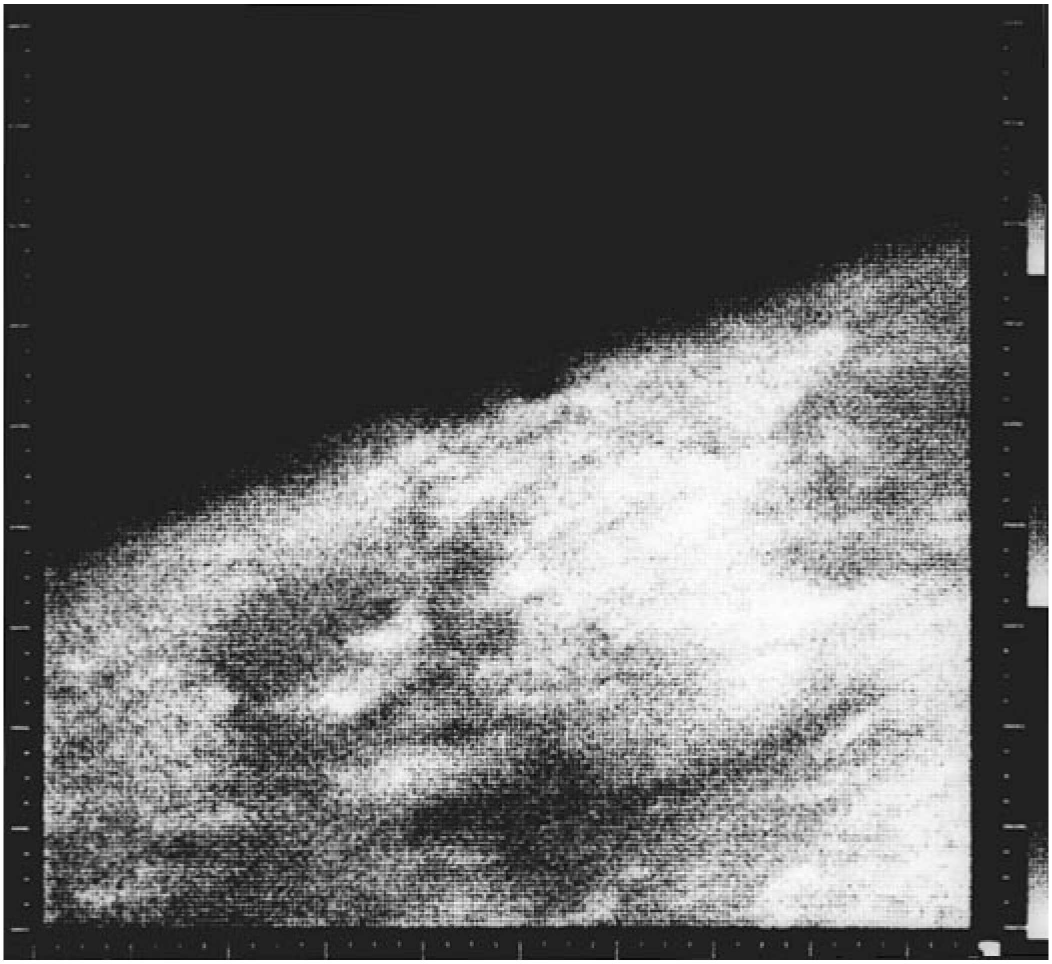
Mars 1962A was a Mars fly-by mission, launched on October 24, 1962 and Mars 1962B a lander mission, launched in late December of the same year both failed from either breaking up as they were going into Earth orbit or having the upper stage explode in orbit during the burn to put the spacecraft into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

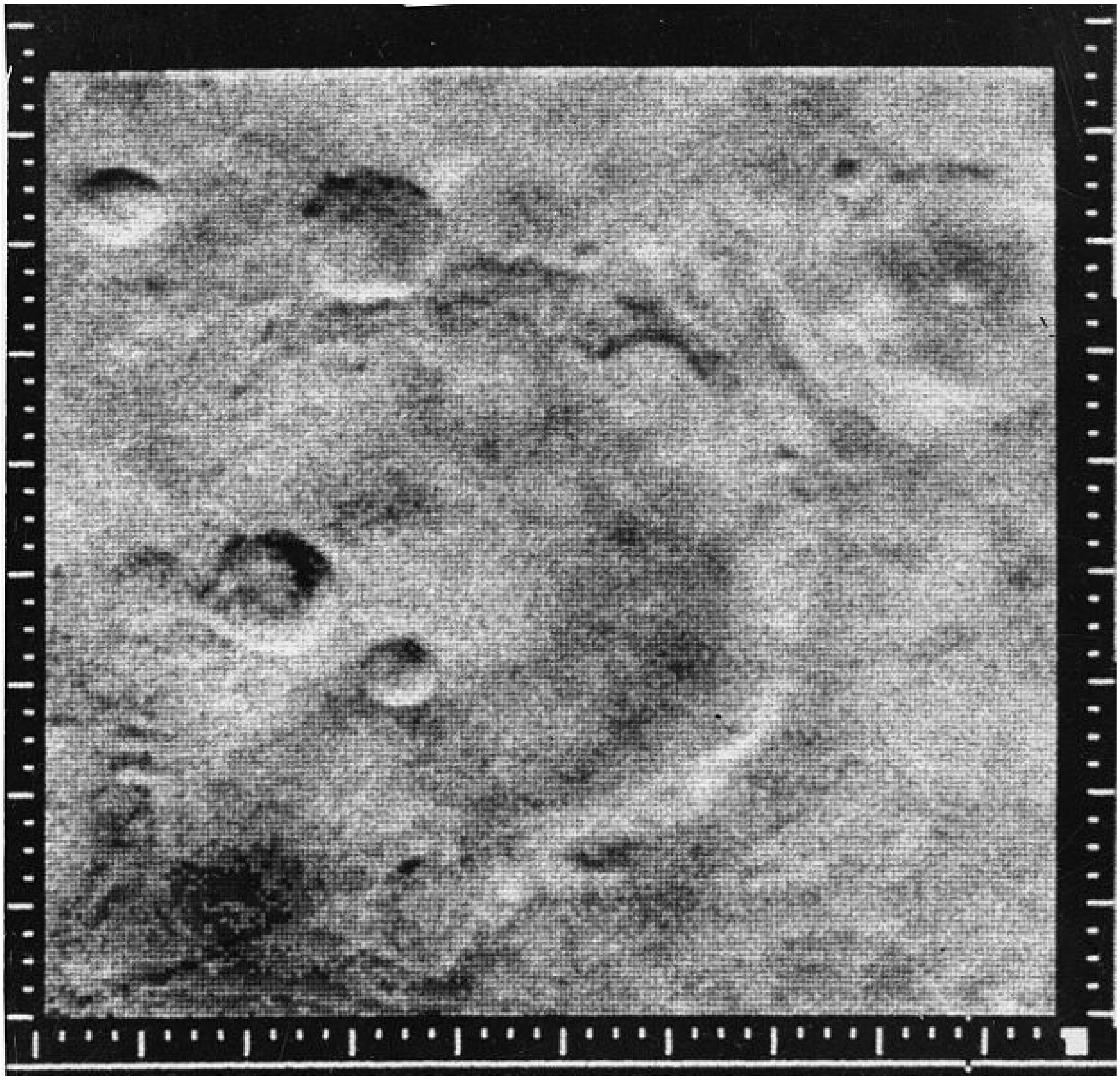
In 1964, both Soviet probe launches, of Zond 1964A on June 4, and Zond 2 on November 30, (part of the Zond program), resulted in failures. Zond 1964A had a failure at launch, while communication was lost with Zond 2 en route to Mars after a mid-course maneuver, in early May 1965.

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.

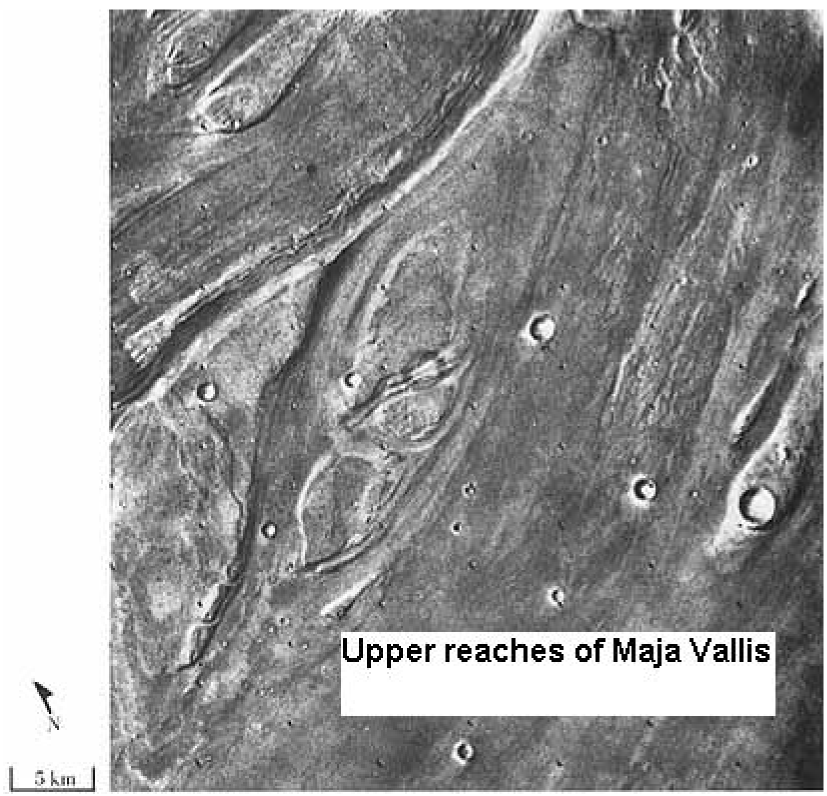
Mariner 4 flew past Mars on July 14, 1965, providing the first close-up photographs of another planet. The pictures, gradually played back to Earth from a small tape recorder on the probe, showed lunar-type impact craters.

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.

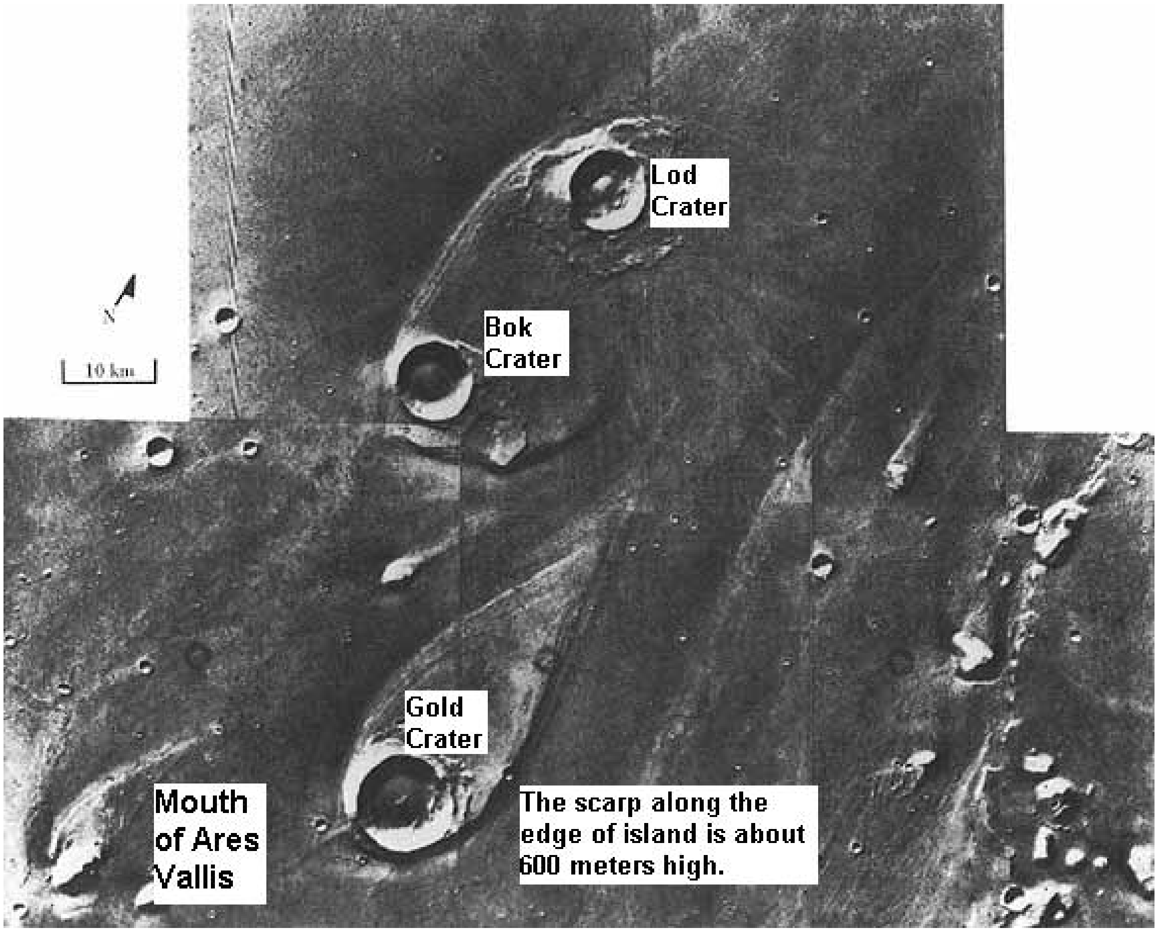
Viking program

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.

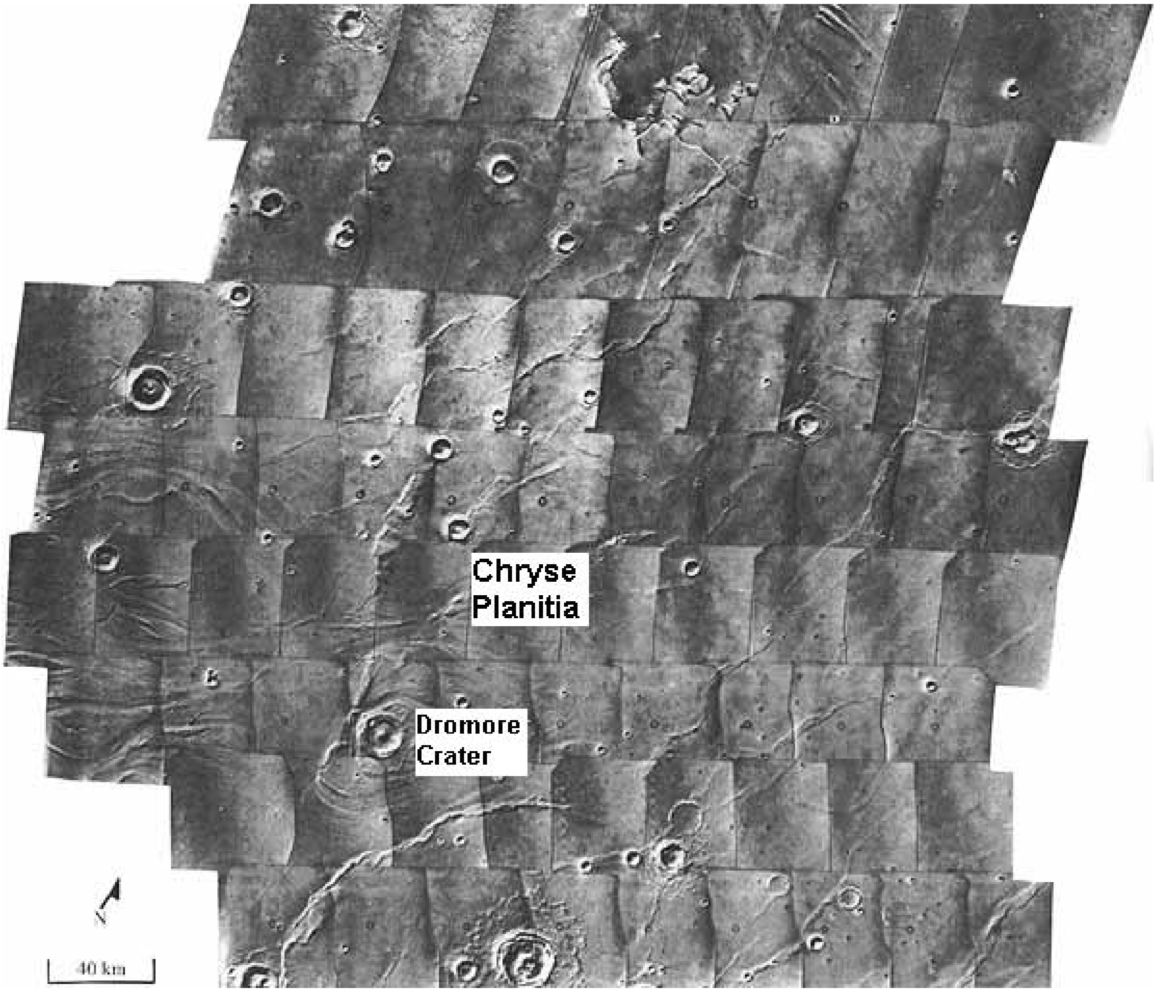
The images below, some of the best from the Viking Orbiters, are mosaics of many small, high resolution images.



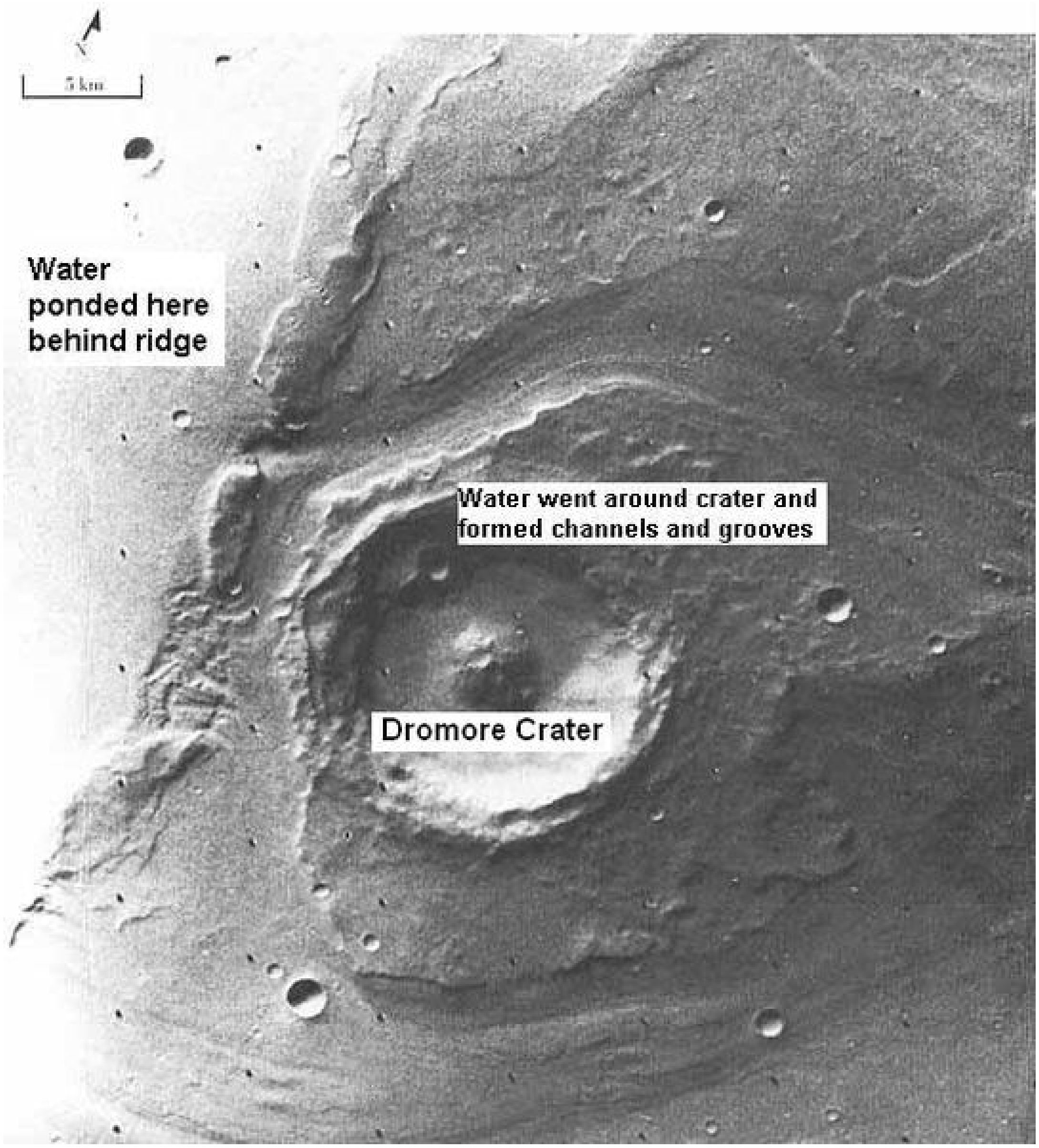
Streamlined Islands seen by Viking showed that large floods occurred on Mars. Image is located in Lunae Palus quadrangle.



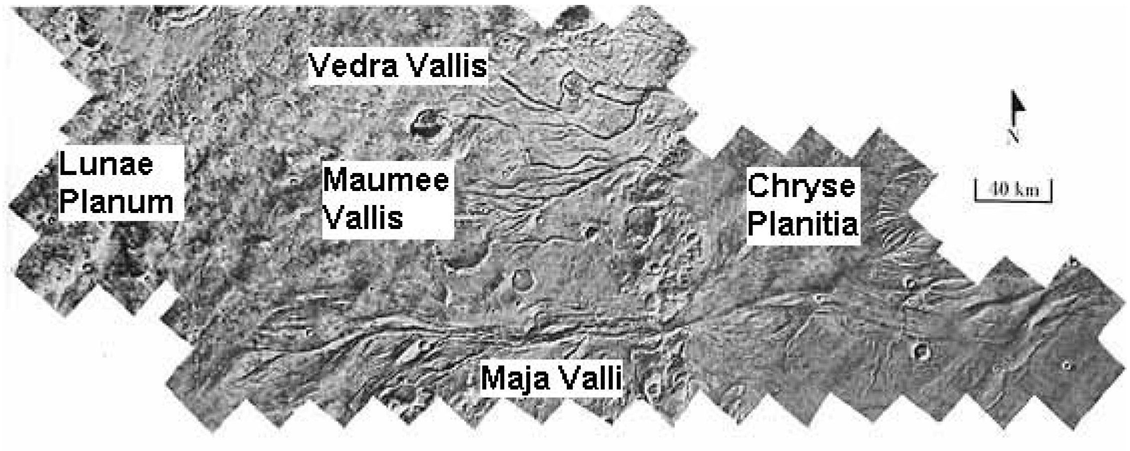
Tear-drop shaped islands caused by flood waters from Maja Valles, as seen by Viking Orbiter. Image is located in Oxia Palus quadrangle. The islands are formed in the ejecta of Lod Crater, Bok Crater, and Gold Crater.



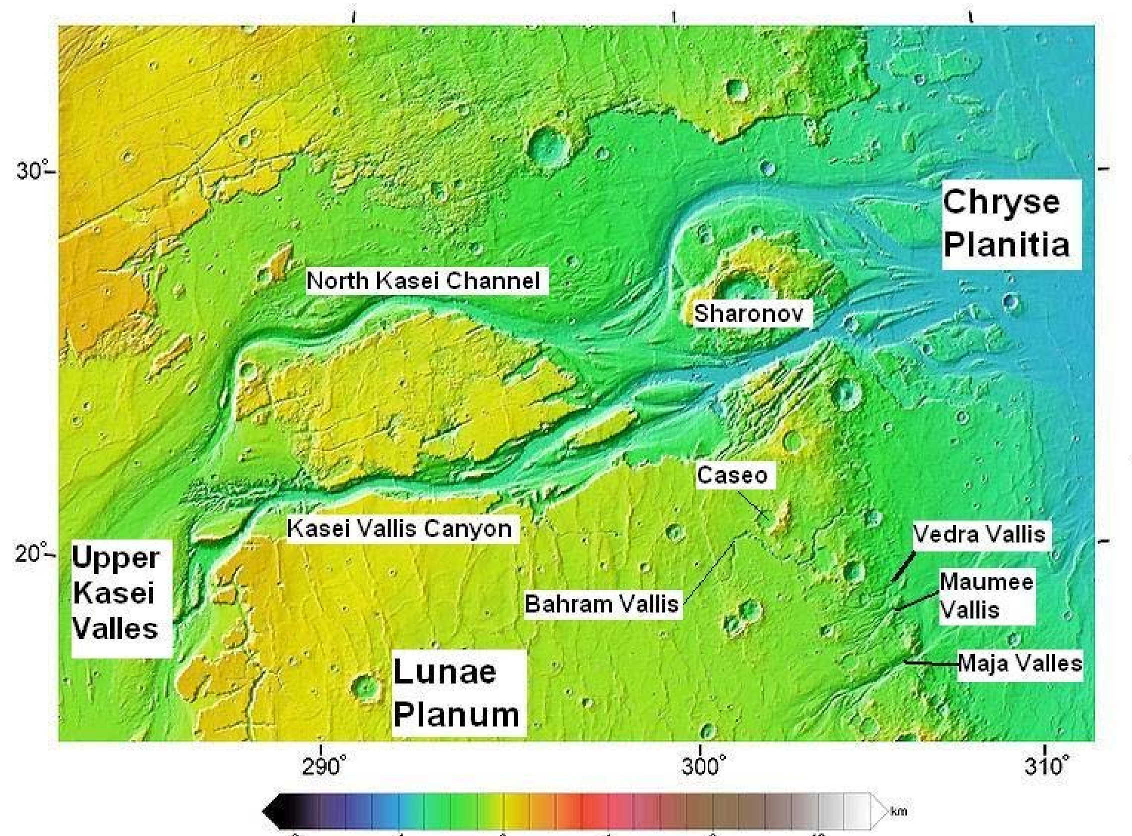
Scour Patterns, located in Lunae Palus quadrangle, were produced by flowing water from Maja Vallis, which lies just to the left of this mosaic. Detail of flow around Dromore Crater is shown on the next image.



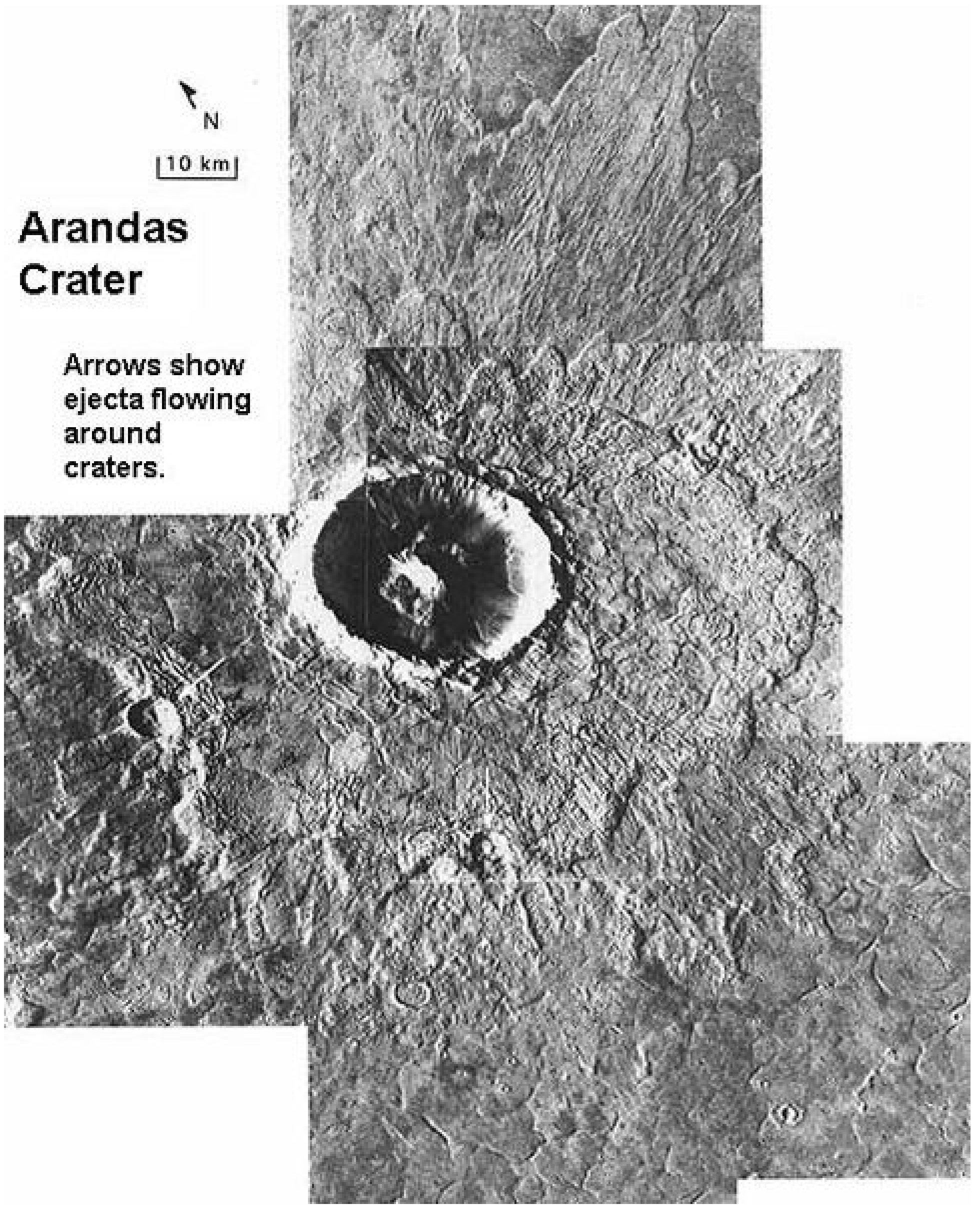
Great amounts of water were required to carry out the erosion shown in this Viking image. Image is located in Lunae Palus quadrangle. The erosion shaped the ejecta around Dromore Crater.



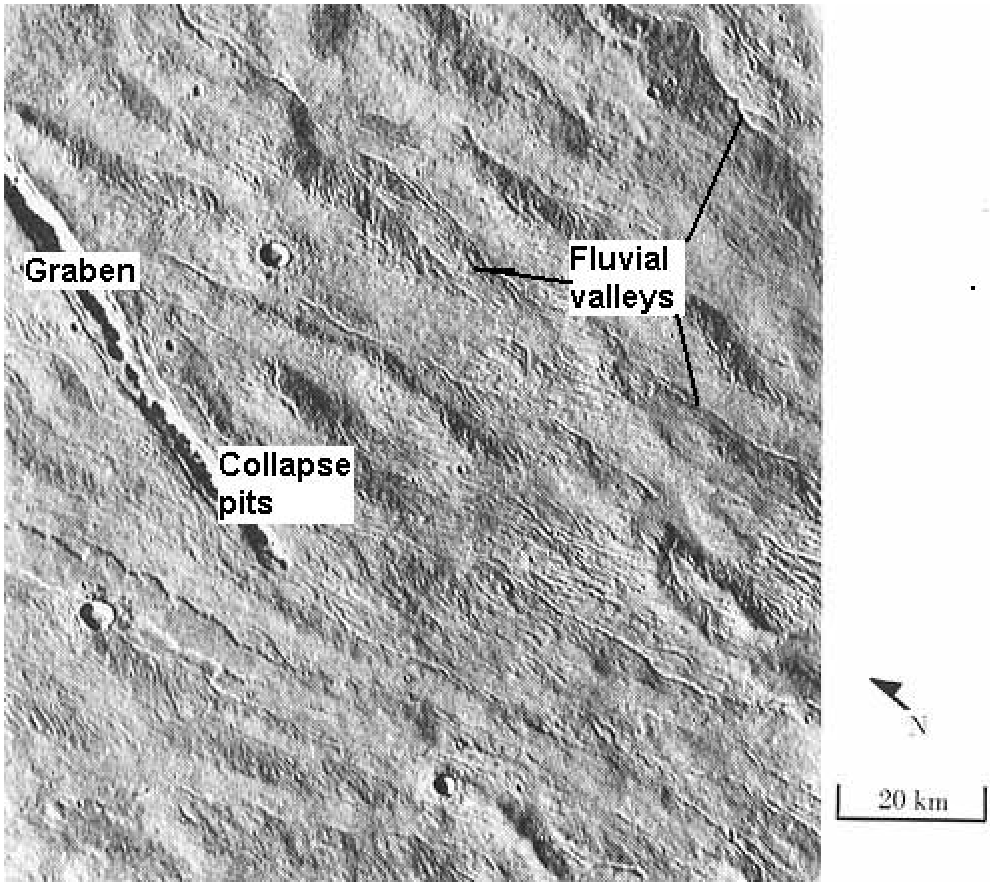
Waters from Vedra Vallis, Maumee Vallis, and Maja Vallis went from Lunae Planum on the left, to Chryse Planitia on the right. Image is located in Lunae Palus quadrangle and was taken by Viking Orbiter.



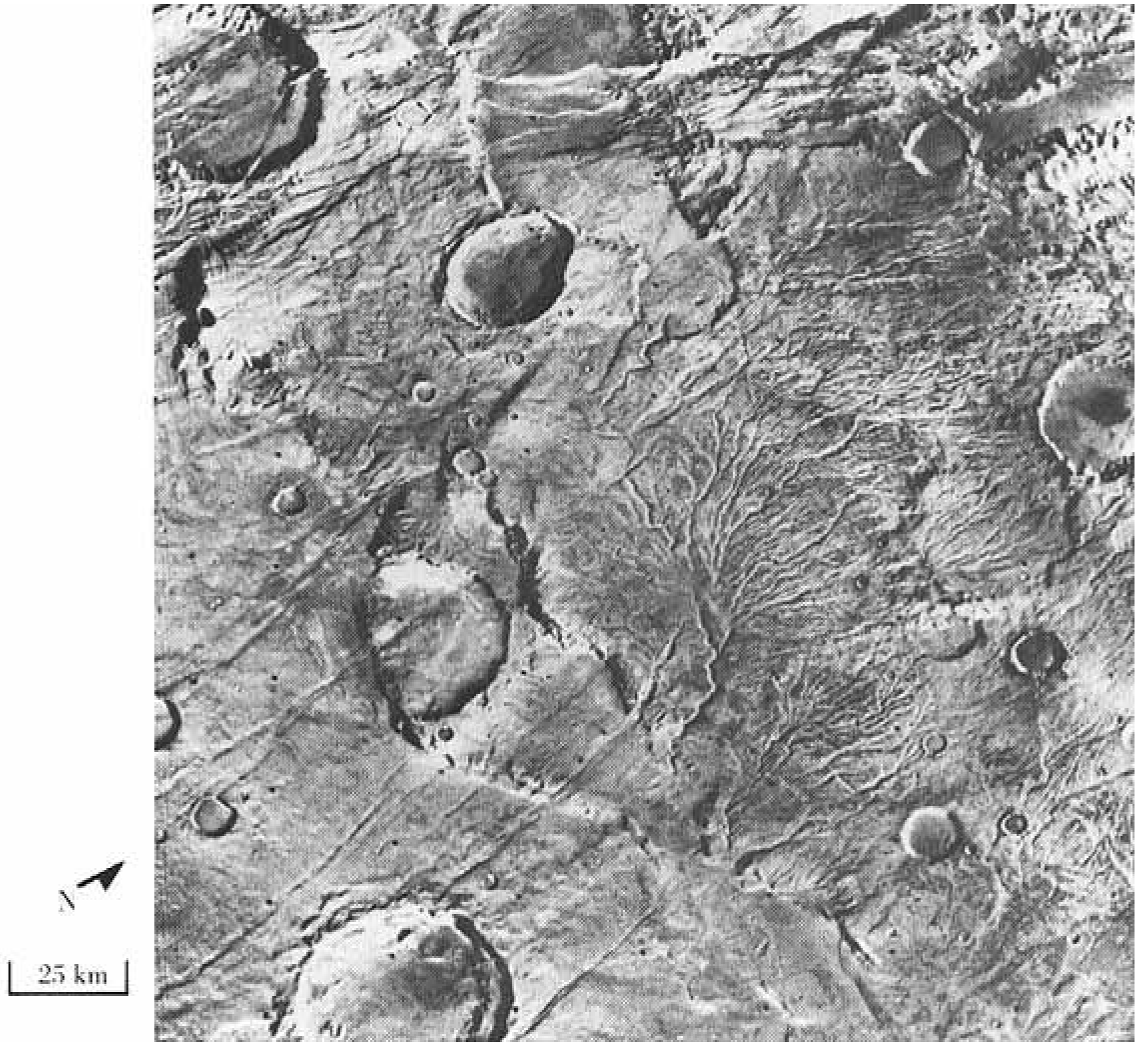
Area around Northern Kasei Valles, showing relationships among Kasei Valles, Bahram Vallis, Vedra Vallis, Maumee Vallis, and Maja Valles. Map location is in Lunae Palus quadrangle and includes parts of Lunae Planum and Chryse Planitia.



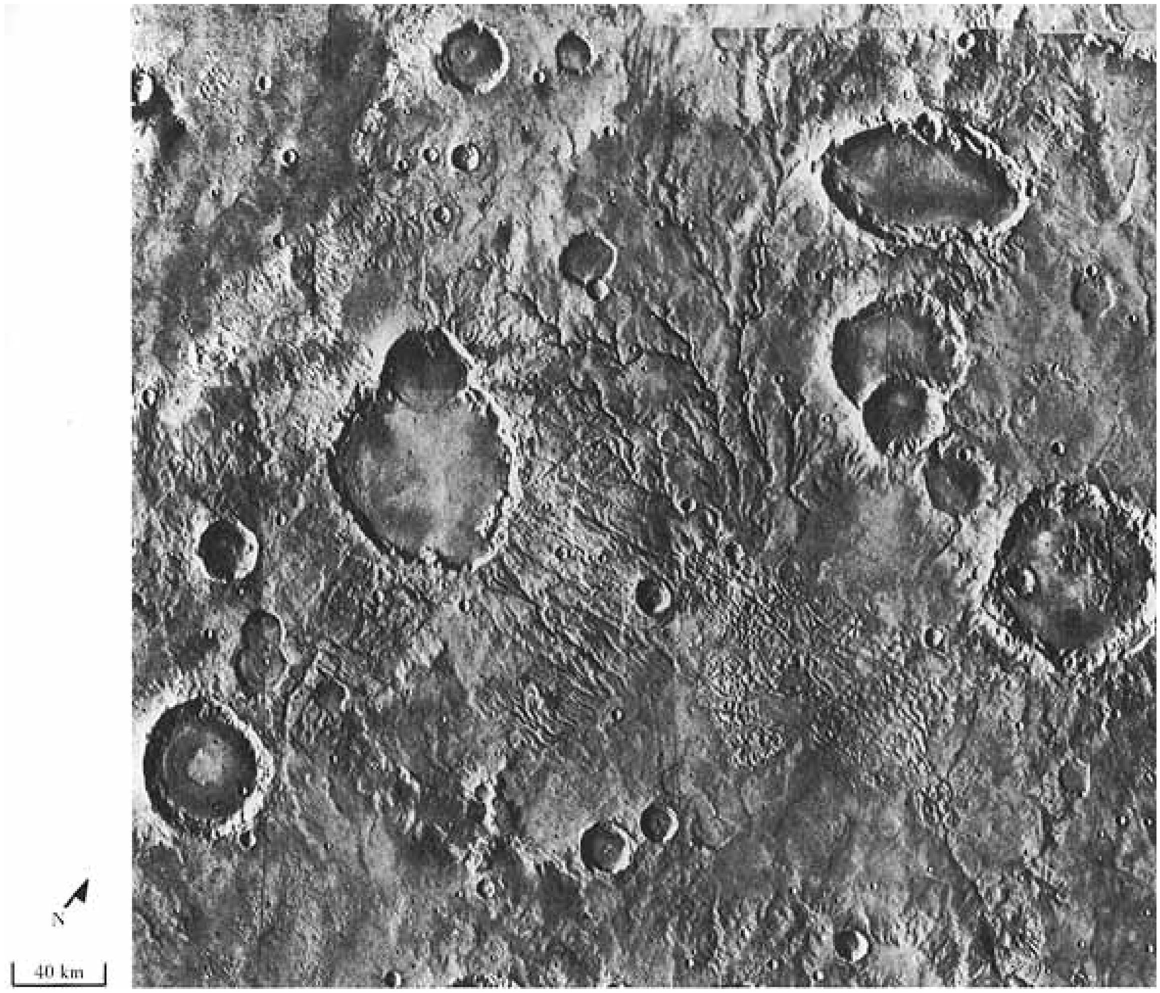
The ejecta from Arandas Crater acts like mud. It moves around small craters (indicated by arrows), instead of just falling down on them. Craters like this suggest that large amounts of frozen water were melted when the impact crater was produced. Image is located in Mare Acidalium quadrangle and was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



This view of the flank of Alba Patera shows several channels/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.

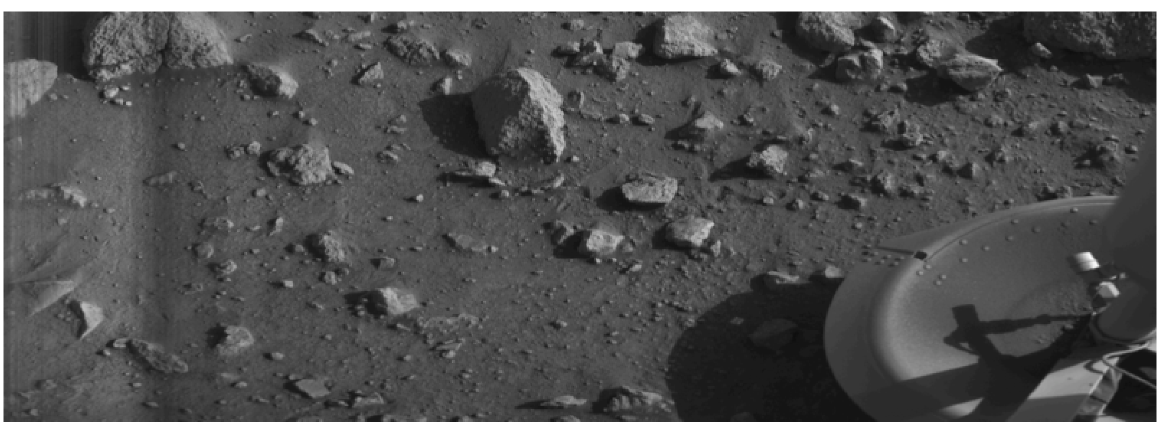


The branched channels seen by Viking from orbit strongly suggested that it rained on Mars in the past. Image is located in Margaritifer Sinus quadrangle.

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.

Chapter- 4

ExoMars (Probably Launch in 2011 for more Mars Exploration)

ExoMars

Operator	ESA, NASA
Mission type	Orbiter, lander and 2 rovers
Orbital insertion date	2017 and 2019
Launch date	2016 and 2018 from Florida, USA
Launch vehicle	Two Atlas V rockets.
Mission duration	Few days for the static lander; 6 months for the ExoMars rover, one year for the MAX-C rover.
Homepage	ExoMars programme
Mass	TGM: 3,130 kg; Lander: 600 kg; ExoMars rover: 270 kg; MAX-C rover: 65 kg.
Power	Solar power

ExoMars (**Exo**biology on **Mars**) is a European-led robotic mission to Mars currently under development by the European Space Agency (ESA) and NASA. Originally conceived as a rover with a static ground station, ExoMars was planned to launch in 2011 aboard a Soyuz Fregat rocket. Within the framework of the new Mars Joint Exploration Initiative signed by NASA and ESA in July 2009, the drastically delayed ExoMars mission was combined with other projects to a multi-spacecraft programme divided over two Atlas V-launches: the Mars Trace Gas Orbiter (TGM) was merged into the project, piggybacking a static meteorological lander being slated for launch in 2016. In 2018 the original robotic ESA-rover will be launched, possibly together with a smaller NASA rover called Mars Astrobiology Explorer-Cacher (MAX-C).

Background and mission history

An outdated ExoMars rover model at the ILA 2006 in Berlin

Another outdated representation of the rover from the Paris Air Show 2007

Since its beginnings in the early 2000s, ExoMars was subject to massive political and financial strife. Originally, the ExoMars concept consisted of one single, large robotic rover being part of ESA's Aurora programme as a *Flagship mission* and was approved by Europe's space ministers in December 2005. Initially planned to launch in 2011, Italy, a leading nation on the ExoMars mission, decided to limit its financial contribution, causing the first of three delays.

In 2007 Canadian-based technology firm MacDonald, Dettwiler and Associates Ltd. (MDA) announced that is has won a one-million-euro contract with EADS Astrium of Britain to design and build a prototype Mars rover chassis for the European Space Agency, which will be used in the upcoming ExoMars mission. Astrium is also contracted to design the final rover itself.

In July 2009 NASA and ESA agreed upon a new Mars Joint Exploration Initiative, significantly altering the technical and financial setting of the ExoMars mission. On June 19, when the rover was still planned to piggyback on the Mars Trace Gas Orbiter, it was reported, that a prospective agreement would require that ExoMars lose enough weight to fit aboard the Atlas vehicle with NASA's orbiter.

In August 2009 it was announced that the Russian Space Agency Roscosmos and ESA had signed a collaboration agreement that includes cooperation on two Mars exploration projects: Russia's Phobos-Grunt project and ESA's ExoMars. Specifically, ESA secured a

Russian Proton rocket as a backup launcher for the ExoMars rover, which should also include Russian-made parts.

In October 2009 it was reported that under the agreed Mars Joint Exploration Initiative, the mission will be split into two parts: a lander/orbiter mission in 2016 and a rover mission in 2018, each with a significant NASA role, including the use of two Atlas V rockets. This initiative would apparently reconcile technological and science goals with available budgets.

On December 17, 2009, the ESA governments gave their final approval to a two-part Mars exploration programme to be conducted with NASA, confirming their commitment to spend €850 million ($1.23 billion) on missions in 2016 and 2018. Another €150 million needed for operating the mission will be solicited during a meeting of ESA government ministers in late 2011 or early 2012. Unlike some ESA programmes, the ExoMars financing will not include a 20 % margin for cost overruns, however.

Mission objectives

The ExoMars mission's scientific objectives, in order of priority, are:

- to search for possible biosignatures of Martian life, past or present.
- to characterise the water and geochemical distribution as a function of depth in the shallow subsurface.
- to study the surface environment and identify hazards to future manned missions to Mars.
- to investigate the planet's subsurface and deep interior to better understand the evolution and habitability of Mars.
- achieve incremental steps ultimately culminating in a sample return flight.

The technological objectives to develop are:

- landing of large payloads on Mars.
- to exploit solar electric power on the surface of Mars.
- to access the subsurface with a drill able to collect samples down to a depth of two metres (just below the degradating reach of UV light, oxidants and ionizing radiation.)
- to develop surface exploration capability using a rover.

Mission architecture

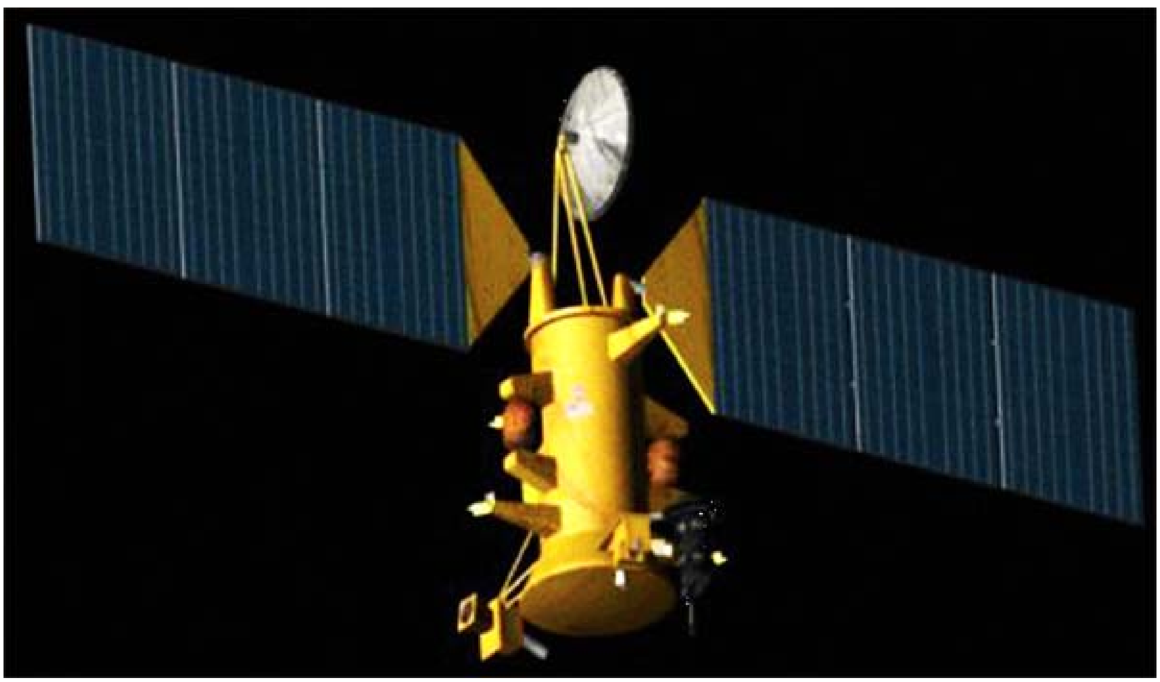
According to current plans, the ExoMars mission will comprise three, possibly four, spacecraft elements sent in two launches, both from Florida:

Contributing agency	First launch in 2016	Second launch in 2018

NASA	Launch vehicle: Atlas V 411	Launch vehicle: Atlas V 551
	One unspecified TGM-payload	Landing system: Sky-crane
		65 kg Mars Astrobiology Explorer-Cacher (Max-C)-rover
esa	Trace Gas Mission (TGM) orbiter	270 kg ExoMars rover
	600 kg static meteorological lander	
	Entry, descent and landing system (EDL)	

2016 launch

Mars Trace Gas Mission orbiter



The Mars Trace Gas Orbiter.

The Mars Trace Gas Mission (TGM) orbiter, to be launched on January 2016, will deliver the ExoMars static lander (a meteorological station) and then proceed to map the sources of methane on Mars and other gases, and in doing so, help select the landing site for the ExoMars rover to be launched on 2018. The presence of methane in Mars' atmosphere is intriguing because its likely origin is either present-day life or geological activity. Upon the arrival of the rover(s) in 2018/2019, the orbiter would be transferred into a suitable lower orbit where it would be able to perform analytical science activities as well as operate as a data-relay satellite. Its operation may be extended to serve future missions well into the 2020s.

Static lander

Originally, this static lander was planned to carry a group of eleven instruments collectively called the "Humboldt payload" that would be dedicated to investigate the geophysics of the deep interior, but a payload confirmation review in the first quarter of 2009 resulted in a severe descope of the lander instruments, and the Humboldt geophysical suite of lander instruments was cancelled entirely. Although the recent partnership with NASA and the decision to launch all mission elements with two rockets has generated new payload reviews, it was decided to first demonstrate ESA's new descent and landing system technology on the lander, so its payload will be very limited.

The Entry, Descent and Landing Demonstrator Module (EDM) will provide Europe with the technology for landing on the surface of Mars with a controlled landing orientation and touchdown velocity. After entering the Martian atmosphere, the module will deploy a parachute and will complete its landing by using a closed-loop Guidance, Navigation and Control system based on a Radar Doppler Altimeter sensor and on-board Inertial Measurement Units. The latter will guide a liquid propulsion system which will produce a semi-soft touchdown on the surface of Mars by the actuation of clusters of thrusters to be operated in pulsed on-off mode.

The EDM lander is expected to survive on the surface of Mars for a short time (about 8 sols) by using the excess energy capacity of its batteries. Its proposed landing site is the Meridiani Planum because it is almost flat and without too many rocks, ideal for its airbag landing system.

2018 launch

Current plans call for the use of NASA's sky crane entry, descent and landing (EDL) system to deliver both rovers together on the surface of Mars.

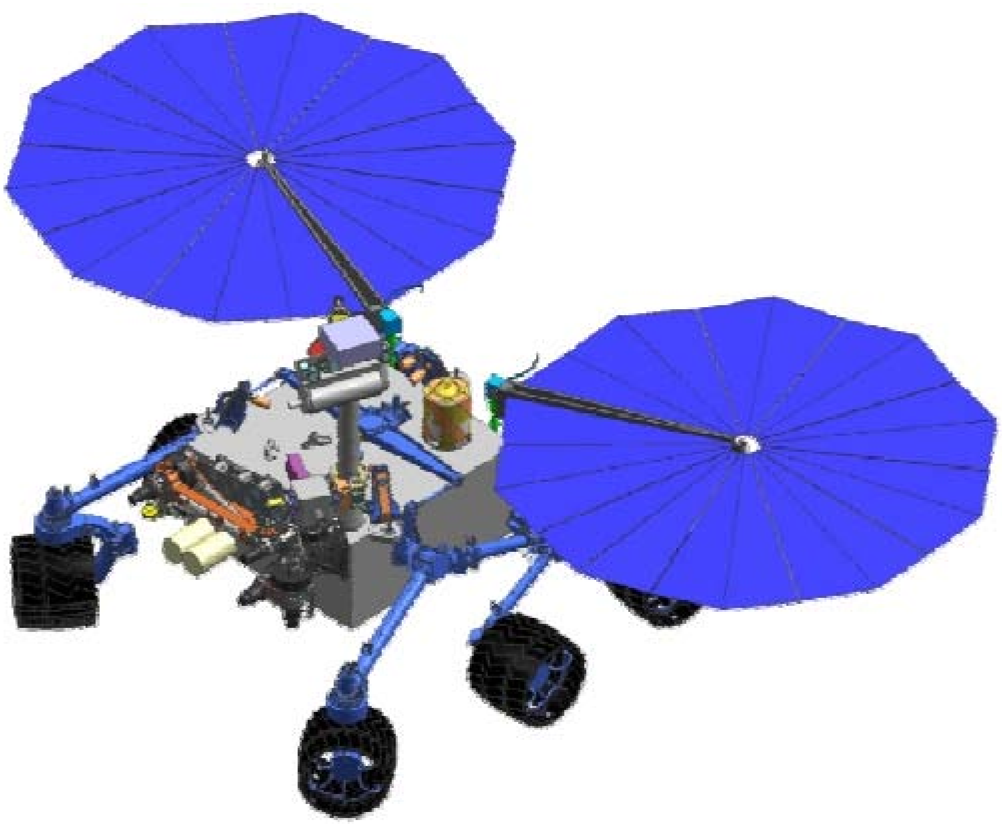
If there will be two rovers delivered to the same location on Mars, Their science objectives and instruments will be complementary in order to minimise duplication. Advantages of operating two rovers in the same area are: rover to rover imaging, cross analysis of similar geological targets, may include a low-frequency ground-penetrating radar on MAX-C and listen with WISDOM on ExoMars to construct rover to rover subsurface transects, and the MAX-C could receive and cache some of the most valuable subsurface samples collected by ExoMars.

ExoMars rover

The ExoMars rover is a highly autonomous six-wheeled terrain vehicle and will weigh 270 kg, ca. 100 kg more than NASA's Mars Exploration Rovers *Spirit* and *Opportunity*. Temporary plans considered a downsized version with a reduced weight of 207 kg. Instrumentation will consist of the 10 kg 'Pasteur Payload' containing, among other instruments, a 2 meter sub-surface drill.

The carrier module will deliver the descent module to Mars from a hyperbolic approach trajectory after which the Sky-crane landing system will ensure a soft landing with high accuracy. Once safely landed on the Martian surface the solar powered rover would begin a 180-sol (6 months) mission. To counter the difficulty of remote control due to communication lag, ExoMars will have autonomous software for visual terrain navigation using compressed stereo images from mast mounted panoramic and infrared cameras and independent maintenance. For this purpose it creates digital maps from navigation stereo pair cameras and autonomously finds the adequate trajectory. Close-up collision avoidance cameras are used to ensure safety enabling the vehicle to navigate and safely travel approximately 100 meters per day. After the lander has been released and landed on the surface of Mars, the Mars Trace Gas Orbiter will operate as the rover's data-relay satellite.

MAX-C rover



Schematic depiction of the proposed Mars Astrobiology Explorer-Cacher (MAX-C)-Rover

The current proposal is that ExoMars may be joined by a slightly smaller NASA rover; this additional rover may be the Mars Astrobiology Explorer-Cacher (MAX-C). The fact that for the first time two rovers will be active at the same location is expected to lead to synergies, such as bistatic radar surveys between the two rovers. The MAX-C rover would collect, analyse, and cache the most valuable samples in a manner suitable for return to Earth by a future mission.

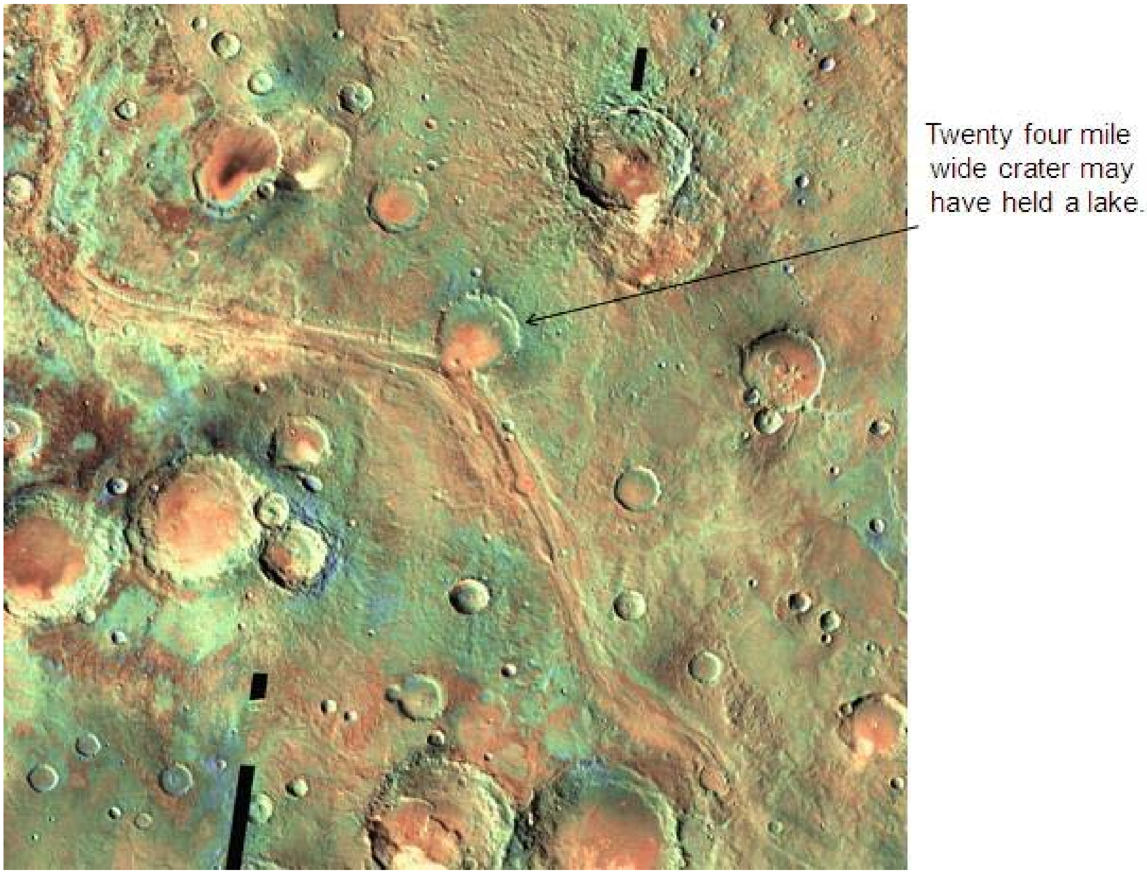
Launch vehicle

Under the agreed collaboration, NASA will provide two Atlas V rockets, as it was decided to divide the weight of the ExoMars system in two launches.

ESA has already worked out a framework agreement with the Russian Space Agency that would allow it to cooperate on ExoMars, including provision of backup launch services and a payload contribution, along with mission support. The backup launcher is the Proton rocket, which is a four-stage rocket that was previously used to launch the Salyut 6, Salyut 7, Mir and some International Space Station components.

Landing system and proposed landing sites

If the collaboration with NASA takes place as proposed, it would be possible to implement NASA's new skycrane entry and descent system, as used on the Mars Science Laboratory rover.



Mawrth Vallis with its potential clues on the history of water on Mars is a landing site-candidate.

As of November 2007, the potential landing sites are:

- Mawrth Vallis
- Nili Fossae
- Meridiani Planum
- Holden Crater
- Gale Crater

However, the 2009 discovery of methane sources on the planet makes them a high value target for exploration. The presence of methane is intriguing because its likely origin is either present-day life or geological activity; confirmation of either would be a major discovery. Methane occurres in extended plumes, and the profiles imply that the methane was released from discrete regions. The profiles suggest that there may be two local source regions, the first centered near 30° N, 260° W and the second near 0°, 310° W. To determine the optimal landing site and secure telecommunications, it was decided to include the Mars Trace Gas Mission orbiter in the 2016 launch in order to map beforehand what appears to be seasonal methane production. The rover could then investigate the methane sources identified by the orbiter.

Instrumentation of the ExoMars rover

The present environment on Mars is exceedingly hostile for the widespread proliferation of surface life: it is too cold and dry and receives large doses of solar UV radiation as well as cosmic radiation. Notwithstanding these hazards, basic microorganisms may still flourish in protected places underground or within rock cracks and inclusions. The science package in the ExoMars rover will hold a variety of instruments to study the environment for past or present habitability and possible biosignatures on Mars. The first instrument proposal (2004) is as follows:

Imaging system

The **Panoramic Camera System (PanCam)** has been designed to perform digital terrain mapping for the rover and to search for morphological signatures of past biological activity preserved on the texture of surface rocks. The PanCam assembly includes two wide angle cameras for multi-spectral stereoscopic panoramic imaging, and a high resolution camera for high-resolution colour imaging. The PanCam will also support the scientific measurements of other instruments by taking high-resolution images of locations that are difficult to access, such as craters or rock walls, and by supporting the selection of the best sites to carry out exobiology studies.

Drill

The ExoMars core drill is devised to acquire soil samples down to a maximum depth of 2 metres, in a variety of soil types. The drill will acquire a core sample (1 cm in diameter x 3 cm in length), extract it and deliver it to the inlet port of the Rover Payload Module, where the sample will be distributed, processed and analyzed. The ExoMars Drill embeds the Mars Multispectral Imager for Subsurface Studies (Ma-Miss) which is a miniaturised IR spectrometer devoted to the borehole exploration. The system will complete experiment cycles and at least 2 vertical surveys down to 2 metres (with four sample acquisitions each). This means that a minimum number of 17 samples shall be acquired and delivered by the drill for subsequent analysis.

Analytical laboratory instruments

These instruments are placed internally and used to study collected samples:

- **Mars Organic Molecule Analyzer** (**MOMA**) consists of a laser desorption ion source and a GC-MS spectrometry. The laser desorption ion source is capable to evaporate organic molecules even if they are not volatile, while the GC separates the highly volatile small molecules within the gas chromatograph. The final analysis of both instruments is done with an ion trap mass spectrometer.

- **Infrared imaging spectrometer** (**MicrOmega-IR**) is an infrared imaging spectrometer that can analyse the powder material derived from crushing samples collected by the drill. Its objective is to study mineral grain assemblages in detail to try to unravel their geological origin, structure, and composition. These data will be vital for interpreting past and present geological processes and environments on Mars. Because MicrOmega-IR is an imaging instrument, it can also be used to identify grains that are particularly interesting, and assigned them as targets for Raman and MOMA-LDMS observations.

- **Mars X-Ray Diffractometer (Mars-XRD)** - Powder diffraction of X-Rays will give exact composition of the crystalline minerals. This instrument includes also an X-ray fluorescence capability that can provide useful atomic composition information.

- **Raman spectrometer (Raman)** will provide geological and mineralogical context information complementary to that obtained by MicrOmega-IR. It is a very useful technique employed to identify mineral phases produced by water-related processes.

- **Ground-penetrating radar**, called **WISDOM** (for Water Ice and Subsurface Deposit Information On Mars) will explore the subsurface of Mars to identify layering and help select interesting buried formations from which to collect samples for analysis. It can transmit and receive signals using two, small Vivaldi-antennas mounted on the aft section of the rover. Electromagnetic waves penetrating into the ground are reflected at places where there is a sudden transition in the electrical parameters of the soil. By studying these reflections it is possible to construct a stratigraphic map of the subsurface and identify underground targets down to 2 to 3 m depth, comparable to the 2-m reach of the rover's drill. These data, combined with those produced by the PanCam and by the analyses carried out on previously collected samples, will be used to support drilling activities.

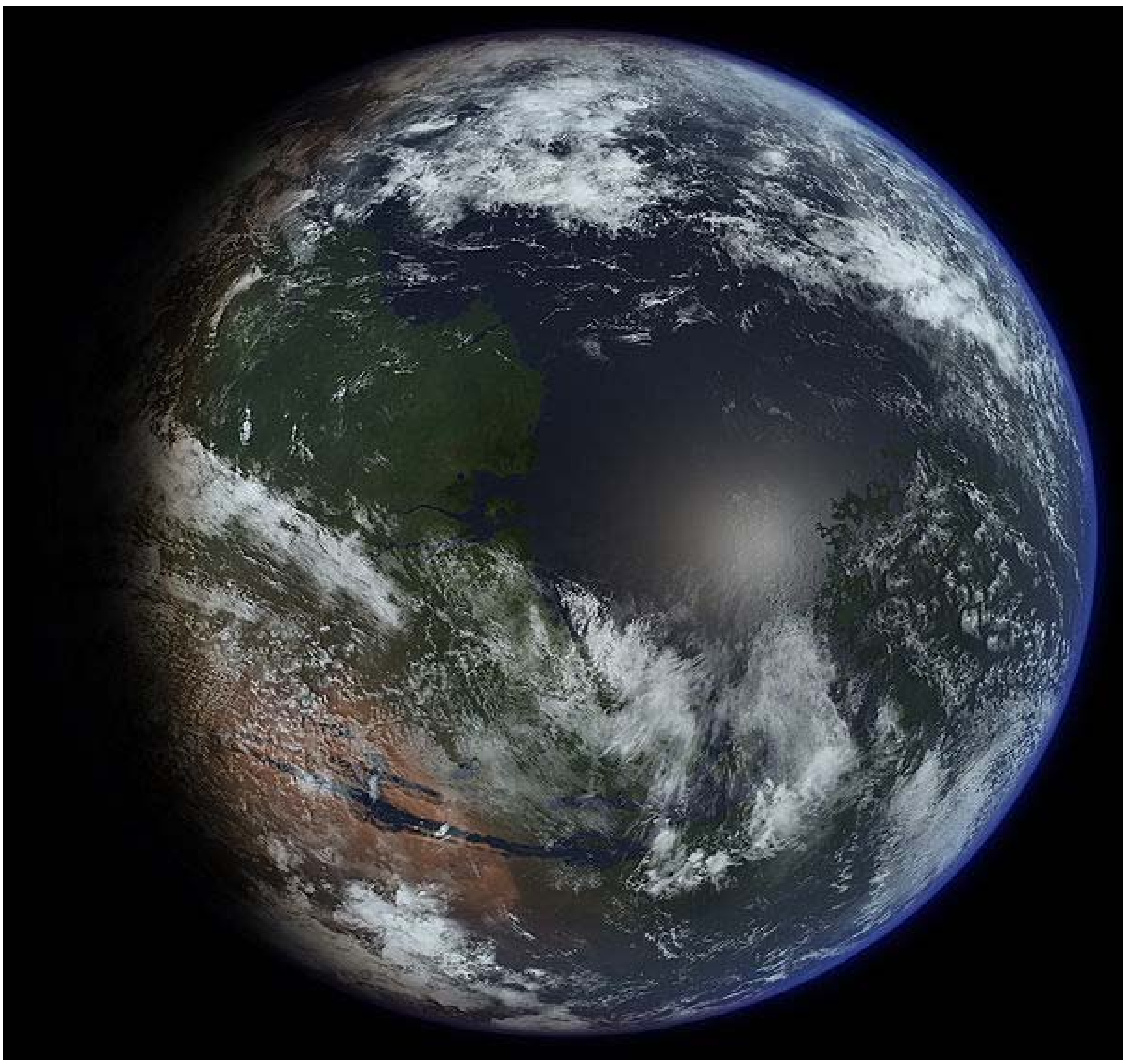
- **Mars Multispectral Imager for Subsurface Studies** (**Ma-MISS**) is an infrared spectrometer located inside the drill. Ma-MISS will observe the lateral wall of the borehole created by the drill to study the subsurface startigraphy, to understand the distribution and state of water-related minerals, and to characterize the geophysical environment. The analyses of unexposed material by Ma-MISS, together with data obtained with the spectrometers located inside the rover, will be crucial for the unambiguous interpretation of the original conditions of Martian rock formation.

Autonomous navigation

The ExoMars Rover is designed to navigate autonomously across the surface. A pair of stereo cameras allow the Rover to build up a 3D map of the terrain, which the Navigation software then uses to assess terrain around it so that it avoids obstacles and find the most efficient route.

Chapter- 5

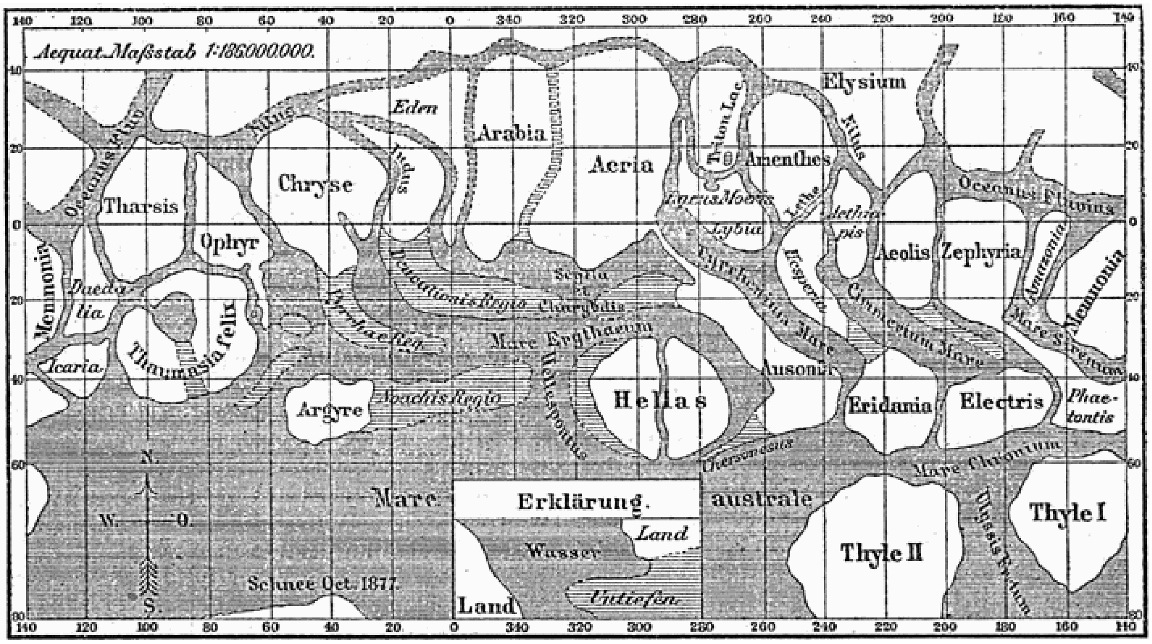
Life on Mars



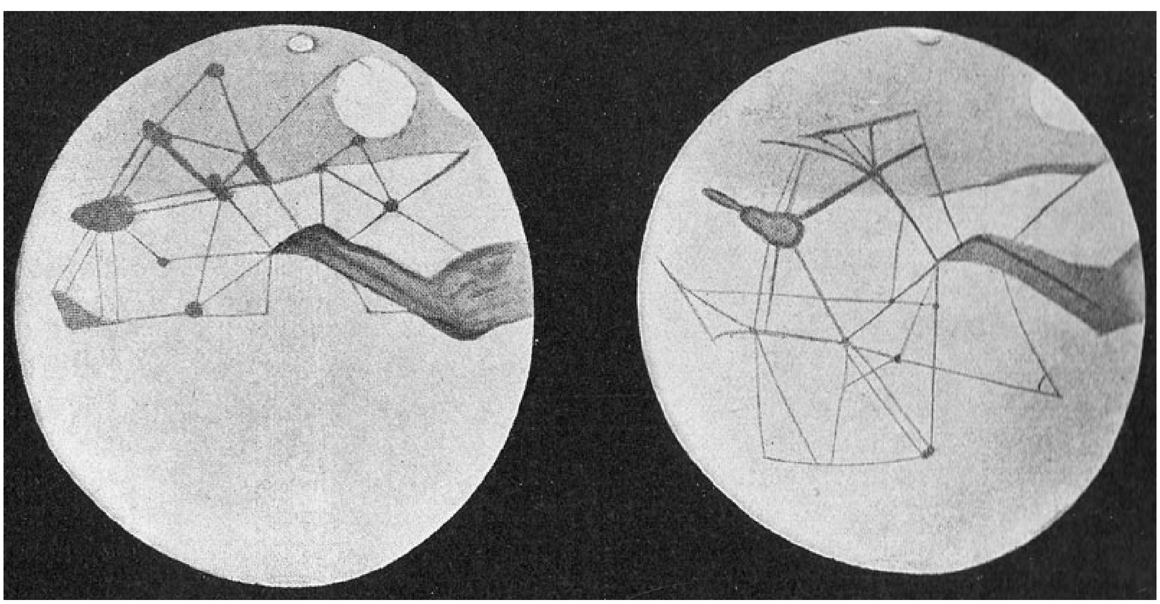
An artist's impression of what Mars' surface and atmosphere may look like if Mars were terraformed.

Scientists have long speculated about the possibility of **life on Mars** owing to the planet's proximity and similarity to Earth. Although fictional Martians have been a recurring feature of popular entertainment, it remains an open question whether life currently exists on Mars, or has existed there in the past.

Early speculation



Historical map of Mars from Giovanni Schiaparelli.



Mars canals, as seen by astronomer P. Lowell, 1898.

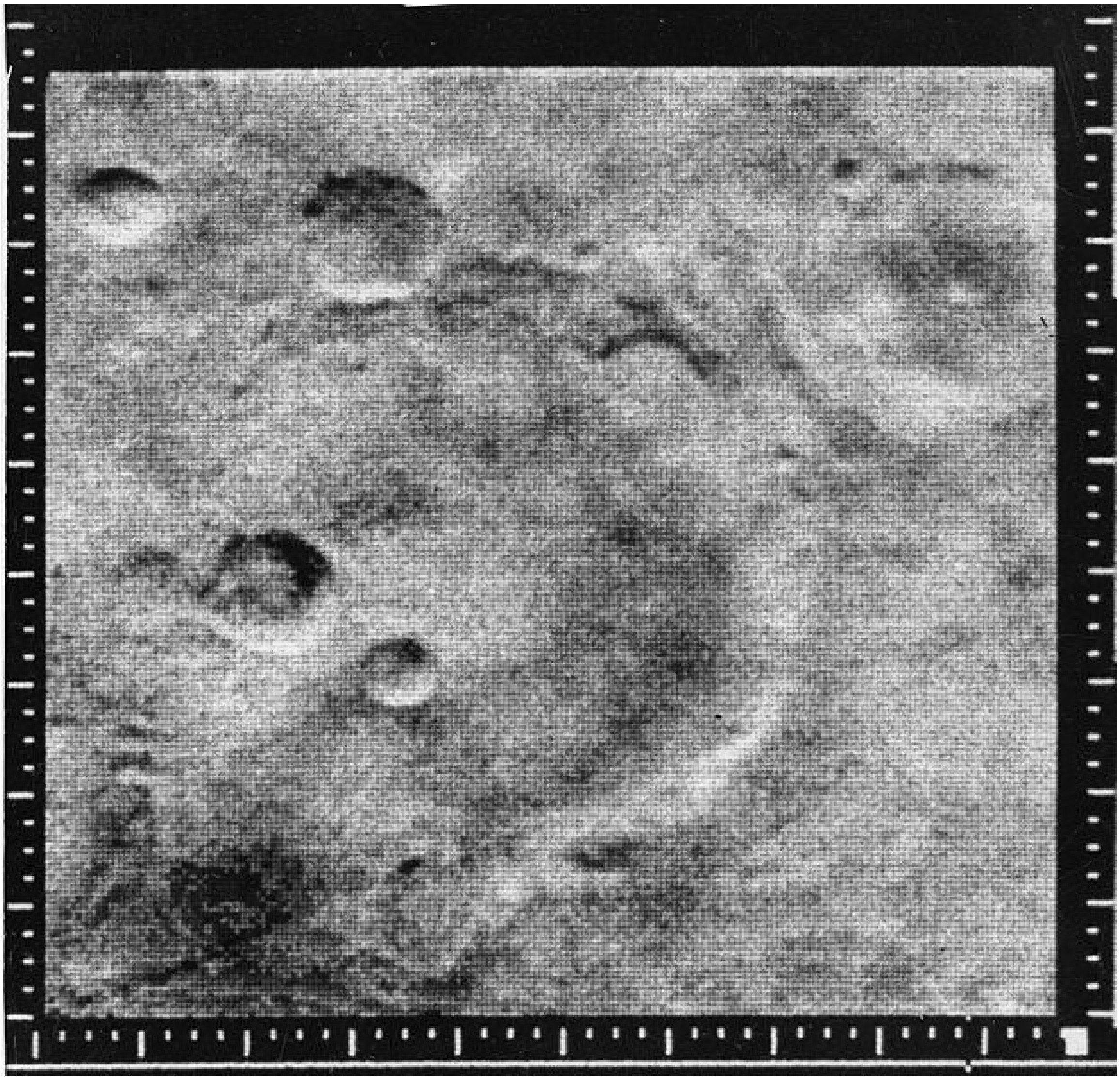
Mars' polar ice caps were observed as early as the mid-17th century, and they were first proven to grow and shrink alternately, in the summer and winter of each hemisphere, by William Herschel in the latter part of the 18th century. By the mid-19th century, astronomers knew that Mars had certain other similarities to Earth, for example that the length of a day on Mars was almost the same as a day on Earth. They also knew that its axial tilt was similar to Earth's, which meant it experienced seasons just as Earth does - but of nearly double the length owing to its much longer year. These observations led to the increase in speculation that the darker albedo features were water, and brighter ones were land. It was therefore natural to suppose that Mars may be inhabited by some form of life.

In 1854, William Whewell, a fellow of Trinity College, Cambridge, who popularized the word *scientist,* theorized that Mars had seas, land and possibly life forms. Speculation about life on Mars exploded in the late 19th century, following telescopic observation by some observers of apparent Martian canals — which were however soon found to be optical illusions. Despite this, in 1895, American astronomer Percival Lowell published his book *Mars,* followed by *Mars and its Canals* in 1906, proposing that the canals were the work of a long-gone civilization. This idea led British writer H. G. Wells to write *The War of the Worlds* in 1897, telling of an invasion by aliens from Mars who were fleeing the planet's desiccation.

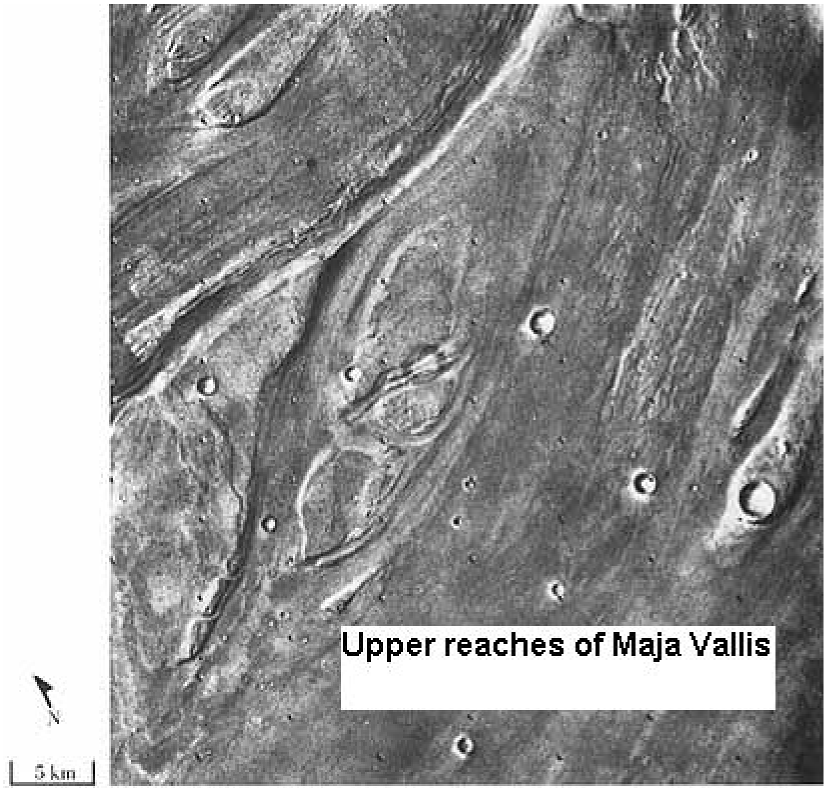
Spectroscopic analysis of Mars' atmosphere began in earnest in 1894, when U.S. astronomer William Wallace Campbell showed that neither water nor oxygen were present in the Martian atmosphere. By 1909 better telescopes and the best perihelic opposition of Mars since 1877 conclusively put an end to the canal theory.

Missions

Mariner 4



Mariner Crater, as seen by Mariner 4 in 1965. Pictures like this suggested that Mars is too dry for any kind of life.



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

Mariner 4 probe performed the first successful flyby of the planet Mars, returning the first pictures of the Martian surface in 1965. The photographs showed an arid Mars without rivers, oceans or any signs of life. Further, it revealed that the surface (at least the parts that it photographed) was covered in craters, indicating a lack of plate tectonics and weathering of any kind for the last 4 billion years. The probe also found that Mars has no global magnetic field that would protect the planet from potentially life-threatening cosmic rays. The probe was able to calculate the atmospheric pressure on the planet to be about 0.6 kPa (compared to Earth's 101.3 kPa), meaning that liquid water could not exist on the planet's surface. After Mariner 4, the search for life on Mars changed to a search for bacteria-like living organisms rather than for multicellular organisms, as the environment was clearly too harsh for these.

Viking orbiters

Liquid water is necessary for life and metabolism, so if water was present on Mars, the chances of it having supported life may have been determinant. The Viking orbiters found evidence of possible river valleys in many areas, erosion and, in the southern hemisphere, branched streams.

Carl Sagan poses next to a replica of the Viking landers.

Viking experiments

The primary mission of the Viking probes of the mid-1970s was to carry out experiments designed to detect microorganisms in Martian soil. The tests were formulated to look for life similar to that found on Earth. Of the four experiments, only the Labeled Release (LR) experiment returned a positive result, showing increased $^{14}CO_2$ production on first exposure of soil to water and nutrients. All scientists agree on two points from the Viking missions: that radiolabeled $^{14}CO_2$ was evolved in the Labeled Release experiment, and that the GC-MS detected no organic molecules. However, there are vastly different interpretations of what those results imply.

One of the designers of the Labeled Release experiment, Gilbert Levin, believes his results are a definitive diagnostic for life on Mars. However, this result is disputed by many scientists, who argue that superoxidant chemicals in the soil could have produced this effect without life being present. An almost general consensus discarded the Labeled Release data as evidence of life, because the gas chromatograph & mass spectrometer, designed to identify natural organic matter, did not detect organic molecules. The results of the Viking mission concerning life are considered by the general expert community, at best, as inconclusive.

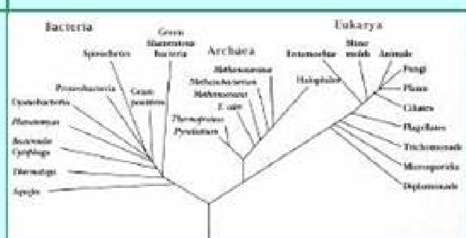
In 2007, during a Seminar of the Geophysical Laboratory of the Carnegie Institution (Washington, D.C., USA), Gilbert Levin's investigation was assessed once more. Levin maintains that his original data were correct, as the positive and negative control experiments were in order.

Ronald Paepe, an edaphologist (soil scientist), communicated to the European Geosciences Union Congress that the discovery of the recent detection of phyllosilicate clays on Mars may indicate pedogenesis, or soil development processes, extended over the entire surface of Mars. Paepe's interpretation views most of Mars surface as active soil, colored red by eons of widespread wearing by water, vegetation and microbial activity.

A research team from the Salk Institute for Biological Studies headed by Rafael Navarro-González, concluded that the equipment used (TV-GC-MS) by the Viking program to search for organic molecules, may not be sensitive enough to detect low levels of organics. Because of the simplicity of sample handling, TV–GC–MS is still considered the standard method for organic detection on future Mars missions, Navarro-González suggests that the design of future organic instruments for Mars should include other methods of detection.

Gillevinia straata

Table 2: Life's major domains (*) and formal systematic position of the active agent characterized by its reported behavior as responsible of the results of the 1976 Viking Mission's Labeled Release experiment.

Organic Life System	Biosphere	Domains	Middle taxa	Known Genera & Species
Solaria	Terrestria		…	Many
	Marciana	Jakobia	…	Levinia straata

* Observational knowledge about Solaria's biospheres is unbalanced; about extra-Solaria biospheres, unexisting.

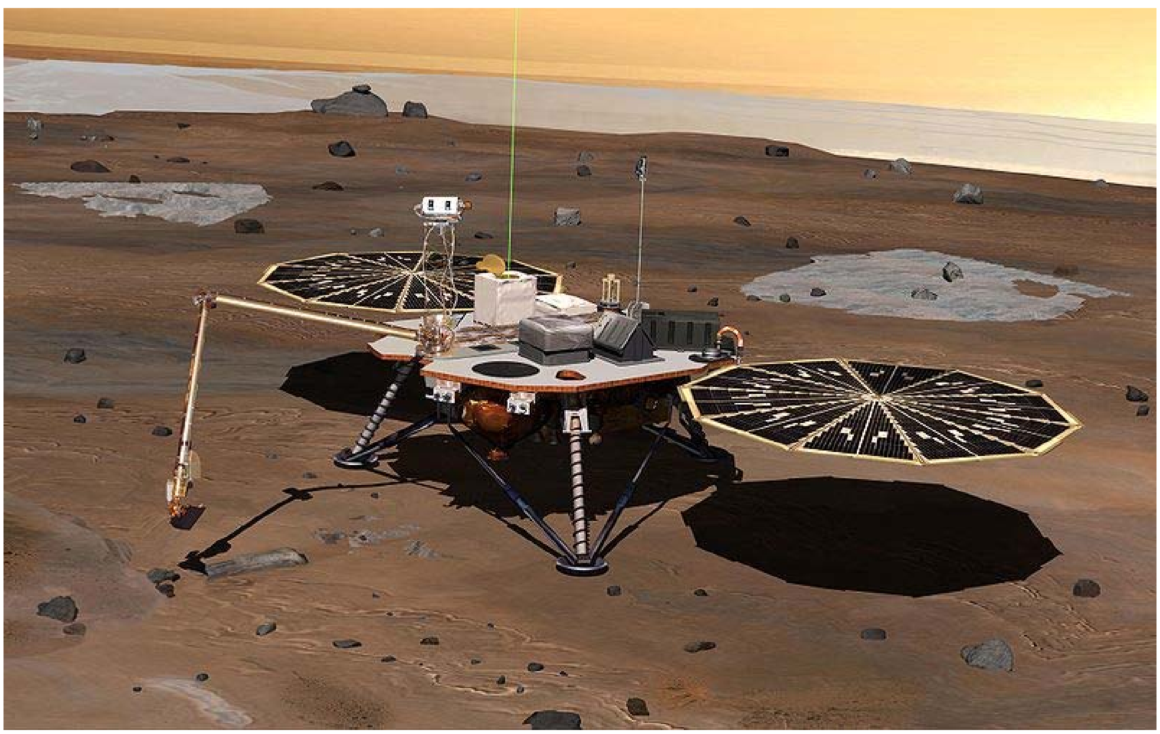
Newly proposed taxonomic system.

The claim for life on Mars, in the form of *Gillevinia straata*, is based on old data reinterpreted as sufficient evidence of life, mainly by professors Gilbert Levin, Rafael Navarro-González and Ronalds Paepe. The evidence supporting the existence of *Gillevinia straata* microorganisms relies on the data collected by the two Mars *Viking* landers that searched for biosignatures of life, but the analytical results were, officially, inconclusive.

In 2006, Mario Crocco, a neurobiologist at the Neuropsychiatric Hospital Borda in Buenos Aires, Argentina, proposed the creation of a new nomenclatural rank that classified the Viking landers' results as 'metabolic' and therefore belonging to a form of life. Crocco proposed to create new biological ranking categories (taxa), in the new kingdom system of life, in order to be able to accommodate the genus of Martian microorganisms. Crocco proposed the following taxonomical entry:

- Organic life system: Solaria
- Biosphere: Marciana
- Kingdom: Jakobia (named after neurobiologist Christfried Jakob)
- Genus et species: *Gillevinia straata*

As a result, the hypothetical *Gillevinia straata* would not be a bacterium (which rather is a terrestrial taxon) but a member of the kingdom 'Jakobia' in the biosphere 'Marciana' of the 'Solaria' system. The intended effect of the new nomenclature was to reverse the burden of proof concerning the life issue, but the taxonomy proposed by Crocco has not been accepted by the scientific community and is considered a single *nomen nudum*. Further, no Mars mission has found traces of biomolecules.



An artist's concept of the Phoenix spacecraft.

Phoenix lander, 2008

The Phoenix mission landed a robotic spacecraft in the polar region of Mars on May 25, 2008 and it operated until November 10, 2008. One of the mission's two primary objectives was to search for a 'habitable zone' in the Martian regolith where microbial life could exist, the other main goal being to study the geological history of water on Mars. The lander has a 2.5 meter robotic arm that was capable of digging shalow trenches in the regolith. There is an electrochemistry experiment which analysed the ions in the regolith and the amount and type of antioxidants on Mars. The Viking program data indicate that oxidants on Mars may vary with latitude, noting that Viking 2 saw fewer oxidants than Viking 1 in its more northerly position. Phoenix landed further north still. Phoenix's preliminary data revealed that Mars soil contains perchlorate, and thus may not be as life-friendly as thought earlier. The pH and salinity level were viewed as benign from the standpoint of biology. The analysers also indicated the presence of bound water and CO_2.

Future missions

- Mars Science Laboratory, a NASA project planned for launch in late 2011, will contain instruments and experiments designed to look for past or present conditions relevant to biological activity.

- ExoMars is a European-led multi-spacecraft programme currently under development by the European Space Agency (ESA) and NASA for launch in 2016 and 2018. Its primary scientific mission will be to search for possible biosignatures on Mars, past or present. Two rovers with a 2 m core drill each will be used to sample various depths beneath the surface where liquid water may be found and where microorganisms might survive cosmic radiation.

- Mars Sample Return Mission — The best life detection experiment proposed is the examination on Earth of a soil sample from Mars. However, the difficulty of providing and maintaining life support over the months of transit from Mars to Earth remains to be solved. Providing for still unknown environmental and nutritional requirements is daunting. Should dead organisms be found in a sample, it would be difficult to conclude that those organisms were alive when obtained.

Meteorites

NASA maintains a catalog of 34 Mars meteorites. These assets are highly valuable since they are the only physical samples available of Mars. Studies conducted by NASA's Johnson Space Center show that at least three of the meteorites contain potential evidence of past life on Mars, in the form of microscopic structures resembling fossilized bacteria (so-called biomorphs). Although the scientific evidence collected is reliable, its interpretation varies. To date, none of the original lines of scientific evidence for the hypothesis that the biomorphs are of exobiological origin (the so-called biogenic hypothesis) have been either discredited or positively ascribed to non-biological explanations.

Over the past few decades, seven criteria have been established for the recognition of past life within terrestrial geologic samples. Those criteria are:

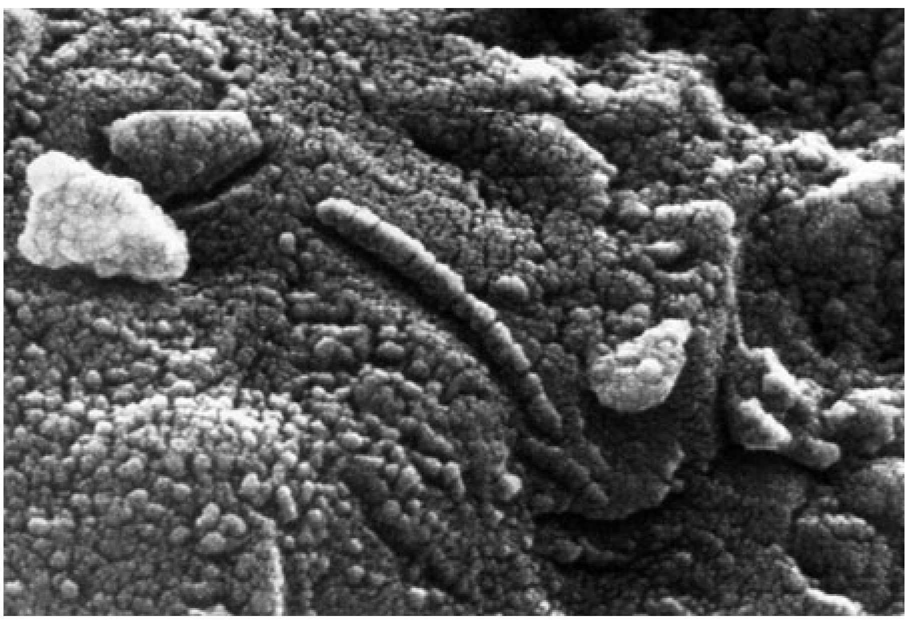
1. Is the geologic context of the sample compatible with past life?

2. Is the age of the sample and its stratigraphic location compatible with possible life?
3. Does the sample contain evidence of cellular morphology and colonies?
4. Is there any evidence of biominerals showing chemical or mineral disequilibria?
5. Is there any evidence of stable isotope patterns unique to biology?
6. Are there any organic biomarkers present?
7. Are the features indigenous to the sample?

For general acceptance of past life in a geologic sample, essentially most or all of these criteria must be met. All seven criteria have not yet been met for any of the Martian samples, but continued investigations are in progress.

As of 2010, reexaminations of the biomorphs found in the three Martian meteorites are underway with more advanced analytical instruments than previously available. The scientists conducting the study at Johnson Space Center believed that before the end of the year they would find in the meteorites definitive evidence for past life on Mars.

ALH84001 meteorite



An electron microscope reveals bacteria-like structures in meteorite fragment ALH84001

The ALH84001 meteorite was found on December 1984 on Antarctica, by members of the ANSMET project; the meteorite weighs 1.93 kilograms (4.3 lb). The sample was ejected from Mars about 17 million years ago and spent 11,000 years in or on the Antarctic ice sheets. Composition analysis by NASA revealed a kind of magnetite that on Earth, is only found in association with certain microorganisms; Then, in August 2002, another NASA team led by Thomas-Keptra published a study indicating that 25% of the magnetite in ALH 84001 occurs as small, uniform-sized crystals that, on Earth, is associated only with biologic activity, and that the remainder of the material appears to be normal inorganic magnetite. The extraction technique did not permit determination as to whether the possibly biological magnetite was organized into chains as would be expected. The meteorite displays indication of relatively low temperature secondary mineralization by water and show evidence of preterrestrial aqueous alteration. Evidence of polycyclic aromatic hydrocarbons (PAHs) have been identified with the levels increasing away from the surface.

Some structures resembling the mineralized casts of terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances) occur in the rims of carbonate globules and preterrestrial aqueous alteration regions. The size and shape of the objects is consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial.

In November 2009, NASA scientists said that a recent, more detailed analysis showed that the meteorite "contains strong evidence that life may have existed on ancient Mars".

Nakhla meteorite

Nakhla Meteorite

The Nakhla meteorite fell on Earth on June 28, 1911 on the locality of Nakhla, Alexandria, Egypt.

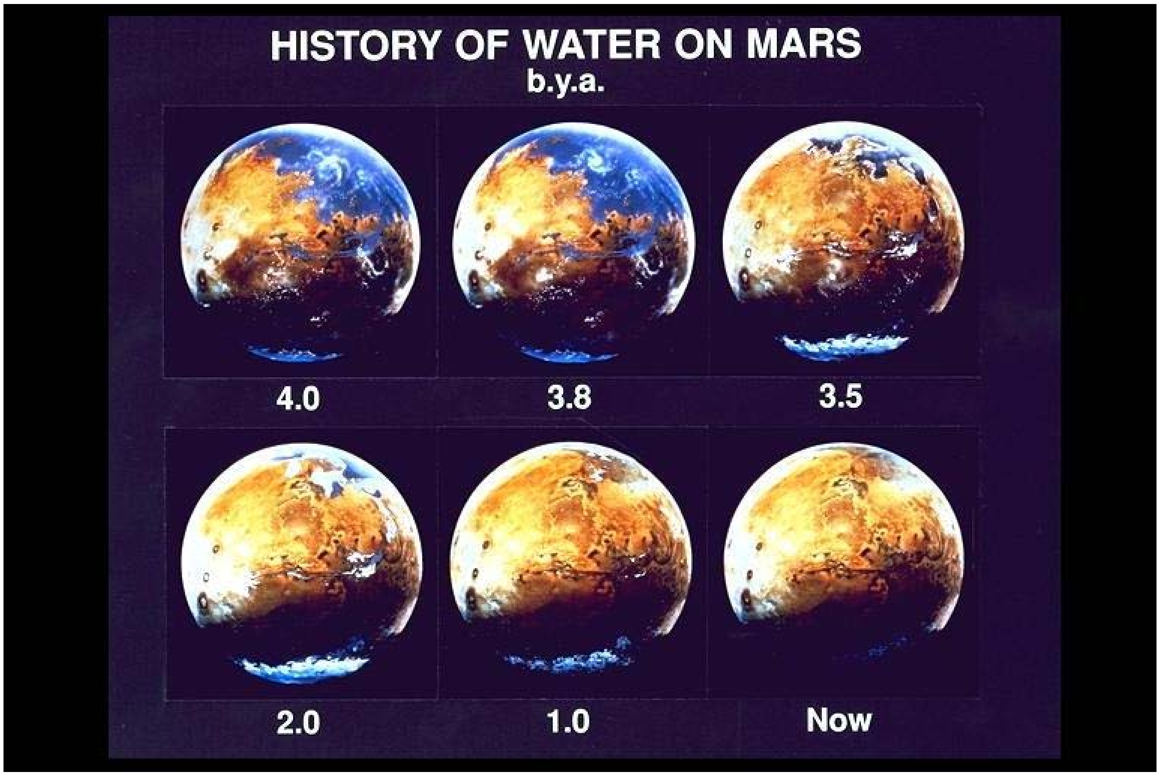
In 1998, a team from NASA's Johnson Space Center obtained a small sample for analysis. Researchers found preterrestrial aqueous alteration phases and objects of the size and shape consistent with Earthly fossilized nanobacteria, but the existence of nanobacteria itself is controversial. Analysis with gas chromatography and mass spectrometry (GC-MS) studied its high molecular weight polycyclic aromatic hydrocarbons in 2000, and NASA scientists concluded that as much as 75% of the organic matter in Nakhla "may not be recent terrestrial contamination".

This caused additional interest in this meteorite, so on 2006, NASA managed to obtain an additional and larger sample from the London Natural History Museum. On this second sample, a large dendritic carbon content was observed. When the results and evidence were published on 2006, some independent researchers claimed that the carbon deposits are of biologic origin. However, it was remarked that since carbon is the fourth most abundant element in the Universe, finding it in curious patterns is not indicative or suggestive of biological origin.

Shergotty meteorite

The Shergotty meteorite, a 4 kg martian meteorite, fell on Earth on Shergotty, India on August 25, 1865 and was retrieved by witnesses almost immediately. This meteorite is relatively young, calculated to have been formed in Mars only 165 million years ago from volcanic origin. It is composed mostly of pyroxene and thought to have undergone preterrestrial aqueous alteration for several centuries. Certain features in its interior suggest to be remnants of biofilm and their associated microbial communities. Work is in progress on searching for magnetites within alteration phases.

Liquid water



A series of artist's conceptions of hypothetical past water coverage on Mars.

No Mars probe since Viking has tested the Martian regolith specifically for metabolism which is the ultimate sign of current life. NASA's recent missions have focused on another question: whether Mars held lakes or oceans of liquid water on its surface in the ancient past. Scientists have found hematite, a mineral that forms in the presence of water. Thus, the mission of the Mars Exploration Rovers of 2004 was not to look for present or past life, but for evidence of liquid water on the surface of Mars in the planet's ancient past.

Since Mars lost most of its magnetic field about 4 billion years ago, the Martian ionosphere is unable to stop the solar wind or radiation, and it interacts directly with exposed soil, making life, as we know it, impossible to exist. Also, liquid water, necessary for life and for metabolism, cannot exist on the surface of Mars under its present low atmospheric pressure and temperature, except at the lowest shaded elevations for short periods and liquid water does not appear at the surface itself.

In June 2000, evidence for water currently under the surface of Mars was discovered in the form of flood-like gullies. Deep subsurface water deposits near the planet's liquid core might form a present-day habitat for life. However, in March 2006, astronomers announced the discovery of similar gullies on the Moon, which is believed never to have had liquid water on its surface. The astronomers suggest that the gullies could be the result of micrometeorite impacts.

In March 2004, NASA announced that its rover *Opportunity* had discovered evidence that Mars was, in the ancient past, a wet planet. This had raised hopes that evidence of past life might be found on the planet today. ESA confirmed that the Mars Express orbiter had directly detected huge reserves of water ice at Mars' south pole in January 2004.

On July 28, 2005, ESA announced that they had recorded photographic evidence of surface water ice near Mars' North pole.

In December 2006, NASA showed images taken by the Mars Global Surveyor that suggested that water occasionally flows on the surface of Mars. The images did not actually show flowing water. Rather, they showed changes in craters and sediment deposits, providing the strongest evidence yet that water coursed through them as recently as several years ago, and is perhaps doing so even now. Some researchers were skeptical that liquid water was responsible for the surface feature changes seen by the spacecraft. They said other materials such as sand or dust can flow like a liquid and produce similar results.

Recent analysis of Martian sandstones, using data obtained from orbital spectrometry, suggests that the waters that previously existed on the surface of Mars would have had too high a salinity to support most Earth-like life. Tosca *et al.* found that the Martian water in the locations they studied all had water activity, $a_w \leq 0.78$ to 0.86—a level fatal to most Terrestrial life. Haloarchaea, however, are able to live in hypersaline solutions, up to the saturation point.

The Phoenix Mars lander from NASA, which landed in the Mars Arctic plain in May 2008, confirmed the presence of frozen water near the surface. This was confirmed when bright material, exposed by the digging arm of the lander, was found to have vaporized and disappeared in 3 to 4 days. This has been attributed to sub-surface ice, exposed by the digging and sublimated on exposure to the atmosphere.

Methane

Trace amounts of methane in the atmosphere of Mars were discovered in 2003 and verified in 2004. The presence of methane indicates, as it is an unstable gas, that there must be an active source on the planet in order to keep such levels in the atmosphere. It is estimated that Mars must produce 270 ton/year of methane, but asteroid impacts account for only 0.8% of the total methane production. Although geologic sources of methane such as serpentinization are possible, the lack of current volcanism, hydrothermal activity or hotspots are not favorable for geologic methane. It has been suggested that the methane was produced by chemical reactions in meteorites, driven by the intense heat during entry through the atmosphere. However, research published in December 2009, ruled out this possibility.

The existence of life in the form of microorganisms such as methanogens are among possible but as yet unproven sources. If microscopic Martian life is producing the methane, it likely resides far below the surface, where it is still warm enough for liquid water to exist.

Since the 2003 discovery of methane in the atmosphere, some scientists have been designing models and *in vitro* experiments testing growth of methanogenic bacteria on simulated Martian soil, where all four methanogen strains tested produced substantial levels of methane, even in the presence of 1.0wt% perchlorate salt. The results reported indicate that the perchlorates discovered by the Phoenix Lander would not rule out the possible presence of methanogens on Mars.

A team led by Levin suggested that both phenomena—methane production and degradation—could be accounted for by an ecology of methane-producing and methane-consuming microorganisms.

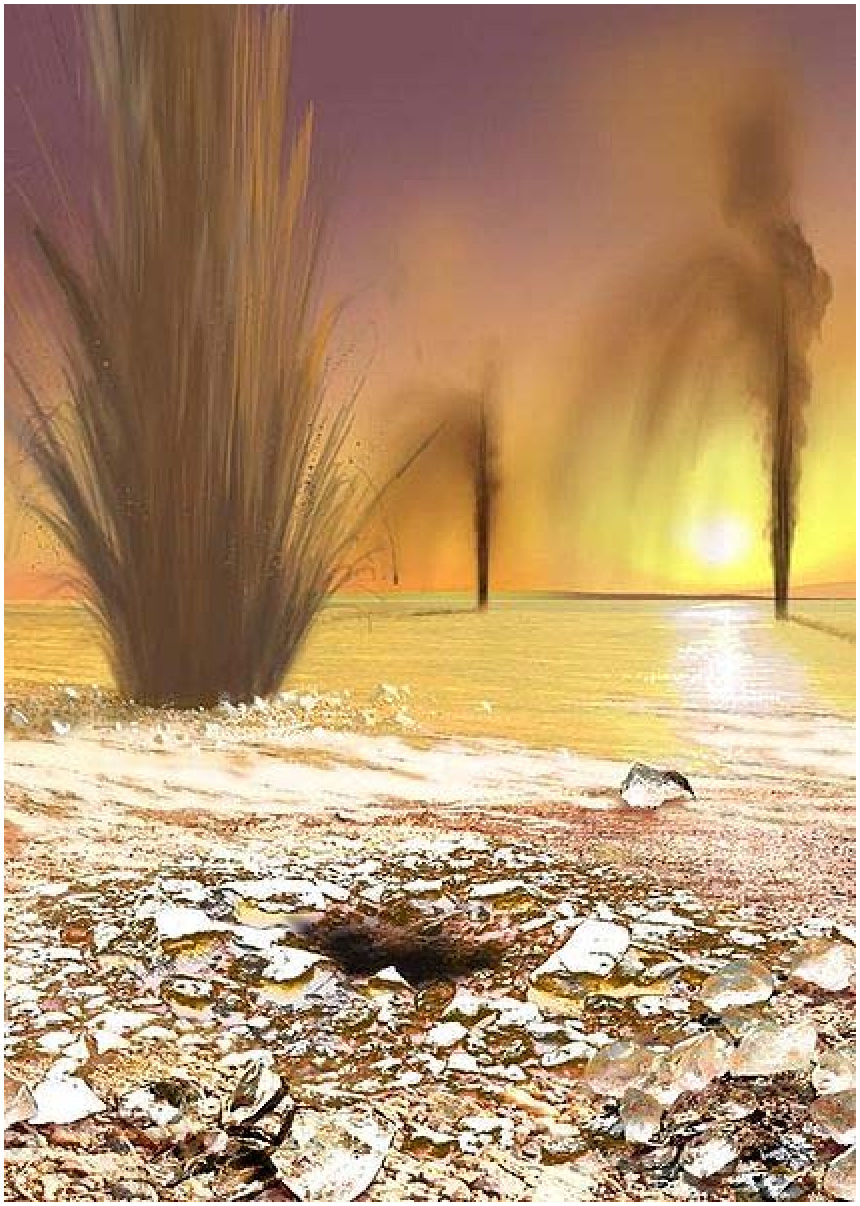
Formaldehyde

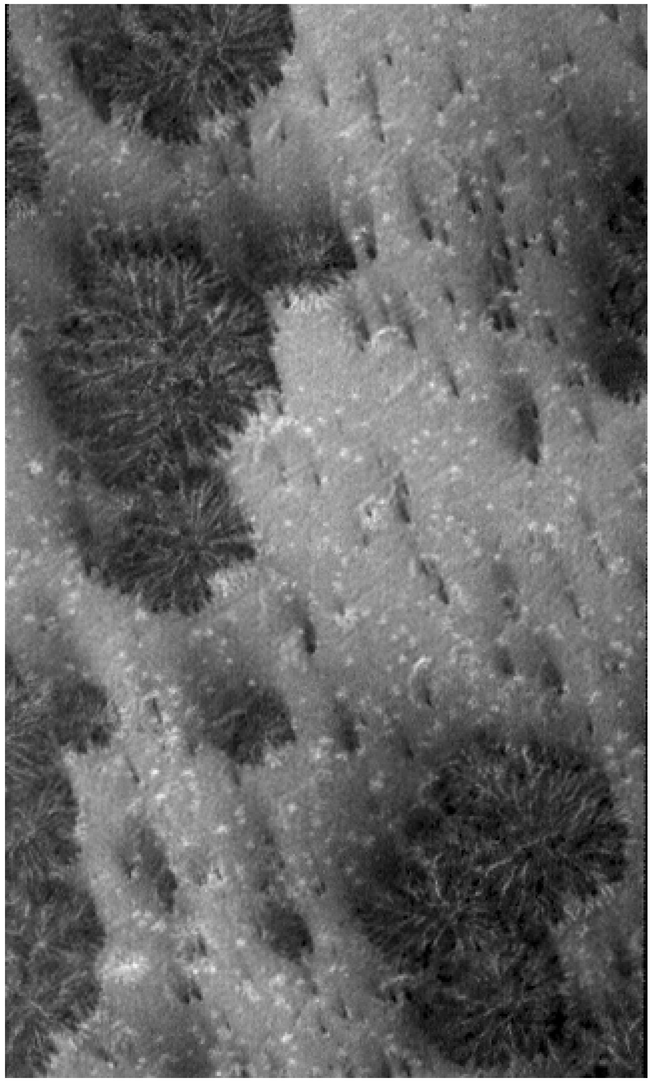
In February 2005, it was announced that the Planetary Fourier Spectrometer (PFS) on the European Space Agency's Mars Express Orbiter, detected traces of formaldehyde in the atmosphere of Mars. Vittorio Formisano, the director of the PFS, has speculated that the formaldehyde could be the byproduct of the oxidation of methane, and according to him, would provide evidence that Mars is either extremely geologically active, or harbouring colonies of microbial life. NASA scientists consider the preliminary findings are well worth a follow-up, but have also rejected the claims of life.

Silica

In May 2007, the Spirit rover disturbed a patch of ground with its inoperative wheel, uncovering an area extremely rich in silica (90%). The feature is reminiscent of the effect of hot spring water or steam coming into contact with volcanic rocks. Scientists consider this as evidence of a past environment that may have been favorable for microbial life, and theorize that one possible origin for the silica may have been produced by the interaction of soil with acid vapors produced by volcanic activity in the presence of water. Another possible origin could have been from water in a hot spring environment.

Geysers on Mars


Artist concept showing sand-laden jets erupt from geysers on Mars.



Close up of dark dune spots, likely created by cold geyser-like eruptions.

The seasonal frosting and defrosting of the southern ice cap results in the formation of spider-like radial channels carved on 1 meter thick ice by sunlight. Then, sublimed CO_2 - and probably water- increase pressure in their interior producing geyser-like eruptions of cold fluids often mixed with dark basaltic sand or mud. This process is rapid, observed happening in the space of a few days, weeks or months, a growth rate rather unusual in geology - especially for Mars.

A team of Hungarian scientists propose that the geysers' most visible features, dark dune spots and spider channels, may be colonies of photosynthetic Martian microorganisms, which over-winter beneath the ice cap, and as the sunlight returns to the pole during early spring, light penetrates the ice, the microorganisms photosynthesise and heat their immediate surroundings. A pocket of liquid water, which would normally evaporate instantly in the thin Martian atmosphere, is trapped around them by the overlying ice. As this ice layer thins, the microorganisms show through grey. When it has completely melted, they rapidly desiccate and turn black surrounded by a grey aureole. The Hungarian scientists believe that even a complex sublimation process is insufficient to explain the formation and evolution of the dark dune spots in space and time. Since their discovery, fiction writer Arthur C. Clarke promoted these formations as deserving of study from an astrobiological perspective.

A multinational European team suggests that if liquid water is present in the spiders' channels during their annual defrost cycle, they might provide a niche where certain microscopic life forms could have retreated and adapted while sheltered from solar radiation. A British team also considers the possibility that organic matter, microbes, or even simple plants might co-exist with these inorganic formations, especially if the mechanism includes liquid water and a geothermal energy source. However, they also remark that the majority of geological structures may be accounted for without invoking any organic "life on Mars" hypothesis.

Cosmic radiation

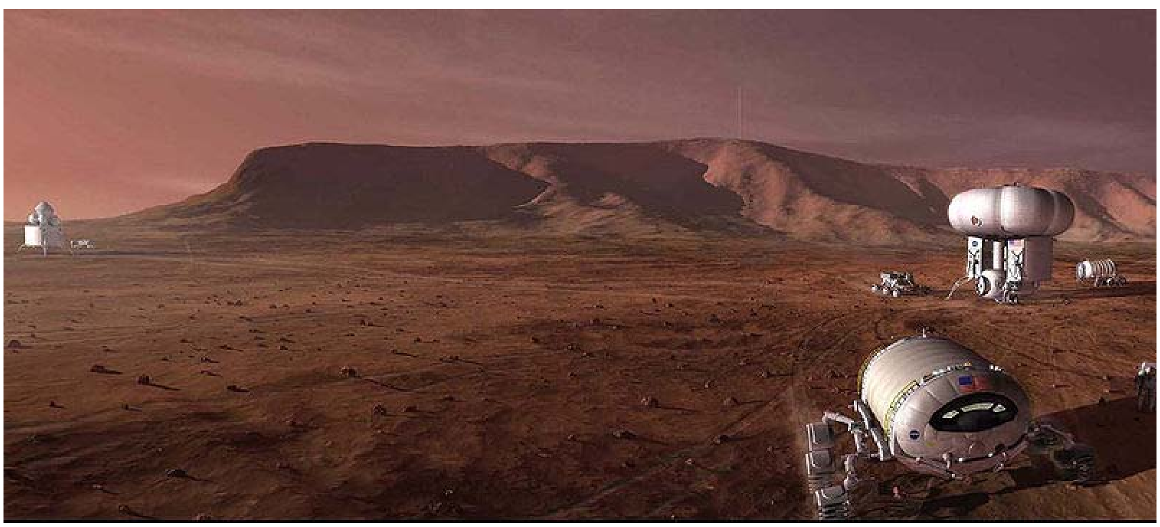
In 1965, the Mariner 4 probe discovered that Mars had no global magnetic field that would protect the planet from potentially life-threatening cosmic radiation and solar radiation; observations made in the late 1990s by the Mars Global Surveyor confirmed this discovery. Scientists speculate that the lack of magnetic shielding helped the solar wind blow away much of Mars's atmosphere over the course of several billion years.

In 2007, it was calculated that DNA and RNA damage by cosmic radiation would limit life on Mars to depths greater than 7.5 metres below the planet's surface. Therefore, the best potential locations for discovering life on Mars may be at subsurface environments that have not been studied yet.

Chapter- 6

Mars to Stay

Mars to Stay is the proposal that astronauts sent to Mars for the first time should stay there indefinitely, both to reduce mission cost and to ensure permanent settlement of Mars. Among many other notable Mars to Stay advocates, former Apollo astronaut Buzz Aldrin has been particularly outspoken, suggesting in numerous forums "Forget the Moon, Let's Head to Mars!" The Mars Underground, Mars Homestead Foundation, and Mars Artists Community have also adopted Mars to Stay policy initiatives. The earliest formal outline of a Mars to Stay mission architecture was given at the Case for Mars VI Workshop in 1990, during a presentation by George Herbert titled "One Way to Mars."



Concept for NASA Design Reference Mission Architecture 5.0 (2009)

Proposals

Original Aldrin Plan

Under a Mars to Stay mission architecture the first humans to travel to Mars would be composed of a six-person team. After this initial landing subsequent missions over five years will raise the number of persons on the Martian surface to 30, thereby beginning an organically evolving Martian settlement. Since the Martian surface offers all the natural resources and elements necessary to sustain human society—unlike, for example the moon—a permanent Martian settlement is thought to be the most effective way to ensure humankind becomes a space-faring, multi-planet species. Through the use of digital fabricators and in vitro fertilization it is assumed a permanent human settlement on Mars can grow organically from an original thirty to forty pioneers.

A Mars exploration program following Aldrin's Mars to Stay initiative would enlist astronauts in the following timeline:

- Age 30: an offer to help settle Mars is extended to select pioneers
- Age 30-35: training and social conditioning for long-duration isolation and time-delay communications
- Age 35: launch three married couples to Mars; followed in subsequent years by a dozen or more couples
- Age 35-65: development of sheltered underground living spaces; artificial insemination ensures genetic diversity
- Age 65: an offer to return to Earth or retire on Mars is given to first generation settlers

As Aldrin has said, "…who knows what advances will have taken place. The first generation can retire there, or maybe we can bring them back."

"Hundred Year Starship Initiative"

On October 2010 NASA Ames Research Center Director Pete Worden introduced the Hundred Year Starship initiative, a project to embark on a one-way mission from Earth to Mars by 2030. The astronauts would be sent supplies from Earth on a regular basis. The mission is planned to take place no earlier than 2030. Controversy immediately arose over the name of the enterprise, given that Mars settlement could have begun within five years of the announcement -- rather than portrayed as an exotic "100 year" fantasy.

"To Boldly Go: A One-Way Human Mission to Mars," Journal of Cosmology

The October-November, 2010, Journal of Cosmology reprinted an article by Dirk Schulze-Makuch (Washington State University) and Paul Davies (Arizona State University) from the book "The Human Mission to Mars. Colonizing the Red Planet." Highlights of their mission plan are:

- No base on the Moon is needed. Given the broad variety of resources available on Mars, the long-term survival of Martian settlers is much more feasible than Lunar settlers.
- Since Mars affords neither an ozone shield nor magnetospheric protection, robots would prepare a basic modular base inside near-surface lava tubes and ice caves for the human settlers.

- A volunteer signing up for a one-way mission to Mars would do so with the full understanding that he or she will not return to Earth; Mars exploration would proceed for a long time on the basis of outbound journeys only.
- The first human contingent would consist of a crew of four, ideally (if budget permits) distributed between two two-man spacecraft for mission redundancy.
- Over time humans on Mars will increase with follow-up missions. Several subsurface biospheres would be created until there were 150+ individuals in a viable gene pool. Genetic engineering would further contribute to the health and longevity of settlers.

Initial and permanent settlement

Initial explorers leave equipment in orbit and at landing zones scattered considerable distances from the main settlement. Subsequent missions therefore are assumed to become easier and safer to undertake, with the likelihood of back-up equipment being present if accidents in transit or landing occur.

Large subsurface, pressurized habitats would be the first step toward human settlement; as Dr. Robert Zubrin suggests in the first chapter of his book *Mars Direct* these structures can be built as Roman-style atria in mountainsides or underground with easily produced Martian brick. During and after this initial phase of habitat construction, hard-plastic radiation- and abrasion-resistant geodesic domes could be deployed on the surface for eventual habitation and crop growth. Nascent industry would begin using indigenous resources: the manufacture of plastics, ceramics and glass could be easily achieved.

The longer-term work of terraforming Mars requires an initial phase of global warming to release atmosphere from the Martian regolith and to create a water-cycle. There would be no cost issue associated to terraforming as it would be in the best interest of settlers to make sure that their daily activities positively influence the improvement of the environment. Three methods of global warming are described by Zubrin, who suggests they are best deployed in tandem: orbital mirrors to heat the surface; factories on the ground to pump halocarbons into the atmosphere; and the seeding of bacteria which can metabolize water, nitrogen and carbon to produce ammonia and methane (these gases would aid in global warming). While the work of terraforming Mars is on-going, robust settlement of Mars can continue.

The Case for Mars acknowledges any Martian colony will be partially Earth-dependent for centuries. However, Zubrin suggests Mars may be profitable for two reasons. First, it may contain concentrated supplies of metals equal to or of greater value than silver, which have not been subjected to millennia of human scavenging; it is suggested such ores may be sold on Earth for profit. Secondly, the concentration of deuterium–an extremely expensive but essential fuel for the nuclear power industry–is five times greater on Mars. Humans emigrating to Mars, under this paradigm, thus have an assured industry; it is assumed the planet will be a magnet for settlers as wage costs will be high. Because of the labor shortage on Mars and its subsequent high pay-scale, Martian civilization and the value placed upon each individual's productivity is proposed as a future engine of both technological and social advancement."

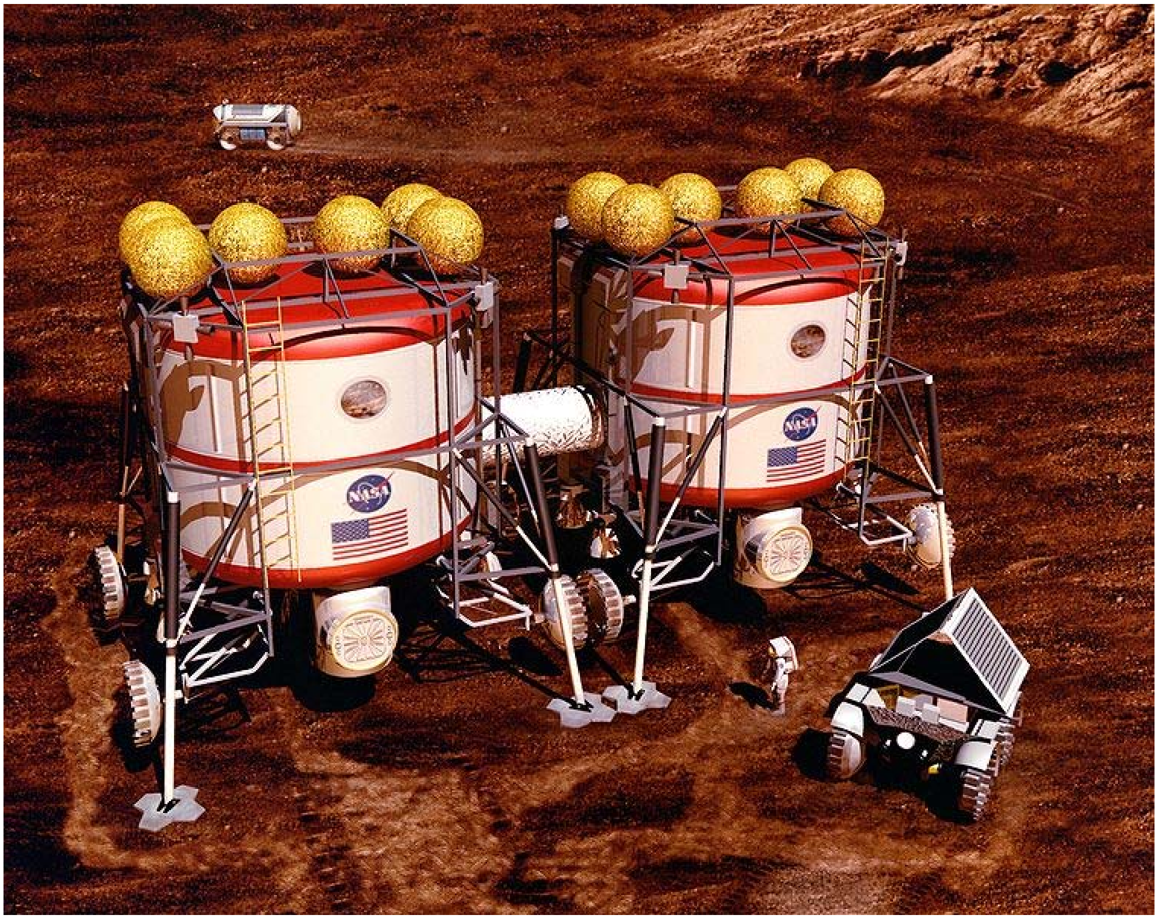
Risks

Artist's conception of a human mission on Mars
1989 painting by Les Bossinas of Lewis Research Center for NASA

In the fifth chapter of "Mars Direct", Zubrin dismisses the idea that radiation and zero-gravity are unduly hazardous. He claims that cancer rates *do* increase for astronauts who have spent extensive time in space, but only marginally. Similarly, while zero-gravity presents challenges, near total recovery of musculature and immune system vitality is assumed once on the Martian surface. Back-contamination — humans acquiring and spreading Martian viruses — is described as "just plain nuts", because there are no host organisms on Mars for disease organisms to have evolved.

In the same chapter, Zubrin decisively denounces and rejects suggestions that the Moon should be used as waypoint to Mars or as a preliminary training area. "It is ultimately much easier to journey to Mars from low Earth orbit than from the moon and using the latter as a staging point is a pointless diversion of resources." While the Moon may superficially appear a good place to perfect Mars exploration and habitation techniques, the two bodies are radically different. The moon has no atmosphere, no analogous geology and a much greater temperature range and rotational period of illumination. It is argued Antarctica, desert areas of Earth, and precisely controlled chilled vacuum chambers on easily accessible NASA centers on Earth provide much better training grounds at lesser cost.

Public reception



Artist's conception of a Mars Habitat
1993 by John Frassanito and Associates for NASA

"Should the United States space program send a mission to Mars, those astronauts should be prepared to stay there," said Lunar astronaut Buzz Aldrin during a high-profile, widely reported interview on "Mars to Stay" initiatives. The time and expense required to send astronauts to Mars, argues Aldrin, "warrants more than a brief sojourn, so those who are on board should think of themselves as pioneers. Like the Pilgrims who came to the New World or the families who headed to the Wild West, they should not plan on coming back home." While the Moon is a shorter trip of two or three days, according to Mars advocates, it offers virtually no potential for independent settlements. Studies have found that Mars, on the other hand, has vast reserves of frozen water, all of the basic elements, and more closely mimics both gravitational and illumination conditions on Earth. "It is easier to subsist, to provide the support needed for people there than on the Moon." In an interview with reporters, the second man to set foot on the Moon said the Red Planet offered far greater potential than Earth's satellite as a place for habitation.

"If we are going to put a few people down there and ensure their appropriate safety, would you then go through all that trouble and then bring them back immediately, after a year, a year and a half?" Aldrin asks. "They need to go there more with the psychology of knowing that you are a pioneering settler and you don't look forward to go back home again after a couple of years," he said.

The most comprehensive statement of a rationale for "Mars to Stay" was laid out by Dr. Aldrin in a May 2009 Popular Mechanics article, as follows:

"The agency's current Vision for Space Exploration will waste decades and hundreds of billions of dollars trying to reach the moon by 2020—a glorified rehash of what we did 40 years ago. Instead of a steppingstone to Mars, NASA's current lunar plan is a detour. It will derail our Mars effort, siphoning off money and engineering talent for the next two decades. If we aspire to a long-term human presence on Mars—and I believe that should be our overarching goal for the foreseeable future—we must drastically change our focus. Our purely exploratory efforts should aim higher than a place we've already set foot on six times. In recent years my philosophy on colonizing Mars has evolved. I now believe that human visitors to the Red Planet should commit to staying there permanently. One-way tickets to Mars will make the missions technically easier and less expensive and get us there sooner. More importantly, they will ensure that our Martian outpost steadily grows as more homesteaders arrive. Instead of explorers, one-way Mars travelers will be 21st-century pilgrims, pioneering a new way of life. It will take a special kind of person. Instead of the traditional pilot/ scientist/engineer, Martian homesteaders will be selected more for their personalities—flexible, inventive and determined in the face of unpredictability. In short, survivors."

The Mars Artists Community has adopted Mars to Stay as their primary policy initiative. During a 2009 public hearing of the U.S. Human Space Flight Plans Committee at which Dr. Robert Zubrin presented a summary of the arguments in book The Case for Mars, dozens of placards reading "Mars Direct Cowards Return to the Moon" were placed throughout the Carnegie Institute. The passionate uproar among space exploration advocates - both favorable and critical - resulted in the Mars Artists Community creating several dozen more designs, with such slogans as, "Traitors Return to Earth" and "What Would Zheng He Do?"

"What if NASA could land astronauts on Mars in a decade, for not ridiculously more money than the $10 billion the agency spends annually on human spaceflight? It's possible, say some space buffs, although there's a catch. The astronauts we'd send would never come home. Relieving NASA of the need to send fuel and rocketry to blast humans off the Martian surface, which has slightly more than twice the gravity of the moon, would actually reduce costs by about a factor of 10, by some estimates."

Hard Science Fiction writer Mike Brotherton has found "Mars to Stay" appealing for both economic and safety reasons, but more emphatically, as a fulfillment of the ultimate mandate by which "our manned space program is sold, at least philosophically and long-term, as a step to colonizing other worlds." Two thirds of the respondents to a poll on his website expressed interest in a one-way ticket to Mars "if mission parameters are well-defined" (not suicidal).

In June 2010 Buzz Aldrin gave an interview to Vanity Fair in which he restated Mars to Stay:

"Did the Pilgrims on the Mayflower sit around Plymouth Rock waiting for a return trip? They came here to settle. And that's what we should be doing on Mars. When you go to Mars, you need to have made the decision that you're there permanently. The more people we have there, the more it can become a sustaining environment. Except for very rare exceptions, the people who go to Mars shouldn't be coming back. Once you get on the surface, you're there."

The October-November, 2010, Journal of Cosmology reprinted an article by Dirk Schulze-Makuch (Washington State University) and Paul Davies (Arizona State University) from the book "The Human Mission to Mars. Colonizing the Red Planet." The following summarizes their rational for Mars to Stay:

"A human mission to Mars is technologically feasible, but hugely expensive requiring enormous financial and political commitments. A creative solution to this dilemma would be a one-way human mission to Mars in place of the manned return mission that remains stuck on the drawing board. Our proposal would cut the costs several fold but ensure at the same time a continuous commitment to the exploration of Mars in particular and space in general. It would also obviate the need for years of rehabilitation for returning astronauts, which would not be an issue if the astronauts were to remain in the low-gravity environment of Mars. We envision that Mars exploration would begin and proceed for a long time on the basis of outbound journeys only."

"New York Times" op-eds

"Mars to Stay" has been explicitly proposed by two op-ed pieces in the "New York Times".

"A One-Way Ticket to Mars" Krauss, Lawrence. New York Times Op-Ed, Sept 1, 2009:"

Following a similar line of argument to Buzz Aldrin, Lawrence Krauss asks in an Op-Ed, "Why are we so interested in bringing the Mars astronauts home again?". While the idea of sending astronauts aloft never to return may be jarring upon first hearing, the rationale for one-way exploration and settlement trips has both historical and practical roots. For example, colonists and pilgrims seldom set off to the New World with the expectation of a return trip. As Lawrence Krauss writes, "To boldly go where no one has gone before does not require coming home again."

Dr. Krauss modifies the standard "Mars to Stay" architecture by "restricting the voyage to older astronauts, whose longevity is limited. Here again, I have found a significant fraction of scientists older than 65 who would be willing to live out their remaining years on the red planet or elsewhere." This initial first generation of elderly astronauts would accept higher radiation doses while building eventual subsurface habitats, presumably, because the effects of increased radiation would not affect them during the remainder of their lives.

"If it sounds unrealistic to suggest that astronauts would be willing to leave home never to return alive, then consider the results of several informal surveys I and several colleagues have conducted recently. One of my peers in Arizona recently accompanied a group of scientists and engineers from the Jet Propulsion Laboratory on a geological field trip. During the day, he asked how many would be willing to go on a one-way mission into space. Every member of the group raised his hand." Krauss, Lawrence. New York Times Op-Ed "A One-Way Ticket to Mars"

Additional immediate and pragmatic reasons to consider one-way human space exploration missions are explored by Krauss. Since much of the cost of a voyage to Mars will be spent on coming home again, if the fuel for the return is carried onboard, this greatly increases the mission mass requirement - which in turn requires even more fuel. "Human space travel is so expensive and so dangerous" according to Krauss, "we are going to need novel, even extreme solutions if we really want to expand the range of human civilization beyond our own planet." Delivering food and supplies to pioneers via unmanned spacecraft is less expensive than designing an immediate return trip.

"Life (and Death) on Mars," Davies, Paul. New York Times Op-Ed, January 15, 2004:"

In an earlier 2004 Op-Ed for the New York Times, Paul Davies motivation for the less expensive, permanent "one-way to stay option" arises from a theme common in "Mars to Stay" advocacy: "Mars is one of the few accessible places beyond Earth that could have sustained life [...and] alone among our sister planets, it is able to support a permanent human presence."

"Why is going to Mars so expensive? Mainly it's the distance from Earth. At its closest point in orbit, Mars lies 35 million miles away from us, necessitating a journey of many months, whereas reaching the Moon requires just a few days' flight. On top of this, Mars has a surface gravity that, though only 38 percent of Earth's, is much greater than the Moon's. It takes a lot of fuel to blast off Mars and get back home. If the propellant has to be transported there from Earth, costs of a launching soar. Without some radical improvements in technology, the prospects for sending astronauts on a round-trip to Mars any time soon are slim, whatever the presidential rhetoric. What's more, the president's suggestion of using the Moon as a base — a place to assemble equipment and produce fuel for a Mars mission less expensively — has the potential to turn into a costly sideshow. There is, however, an obvious way to slash the costs and bring Mars within reach of early manned exploration. The answer lies with a one-way mission."

Under Davies' plan an initial colony of four astronauts equipped with a small nuclear reactor and a couple of rover vehicles would make their own oxygen, grow food, and even initiate building projects using local raw materials. Supplemented by food shipments, medical supplies, and replacement gadgets from Earth, the colony would be indefinitely sustained. Davies argues that since, "some people gleefully dice with death in the name of sport or adventure [and since] dangerous occupations that reduce life expectancy through exposure to hazardous conditions or substances are commonplace," we ought to not find the risks involved in a Mars to Stay architecture unusual.

"A century ago, explorers set out to trek across Antarctica in the full knowledge that they could die in the process, and that even if they succeeded their health might be irreversibly harmed. Yet governments and scientific societies were willing sponsors of these enterprises." Asks Davies, "Why should it be different today?"

Chapter- 7

Space Tourism

Space tourist Mark Shuttleworth

Space tourism is space travel for recreational, leisure or business purposes. Orbital space tourism opportunities are limited and expensive, with only the Russian Space Agency providing transport. The price for a flight brokered by Space Adventures to the International Space Station aboard a Soyuz spacecraft was US$ 20–35 million. The space tourists usually sign contracts with third parties to conduct certain research while in orbit. This helps to minimize their own expenses.

Some use the term "personal spaceflight" as in the case of the Personal Spaceflight Federation.

A number of startup companies have sprung up in recent years, hoping to create a space tourism industry.

Russia halted orbital space tourism in 2010 due to the increase in the International Space Station crew size, using the seats for expedition crews that would be sold to paying spaceflight participants. However it is planned to resume in 2012, when the number of single-use three-man Soyuz launches rises to five a year.

Early dreams

After early successes in space, much of the public saw intensive space exploration as inevitable. Those aspirations are remembered in science fiction such as Arthur C. Clarke's *A Fall of Moondust* and also *2001: A Space Odyssey*, Roald Dahl's *Charlie and the Great Glass Elevator*, Joanna Russ's 1968 novel *Picnic on Paradise*, and Larry Niven's Known Space stories. Lucian in the 2nd century AD in his book *True History* examines the idea of a crew of men whose ship travels to the Moon during a storm. Jules Verne also took up the theme of lunar visits in his books, *From the Earth to the Moon* and *Around the Moon*. Robert A. Heinlein’s short story *The Menace from Earth*, published in 1957, was one of the first to incorporate elements of a developed space tourism industry within its framework. During the 1960s and 1970s, it was common belief that space hotels would be launched by 2000. Many futurologists around the middle of the 20th century speculated that the average family of the early 21st century would be able to enjoy a holiday on the Moon. In the 1960s, Pan Am established a waiting list for future flights to the moon, issuing free "First Moon Flights Club" membership cards to those who requested them.

The end of the Space Race, however, signified by the Moon landing, decreased the emphasis placed on space exploration by national governments and therefore led to decreased demands for public funding of manned space flights.

Precursors

The Soviet space program was aggressive in broadening the pool of cosmonauts. The Soviet Intercosmos program include cosmonauts selected from Warsaw Pact members (from Czechoslovakia, Poland, East Germany, Bulgaria, Hungary, Romania) and later from allies of the USSR (Cuba, Mongolia, Vietnam) and non-aligned countries (India, Syria, Afghanistan). Most of these cosmonauts received full training for their missions and were treated as equals, but especially after the Mir program began, were generally given shorter flights than Soviet cosmonauts. The European Space Agency took advantage of the program as well.

The U.S. space shuttle program included payload specialist positions which were usually filled by representatives of companies or institutions managing a specific payload on that mission. These payload specialists did not receive the same training as professional NASA astronauts and were not employed by NASA. In 1983, Ulf Merbold from ESA and Byron Lichtenberg from MIT (engineer and Air Force fighter pilot) were the first Payload Specialists to fly on the shuttle, becoming the first non-NASA astronauts. In 1984, Charlie Walker became the first non-government astronaut to fly, with his flight paid for by his employer, McDonnell Douglas. NASA was also eager to prove its capability to Congressional sponsors. Senator Jake Garn was flown on the shuttle in 1985, followed by Representative Bill Nelson (now Senator) in 1986. As the shuttle program expanded, the Teacher in Space program was developed as a way to expand publicity and educational opportunities for NASA. Christa McAuliffe would have been the first Teacher in Space, but was killed in the Challenger disaster and the program was canceled. During the same period a Journalist in Space program was frequently discussed, with individuals such as Walter Cronkite considered a front runners, but no formal program was ever developed. McAuliffe's backup in the Teacher in Space Program, Barbara Morgan, eventually got hired in 1998 as a professional astronaut and flew on STS-118 as a mission specialist where she spoke to many students as an educator during the trip.

A second journalist-in-space program, in which NASA green-lighted Miles O'Brien to fly on the space shuttle, was scheduled to be announced in 2003. That program was canceled in the wake of the Columbia accident on STS-107 and subsequent emphasis on finishing the International Space Station before retiring the space shuttle.

With the realities of the post-Perestroika economy in Russia, its space industry was especially starved for cash. The Tokyo Broadcasting System (TBS) offered to pay for one of its reporters to fly on a mission. For $28 million, Toyohiro Akiyama was flown in 1990 to Mir with the eighth crew and returned a week later with the seventh crew. Akiyama gave a daily TV broadcast from orbit and also performed scientific experiments for Russian and Japanese companies. However, since the cost of the flight was paid by his employer, Akiyama could be considered a business traveler rather than a tourist.

In 1991, British chemist Helen Sharman was selected from a pool of 13,000 applicants to be the first Briton in space. The program was known as Project Juno and was a cooperative arrangement between the Soviet Union and a group of British companies. The Project Juno consortium failed to raise the funds required, and the program was almost cancelled. Reportedly Mikhail Gorbachev ordered it to proceed under Soviet expense in the interests of international relations, but in the absence of Western underwriting, less expensive experiments were substituted for those in the original plans. Sharman flew aboard Soyuz TM-12 to Mir and returned aboard Soyuz TM-11.

Orbital space tourism

At the end of the 1990s, MirCorp, a private venture by then in charge of the space station, began seeking potential space tourists to visit Mir in order to offset some of its maintenance costs. Dennis Tito, an American businessman and former JPL scientist, became their first candidate. When the decision to de-orbit Mir was made, Tito managed to switch his trip to the International Space Station through a deal between MirCorp and U.S.-based Space Adventures, Ltd., despite strong opposition from senior figures at NASA. From the beginning of the International Space Station expeditions, NASA stated it wasn't interested in space guests. Space Adventures remains the only company to have sent paying passengers to space.

In conjunction with the Federal Space Agency of the Russian Federation and Rocket and Space Corporation (Energia), Space Adventures facilitated the flights for all of the world's first private space explorers. The first three participants paid in excess of $20 million (USD) each for their 10-day visit to the ISS.

On April 28, 2001, Dennis Tito became the first "fee-paying" space tourist when he visited the International Space Station (ISS) for seven days. He was followed in 2002 by South African computer millionaire Mark Shuttleworth. The third was Gregory Olsen in 2005, who was trained as a scientist and whose company produced specialist high-sensitivity cameras. Olsen planned to use his time on the ISS to conduct a number of experiments, in part to test his company's products. Olsen had planned an earlier flight, but had to cancel for health reasons.

After the Columbia disaster, space tourism on the Russian Soyuz program was temporarily put on hold, because Soyuz vehicles became the only available transport to the ISS. However, in 2006, space tourism was resumed. On September 18, 2006, Anousheh Ansari, an Iranian American (Soyuz TMA-9), became the fourth space tourist (she prefers "private space explorer".). On April 7, 2007, Charles Simonyi, an American businessman of Hungarian descent, joined their ranks (Soyuz TMA-10). Simonyi became the first repeat space tourist, paying again to fly on Soyuz TMA-14 in March–April 2009. Guy Laliberté became the next space tourist in September, 2009 aboard Soyuz TMA-16.

In 2003, NASA and the Russian Space Agency agreed to use the term 'Spaceflight Participant' to distinguish those space travelers from astronauts on missions coordinated by those two agencies. Tito, Shuttleworth, Olsen, Ansari, and Simonyi were designated as such during their respective space flights. NASA also lists Christa McAuliffe as a "Space Flight Participant" (although she did not pay a fee), apparently due to her non-technical duties aboard the STS-51-L flight.

As reported by Reuters on 3 March 2010, Russia announced that the country will double the number of launches of three-man Soyuz ships to four that year, because "permanent crews of professional astronauts aboard the expanded [ISS] station are set to rise to six"; regarding space tourism, the head of the Russian Cosmonauts' Training Center said "for some time there will be a break in these journeys". Then, on 18 March 2010 Interfax news agency reported that Russia plans to launch five Soyuz spacecrafts a year since 2012: four per the ISS program, and an additional spacecraft which may be used for space tourism. On January 12, 2011, Space Adventures and the Russian Federal Space Agency announced that orbital space tourism would resume in 2013 with the increase of manned Soyuz launches to the ISS from four to five per year.

List of flown space tourists

Seven of the space tourists flew to and from the International Space Station on Soyuz spacecraft through the space tourism company, Space Adventures:

Space tourist	Nationality	Year	Duration of flight	Flight
1. Dennis Tito	American	2001	9 days (Apr 28 – May 6)	Launch: Soyuz TM-32 Return: Soyuz TM-31
2. Mark Shuttleworth	South African	2002	11 days (Apr 25 – May 5)	Launch: Soyuz TM-34 Return: Soyuz TM-33
3. Gregory Olsen	American	2005	11 days (Oct 1 – Oct 11)	Launch: Soyuz TMA-7 Return: Soyuz TMA-6
4. Anousheh Ansari	Iranian / American	2006	12 days (Sept 18 – Sept 29)	Launch: Soyuz TMA-9 Return: Soyuz TMA-8
5. Charles Simonyi	Hungarian / American	2007	15 days (Apr 7 – Apr 21)	Launch: Soyuz TMA-10 Return: Soyuz TMA-9
		2009	14 days (Mar 26 – Apr 8)	Launch: Soyuz TMA-14 Return: Soyuz TMA-13
6. Richard Garriott	American / British	2008	12 days (Oct 12 – Oct 23)	Launch: Soyuz TMA-13 Return: Soyuz TMA-12
7. Guy Laliberté	Canadian	2009	12 days (Sept 30 – Oct 11)	Launch: Soyuz TMA-16 Return: Soyuz TMA-14

Suborbital flights

No suborbital space tourism has occurred yet, but since it is projected to be more affordable, it is viewed as a money-making proposition by several companies, including RocketShip Tours, Space Adventures, Virgin Galactic, Starchaser, Blue Origin, Armadillo Aerospace, XCOR Aerospace, the European "Project Enterprise", and others (for example, in 1966 Robert Truax founded company Truax Engineering, Inc. and the new projekt of a Danish non-profit rocketgroup Copenhagen Suborbitals - 2010). Most are proposing vehicles that make suborbital flights peaking at an altitude of 100-160 kilometres. Passengers would experience three to six minutes of weightlessness, a view of a twinkle-free starfield, and a vista of the curved Earth below. Projected costs are expected to be about $200,000 per passenger.

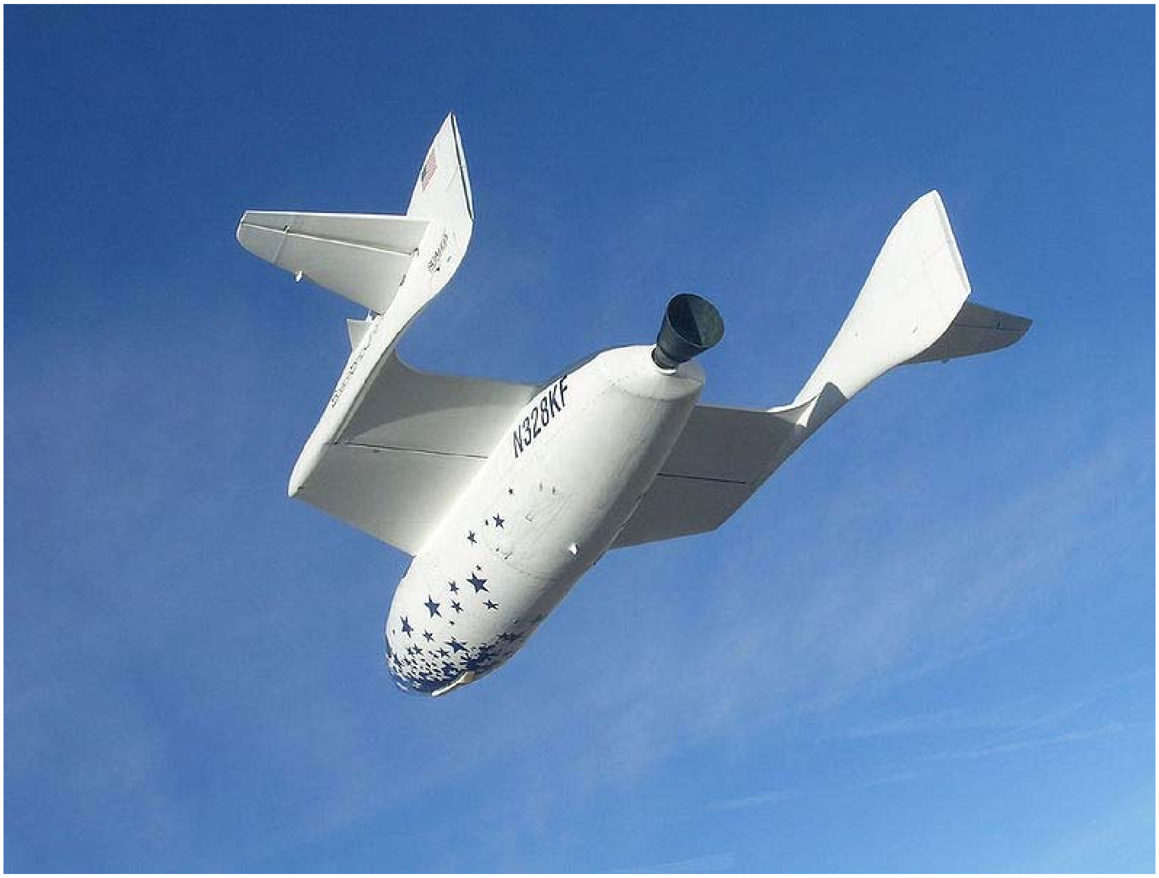
As of November 2007 Virgin Galactic had pre-sold nearly 200 seats for their suborbital space tourism flights, according to the company's president.

The X Prize

The X-Prize being awarded to the Scaled Composites team

On October 4, 2004, the SpaceShipOne, designed by Burt Rutan of Scaled Composites, won the $10,000,000 X Prize, which was designed to be won by the first private company who could reach and surpass an altitude of 62 miles (100 km) twice within two weeks. The altitude is beyond the Kármán Line, the arbitrarily defined boundary of space. The first flight was flown by Michael Melvill on June 21, 2004 to a height of 62 miles, making him the first commercial astronaut. The prize-winning flight was flown by Brian Binnie, which reached a height of 69.6 miles, breaking the X-15 record.

Virgin Galactic



Spaceship One, the first privately funded and constructed spacecraft to fly above the 100 km Karman Line.

Virgin Galactic, one of the leading potential space tourism groups, is planning to begin passenger service aboard the VSS Enterprise, a Scaled Composites SpaceShipTwo type spacecraft. The initial seat price will be $200,000, but that price is expected to eventually fall to $20,000. To date, over 80,000 people have made down payments on bookings. Headed by Sir Richard Branson's Virgin Group, Virgin Galactic hopes to be the first private space tourism company to regularly send civilians into space. A citizen astronaut will only require three days of training before spaceflight. SpaceShipTwo is a scaled up version of SpaceShipOne, the spacecraft which claimed the Ansari X Prize. Both spacecraft were designed by Burt Rutan's Scaled Composites. Launches will initially occur at the Mojave Spaceport in California, and will then be moved to Spaceport America in Upham, New Mexico. Tourists will also be flown from Kiruna, Sweden The spacecraft will travel 360,000 feet (109.73 km/68.18 miles) high. This goes beyond the internationally defined boundary between Earth and space of 100 km. Spaceflights will last 2.5 hours, carry 6 passengers, and reach a speed of Mach 3. SpaceShipTwo will not require a space shuttle-like heat shield for atmospheric reentry as it will not experience the extreme aerodynamic heating experienced during reentry at orbital velocities (approximately Mach 22.5 at a typical shuttle altitude of 300 km, or 185 miles). The glider will employ a "feathering" technique to manage drag during the unpowered descent and landing. SpaceShipTwo will use a single hybrid rocket motor to launch from mid-air after detaching from a mother ship at 50,000 feet, instead of NASA's space shuttle's ground-based launch.

Project Enterprise

Project Enterprise was launched by the German TALIS Institute in 2004 and is the first project of its kind in Europe. The goal is to develop a rocket-propelled spaceplane by 2011 that will carry one pilot and up to five passengers into suborbital space. The plane will launch from the ground using rockets, and will return in an unpowered flight like Virgin Galactic's SpaceShipTwo. The prototypes and finished spaceplane will be launched from an airport near Cochstedt (Germany; Saxony-Anhalt).

Since 2004, the TALIS Institute has gained many industrial partners, including XtremeAir, who will manufacture the airframe, and Swiss Propulsion Laboratory SPL, who will deliver the propulsion components. XtremeAir is known for their acrobatic airplanes, and SPL has designed and tested liquid propellant rocket engines since 1998.

Current work is focusing on the first prototype, the "Black Sky": An existing acrobatic airplane that would be fitted with a single rocket engine and a new wing. The rocket engine is expected to deliver a thrust of 10 kN. The test program for this engine started in 2007 at SPL and is expected to fly by 2010.

Legality

United States

In December 2005, the U.S. Government released a set of proposed rules for space tourism. These included screening procedures and training for emergency situations, but not health requirements.

Under current US law, any company proposing to launch paying passengers from American soil on a suborbital rocket must receive a license from the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST). The licensing process focuses on public safety and safety of property, and the details can be found in the Code of Federal Regulations, Title 14, Chapter III. This is in accordance with the Commercial Space Launch Amendments Act passed by Congress in 2004.

Orbital flights, space stations and space hotels

- EADS Astrium, a subsidiary of European aerospace giant EADS, announced its space tourism project on June 13, 2007.
- SpaceX is a private space company which is developing their own rocket family called *Falcon* and a capsule named Dragon, capable of sending up to 7 people to any space station, either ISS or a possible station by Bigelow Aerospace. Falcon 1

has already undertaken testflights and successfully completed its first commercial flight on July 14, 2009, deploying the Malaysian RazakSAT into orbit. Falcon 9 (which will be the rocket for the Dragon capsule) was first launched June 4, 2010 at Space Launch Complex 40 in Cape Canaveral. An initial prototype of the Dragon capsule is expected to be used on this test flight; SpaceX anticipates that Dragon could be qualified for human spaceflight within 3 years of the receipt of NASA CCDV funding.

- Space Adventures Ltd. have also announced that they are working on circumlunar missions to the moon, with the price per passenger being $100,000,000. They are currently developing spaceports at the United Arab Emirates (Ras al-Khaimah) and in Singapore.
- Orbital space tourist flights are also being planned by Excalibur Almaz, using modernized *TKS* space capsules.

Several plans have been proposed for using a space station as a hotel. American motel tycoon Robert Bigelow has acquired the designs for inflatable space habitats from the Transhab program abandoned by NASA. His company, Bigelow Aerospace, has already launched two first inflatable habitat modules. The first, named Genesis I, was launched 12 July 2006. The second test module, Genesis II, was launched 28 June 2007. Both Genesis habitats remain in orbit as of mid-2009. As of 2006, Bigelow planned to officially launch the first commercial space station by 2012 (tagged *Nautilus*) which will have 330 cubic meters (almost as big as the ISS's 425 cubic meters of usable volume).

Bigelow Aerospace was offering the America's Space Prize, a $50 million prize to the first US company to create a reusable spacecraft capable of carrying passengers to a Nautilus space station, no one made an attempt to win the prize.

Other companies have also expressed interest in constructing "space hotels". For example, Excalibur Almaz plans to modernize and launch its Soviet-era Almaz space stations, which will feature the largest windows ever on spacecraft. Virgin's Richard Branson has expressed his hope for the construction of a space hotel within his lifetime. He expects that beginning a space tourism program will cost $100 million. Hilton International announced the Space Islands Project, a plan to connect together used space shuttle fuel tanks, each the diameter of a Boeing 747 aircraft. A separate organization, Space Island Group announced their distinct Space Island Project (note the singular "Island"), and plans on having 20,000 people on their "space island" by 2020, with the number of people doubling for each decade. British Airways has expressed interest in the venture. If and when Space Hotels develop, it would initially cost a passenger $60,000, with prices lowering over time.

Fashion designer Eri Matsui has designed clothing, including a wedding gown, intended to look best in weightless environments.

Advocacy, education, and industry organizations

Several organizations have been formed to promote the space tourism industry, including the Space Tourism Society, and others.   More information about the future of Space Tourism can be found at Space Tourism Lecture, which is a free online Space Tourism Lecture handout collection. Since 2003 Dr. Robert A. Goehlich teaches the world's first and only Space Tourism class at Keio University, Yokohama, Japan. Space Tourism Syllabus UniGalactic Space Travel Magazine is a bi-monthly educational publication covering space tourism and space exploration developments in companies like SpaceX, Orbital Sciences, Virgin Galactic and organizations like NASA. The content of UniGalactic Space Travel Magazine can be found on UniGalactic web site.

Opinions of commercial space tourism

A web-based survey suggested that over 70% of those surveyed wanted less than or equal to 2 weeks in space; in addition, 88% wanted to spacewalk (only 74% of these would do it for a 50% premium), and 21% wanted a hotel or space station.

The concept has met with some criticism from bureaucrats, notably Günter Verheugen, vice-president of the European Commission, who said of the EADS Astrium Space Tourism Project "It's only for the super rich, which is against my social convictions".

Objections to "space tourist" terminology

Dennis Tito, Mark Shuttleworth, Gregory Olsen, Anousheh Ansari and Richard Garriott have all expressed a preference to be called something other than "space tourist". In each case, they explained their preferences by pointing out that they carried out scientific experiments as part of their journey; Garriott additionally emphasized their training is identical to requirements of non-Russian Soyuz crew members, and that teachers and other non-professional astronauts chosen to fly with NASA are called astronauts. Garriott prefers "cosmonaut" or "astronaut", but will accept "private" in front of either. Tito has asked to be known as an "independent researcher". Shuttleworth proposed "pioneer of commercial space travel". Olsen preferred "private researcher." Ansari prefers the term "private space explorer". Alone among those who have paid to go to orbit so far, Charles Simonyi seems to have no concerns about calling it "space tourism", even in reference to his own experience. Asked in an interview "Do you foresee a day when space tourism is not just the province of billionaires - when it will be as affordable as plane travel?", he did not object to the implicit categorization of his own trip, but rather answered "Yes, the only question is when ...."

NASA and the Russian Federal Space Agency agreed to use the term "spaceflight participant" to distinguish those space travelers from astronauts on missions coordinated by those two agencies.

Although many space enthusiasts subscribe to the notion of space tourism as a potential burgeoning industry that could further the development and settlement of space, some of these same enthusiasts object to the use of the term "space tourist". Rick Tumlinson of the Space Frontier Foundation, for example, has said

"I hate the word tourist, and I always will .... 'Tourist' is somebody in a flowered shirt with three cameras around his neck."

Others with perhaps less enthusiasm for space development seem to agree. Alex Tabarrok has categorized it as a kind of "space adventure travel". The mere fact of people paying for a travel experience does not, in his view, make that activity "tourism".

"At best and for the foreseeable future space travel will remain akin to climbing Everest, dangerous and uncommon. Yes, we might see 100 flights a year but that's not space tourism - tourism is fat guys with cameras."

Brian Binnie, and Mike Melvill, the pilots of Scaled Composites Space Ship One were awarded the title of Commercial Astronaut by the United States Federal Aviation Administration. This is a new classification that distinguishes the holder as an astronaut, but is not associated with the United States NASA space program.

Chapter- 8

Private Spaceflight

Astronaut Dale A. Gardner holding a "For Sale" sign

Private spaceflight is flight above 100 km (62 mi) Earth altitude conducted by and paid for by an entity other than a government. In the early decades of the Space Age, the government space agencies of the Soviet Union and United States pioneered space technology augmented by collaboration with affiliated design bureaus in the USSR and private companies in the US. The European Space Agency was formed in 1975, largely following the same model of space technology development. Later on, large defence contractors began to develop and operate space launch systems, derived from government rockets and commercial satellites. Private spaceflight in Earth orbit includes communications satellites, satellite television, satellite radio, astronaut transport and suborbital and orbital space tourism. Recently, entrepreneurs have begun designing and deploying competitive space systems to the national-monopoly governmental systems of the early decades of the space age. Successes to date include flying suborbital spaceplanes and launching lightweight orbital rockets. Planned private spaceflights beyond Earth orbit include solar sailing prototypes, deep space burial and personal spaceflights around the Moon. A private orbital habitat prototype is already in Earth orbit, with larger versions to follow.

History of commercial space transportation

Launch of a Proton rocket

During the early years of spaceflight, since the mid-twentieth century, only nation states had the resources to develop and fly spacecraft. Spaceflight was thus the monopoly province of a small group of national governments. "The primary reason for this was the fact that space exploration is extremely expensive and highly complicated to achieve successfully."

Both the U.S. space program and Soviet space program were operated using mainly military pilots as astronauts. During this period, no commercial space launches were available to private operators, and no private organization was able to offer space launches. Eventually, private organizations were able to both offer and purchase space launches, thus beginning the period of private spaceflight.

The first phase of private space operation was the launch of the first commercial communications satellites. The U.S. Communications Satellite Act of 1962 opened the way to commercial consortia owning and operating their own satellites, although these were still launched on state-owned launch vehicles.

History of full private space transportation includes early efforts by Germany OTRAG company in the 20th century and numerous modern projects of orbital and suborbital launch systems in the 21st century. Last ones counts the manned programs also - most famous and important of them are suborbital flights of Virgin Galactic and orbital flights of SpaceX and other COTS participants.

European state-sponsorship

On March 26, 1980, the European Space Agency created Arianespace, the world's first commercial space transportation company. Arianespace produces, operates and markets the Ariane launcher family. By 1995 Arianespace lofted its 100th satellite and by 1997 the Ariane rocket had its 100th launch. Arianespace's 23 shareholders represent scientific, technical, financial and political entities from 10 different European countries.

Private European

American deregulation

From the beginning of the Shuttle program until the Challenger disaster in 1986, it was the policy of the United States that NASA be the public-sector provider of U.S. launch capacity to the world market. Initially NASA subsidized satellite launches with the intention of eventually pricing Shuttle service for the commercial market at long-run marginal cost.

On October 30, 1984, United States President Ronald Reagan signed into law the Commercial Space Launch Act. This enabled an American industry of private operators of expendable launch systems. Prior to the signing of this law, all commercial satellite launches in the United States were restricted by Federal regulation to NASA's Space Shuttle.

On November 5, 1990, United States President George H. W. Bush signed into law the Launch Services Purchase Act. The Act, in a complete reversal of the earlier Space Shuttle monopoly, ordered NASA to purchase launch services for its primary payloads from commercial providers whenever such services are required in the course of its activities.

Commercial launches outnumbered government launches at the Eastern Test Range in 1997.

Russian privatization

The Russian government sold part of its stake in RSC Energia to private investors in 1994. Energia together with Khrunichev constituted most of the Russian manned space program. In 1997, the Russian government sold off enough of its share to lose the majority position.

American subsidization

In 1996 the United States government selected Lockheed Martin and Boeing to each develop Evolved Expendable Launch Vehicles (EELV) to compete for launch contracts and provide assured access to space. The government's acquisition strategy relied on the strong commercial viability of both vehicles to lower unit costs. This anticipated market demand did not materialize, but both the Delta IV and Atlas V EELVs remain in active service.

Launch alliances

Since 1995 Khrunichev's Proton rocket is marketed through International Launch Services while the Soyuz rocket is marketed via Starsem. Energia builds the Soyuz rocket and owns part of the Sea Launch project which flies the Ukrainian Zenit rocket.

In 2003 Arianespace joined with Boeing Launch Services and Mitsubishi Heavy Industries to create the Launch Services Alliance. In 2005, continued weak commercial demand for EELV launches drove Lockheed Martin and Boeing to propose a joint venture called the United Launch Alliance to service the United States government launch market.

Human spaceflight privatization

On February 1, 2010 United States President Barack Obama proposed in a speech that NASA exit the business of flying astronauts from Earth to orbit. The proposal acted on the findings of the 2009 Augustine Commission and built on the success of the Commercial Resupply Services that outsourced American cargo delivery to the International Space Station.

Today many commercial space transportation companies offer launch services to satellite companies and government space organizations around the world. In 2005 there were 18 total commercial launches and 37 non-commercial launches. Russia flew 44% of commercial orbital launches, while Europe had 28% and the United States had 6%.

Private spaceflight companies

Commercial launchers

The space transport business serves primarily national government and large commercial customer segments. Launches of government payloads, including military, civilian and scientific satellites, is the largest market segment at nearly $100 billion a year. This segment is dominated by domestic favorites such as the United Launch Alliance for U.S. government payloads and Arianespace for European satellites. The commercial payload segment, valued at under $3 billion a year, is dominated by Arianespace, with over 50% of the market segment, followed by Russian launchers.

Commercial Orbital Transportation Services

Computer rendering of SpaceX Dragon docking with the ISS

On January 18, 2006 NASA announced an opportunity for commercial providers to demonstrate orbital transportation services. NASA plans to spend $500 million through 2010 to finance development of private sector capability to transport payloads to the International Space Station (ISS). This is more challenging than extant commercial space transportation because it requires precision orbit insertion, rendezvous and possibly docking with another spacecraft. The commercial vendors will compete in specific service areas. NASA Administrator Michael D. Griffin has stated that without affordable commercial orbital transportation services (COTS), the agency will not have enough funds remaining to achieve the objectives of the Vision for Space Exploration.

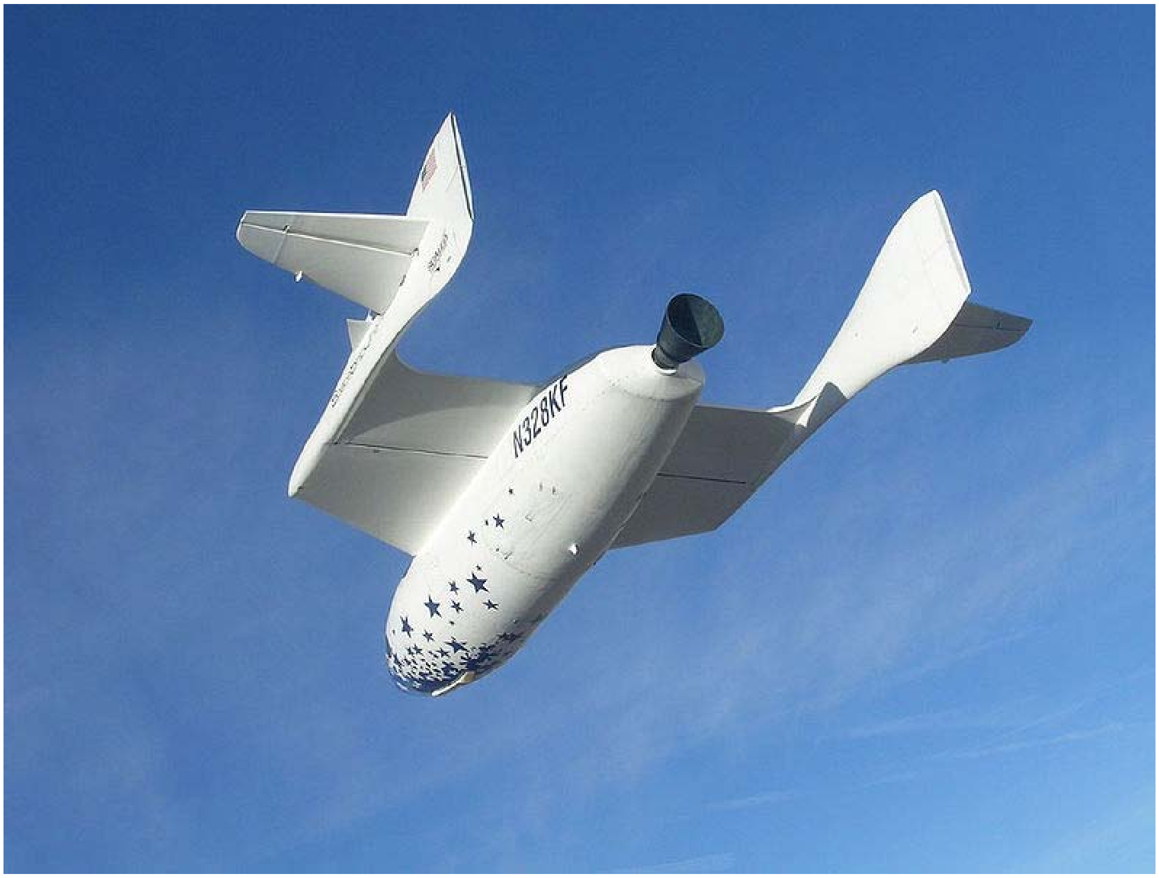
In August 2006, NASA announced that two fledgling aerospace companies, SpaceX and Rocketplane Kistler, had been awarded $278m and $207m, respectively, under the COTS program. NASA anticipates that COTS services to ISS will be necessary through at least 2015. The NASA Administrator has suggested that space transportation services procurement may be expanded to orbital fuel depots and lunar surface deliveries should the first phase of COTS prove successful.

After it transpired that Rocketplane Kistler was failing to meet its deadlines, the NASA terminated their contract in August 2008, after only $32m had been spent. Several months later, in December 2008, NASA announced that they have awarded the remaining $170m to the trusted Orbital Sciences Corporation to develop resupply services to the ISS.

Commercial Space Station

Bigelow Aerospace is developing the *Next-Generation Commercial Space Station*, a private orbital space complex. The space station will be constructed of both Sundancer and BA 330 expandable spacecraft modules as well as a central docking node, propulsion, solar arrays, and attached crew capsules. As of July 2010, initial launch of space station components is planned for 2014, with portions of the station projected to be available for leased use as early as 2015.

Emerging personal spaceflight



SpaceShipOne has a 5-meter wingspan and a 3-person cabin.

Before 2004 no privately operated manned spaceflight had ever occurred. The only private individuals to journey to space went as space tourists in the Space Shuttle or on Russian Soyuz flights to Mir or the International Space Station.

All private individuals who flew to space before Dennis Tito's self-financed International Space Station visit in 2001 had been sponsored by their home governments. Those trips include US Congressman Bill Nelson's January 1986 flight on the Space Shuttle Columbia and Japanese television reporter Toyohiro Akiyama's 1990 flight to the Mir Space Station.

The Ansari X PRIZE was intended to stimulate private investment in the development of spaceflight technologies. The June 21, 2004 test flight of SpaceShipOne, a contender for the X PRIZE, was the first human spaceflight in a privately developed and operated vehicle.

On September 27, 2004, following the success of SpaceShipOne, Richard Branson, owner of Virgin and Burt Rutan, SpaceShipOne's designer, announced that Virgin Galactic had licensed the craft's technology, and were planning commercial space flights in 2.5 to 3 years. A fleet of five craft (SpaceShipTwo, launched from the WhiteKnightTwo carrier airplane) is to be constructed, and flights will be offered at around $200,000 each, although Branson has said he plans to use this money to make flights more affordable in the long term.

XCOR Aerospace also plans to initiate a suborbital commercial spaceflight service with the Lynx rocketplane in 2012 through a partnership with RocketShip Tours. First test flights are planned for 2010.

In December 2004, United States President George W. Bush signed in to law the Commercial Space Launch Amendments Act. The Act resolved the regulatory ambiguity surrounding private spaceflights and is designed to promote the development of the emerging U.S. commercial human space flight industry.

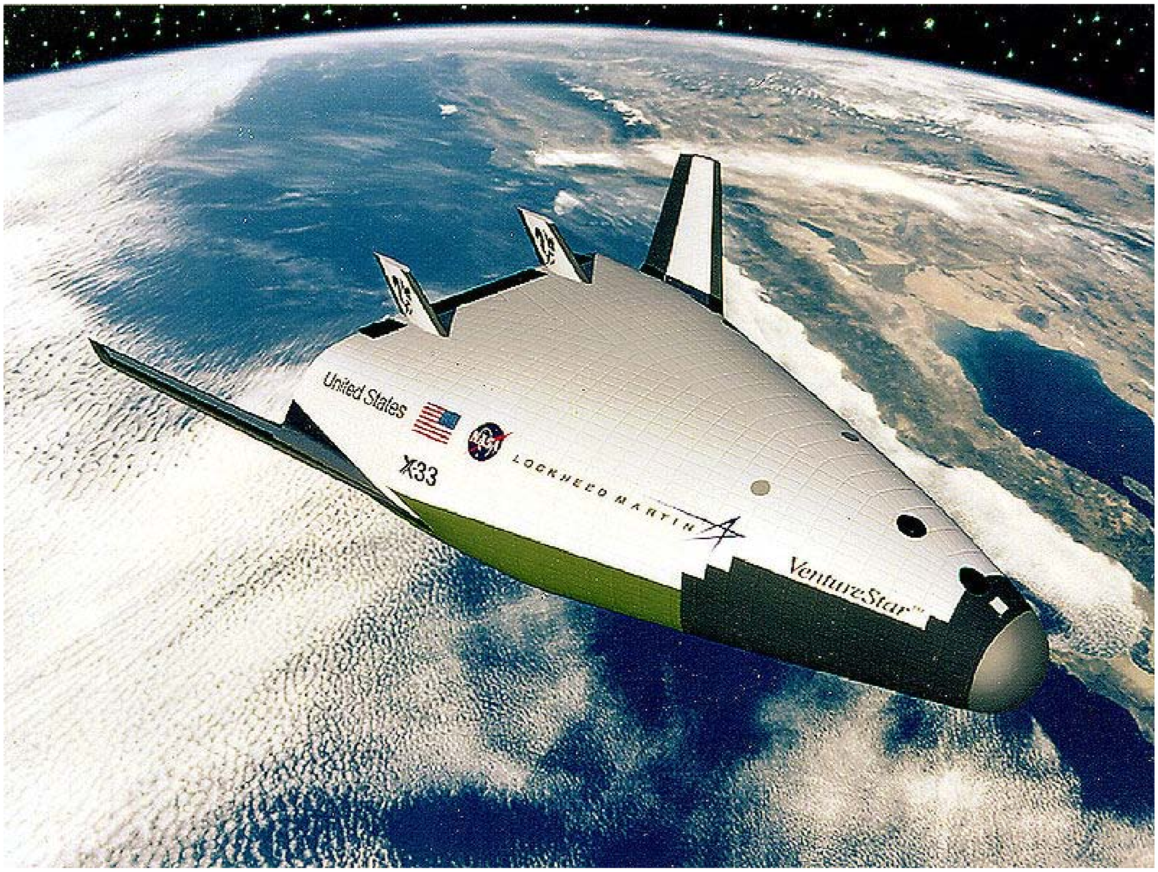
On July 12, 2006, Bigelow Aerospace launched the *Genesis I*, a subscale pathfinder of an orbital space station module. *Genesis II* was launched on June 28, 2007, and there are plans for additional prototypes to be launched in preparation for the production model *BA 330* spacecraft.

On September 28, 2006, Jim Benson, SpaceDev founder, announced he was founding Benson Space Company with the intention of being first to market with the safest and lowest cost suborbital personal spaceflight launches, using the vertical takeoff and horizontal landing Dream Chaser vehicle based on the NASA HL-20 Personnel Launch System vehicle.

Failed spaceflight ventures

After earlier first effort of OTRAG, in the 1990s the projection of a significant demand for communications satellite launches attracted the development of a number of commercial space launch providers. The launch demand largely vanished when some of the largest satellite constellations, such as 288 satellite Teledesic network, were never built. The historic tendency of NASA to compete against the private sector and the Department of Defense's preference for the traditional military industrial complex has discouraged many new space launch ventures.

VentureStar



Lockheed Martin VentureStar

In 1996 NASA selected Lockheed Martin Skunk Works to build the X-33 VentureStar prototype for a single stage to orbit (SSTO) reusable launch vehicle. In 1999, the subscale X-33 prototype's composite liquid hydrogen fuel tank failed during testing. At project termination on March 31, 2001, NASA had funded $912 million of this wedge shaped spacecraft while Lockheed Martin financed $357 million of it. The VentureStar was to have been a full-scale commercial space transport operated by Lockheed Martin.

Beal Aerospace

In 1997 Beal Aerospace proposed the BA-2, a low-cost heavy-lift commercial launch vehicle. On March 4, 2000, the BA-2 project tested the largest liquid rocket engine built since the Saturn V. In October 2000, Beal Aerospace ceased operations citing a decision by NASA and the Department of Defense to commit themselves to the development of the competing government-financed EELV program.

Rotary Rocket

In 1998 Rotary Rocket proposed the Roton, a Single Stage to Orbit (SSTO) piloted Vertical Take-off and Landing (VTOL) space transport. A full scale Roton Atmospheric Test Vehicle flew three times in 1999. After spending tens of millions of dollars in development the Roton failed to secure launch contracts and Rotary Rocket ceased operations in 2001.

Future plans

Many have speculated on where private spaceflight may go in the near future. Numerous projects of orbital and suborbital launch systems for satellites and manned flights exist. Some orbital manned missions would be state-sponsored like most of SpaceX and other COTS participants, and few others would be fully private like Bigelow Aerospace (that order launch service from others) and Excalibur Almaz, PlanetSpace-Silver Dart etc. (that develop their own launch systems). Another possibility is for paid suborbital tourism on craft like those from Virgin Galactic, Space Adventures, XCOR Aerospace, RocketShip Tours, ARCASPACE, PlanetSpace-Canadian Arrow, British Starchaser Industries or non-commercial like Copenhagen Suborbitals. Additionally, suborbital spacecraft have applications for faster intercontinental package delivery and passenger flight.

Private orbital spaceflight, space stations

SpaceX's Falcon 9 rocket, first launched in 2010 with no passengers, is designed to be subsequently man-rated. This would be the first American orbital vehicle since the Space Shuttle to receive this designation, in principle allowing the vehicle to transport paying customers to orbit.

Plans and a full-scale prototype for the SpaceX Dragon, a manned capsule carrying up to 7 passengers, were announced on March 6, 2006.

In December 2010, SpaceX launched the second Falcon 9 and the first operational Dragon spacecraft. The mission was deemed fully successful, marking the first launch, atmospheric reentry and recovery of a spacecraft by a private company. Subsequent COTS missions include increasingly complex orbital tasks, culminating in Dragon docking to the ISS.

An early flight of the Falcon 9 is planned to carry Sundancer, the prototype expandable and habitable space module (based on the former NASA TransHab design) constructed by Bigelow Aerospace. Bigelow Aerospace expects modules like Sundancer and the larger BA 330 to be used for activities like microgravity research, space manufacturing, and space tourism (with modules serving as orbital hotels). To promote private manned launch efforts, Bigelow offered the US$50 million America's Space Prize for the first US-based privately funded team to launch a manned reusable spacecraft to orbit on or before January 10, 2010, though no company was able to meet this deadline.

Excalibur Almaz plans to launch a modernized TKS Spacecraft (for Almaz space station), for tourism and other uses. It will feature the largest window ever on a spacecraft.

On-orbit propellant depots

In a presentation given November 15, 2005, to the 52nd Annual Conference of the American Astronautical Society, NASA Administrator Michael D. Griffin suggested that establishing an on-orbit propellant depot is, "Exactly the type of enterprise which should be left to industry and to the marketplace." At the Space Technology and Applications International Forum in 2007, Dallas Bienhoff of Boeing made a presentation detailing the benefits of propellant depots.

Asteroid mining

Asteroid mining spacecraft

Some have speculated on the profitability of mining metal from asteroids. According to some estimates, a one kilometer-diameter asteroid would contain 30 million tons of nickel, 1.5 million tons of metal cobalt and 7,500 tons of platinum; the platinum alone would have a value of more than $500 billion at current prices. While the potential rewards from asteroid mining are indeed huge, the technical challenges are equally large and it seems likely that the private sector will wait for the publicly funded space program to solve them (e.g. by establishing experimental mines on the Moon).

Energy from space

Future energy development may use energy sources in space and on other planets. Examples include Helium-3 extraction from the Moon, and solar power satellite systems.

Space elevators

A Space Elevator system is a possible launch system, currently under investigation by at least one private venture. There are concerns over cost, general feasibility and some political issues. On the plus side the potential to scale the system to accommodate traffic would (in theory) be greater than some other alternatives. Some factions contend that a space elevator — if successful — would not supplant existing launch solutions but complement them.

Chapter- 9

Space Colonization

Artist Les Bossinas' 1989 concept of Mars mission

Space colonization (also called *space settlement*, *space humanization*, or *space habitation*) is the concept of permanent human habitation outside of Earth. Although hypothetical at the present time, there are many proposals and speculations about the first space colony. It is seen as a long-term goal of some 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 free 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.

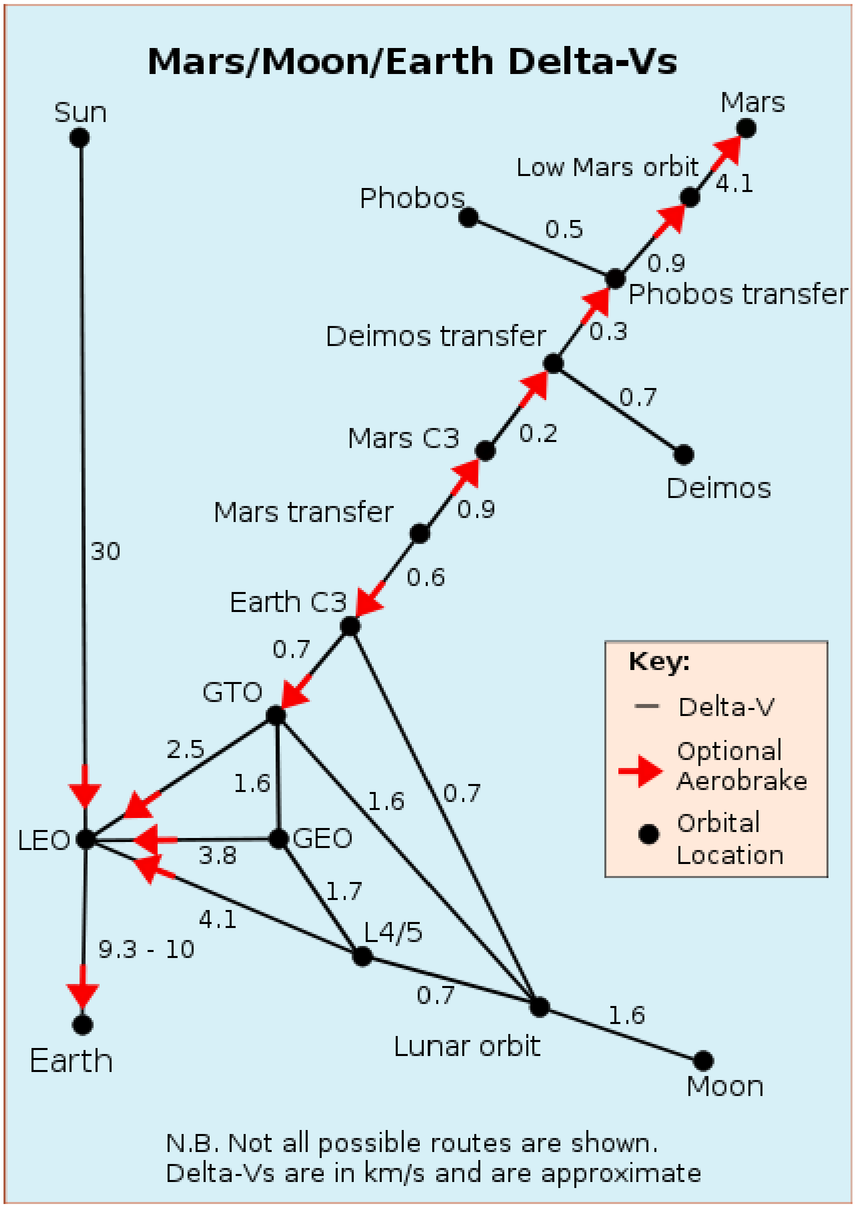
Large structures would be needed to convert sunlight into significant amounts of electrical power for settlers' use. In highly electrified nations on Earth, electrical consumption can average 1 kilowatt/person (or roughly 10 megawatt-hours per person per year.)

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:

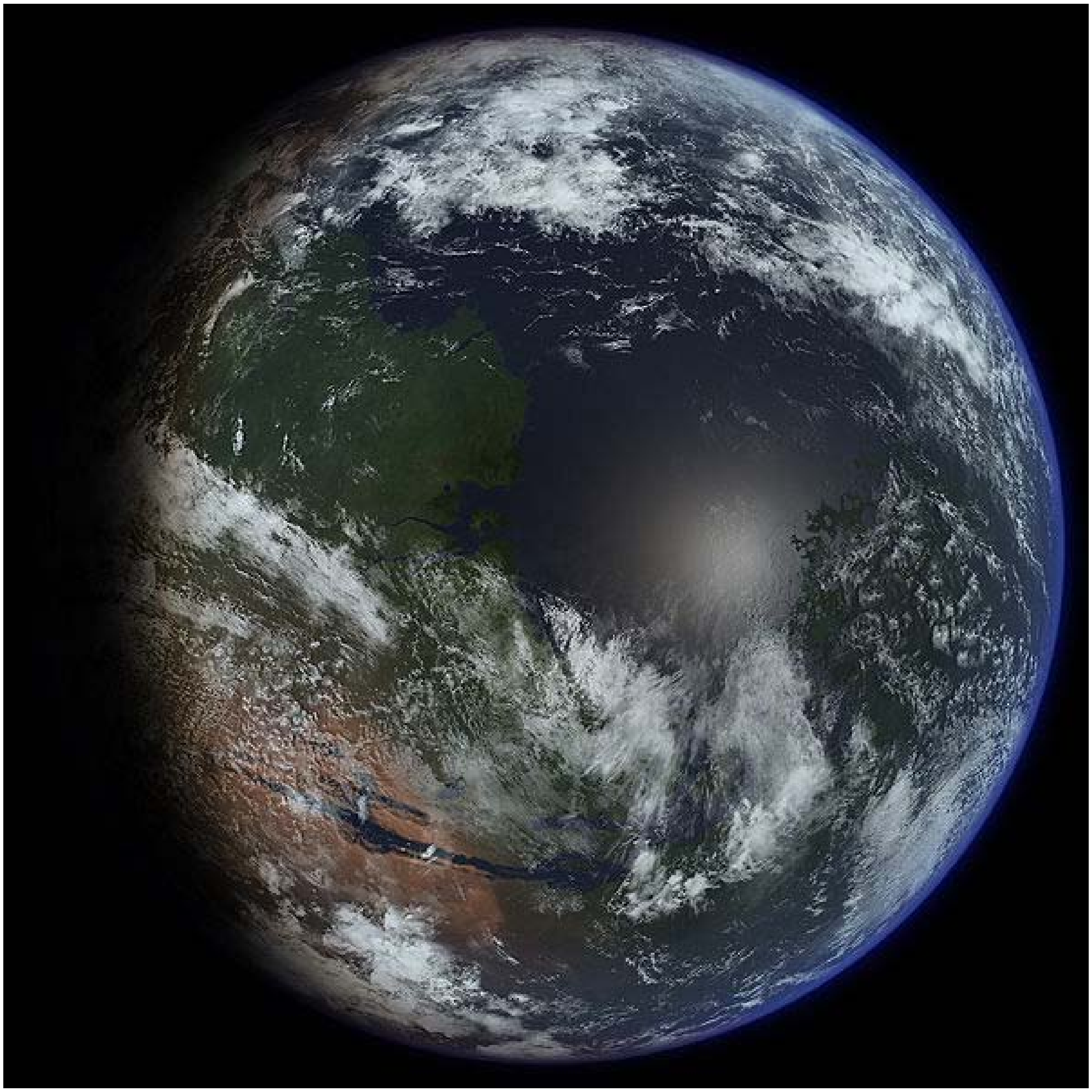
Mars

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)

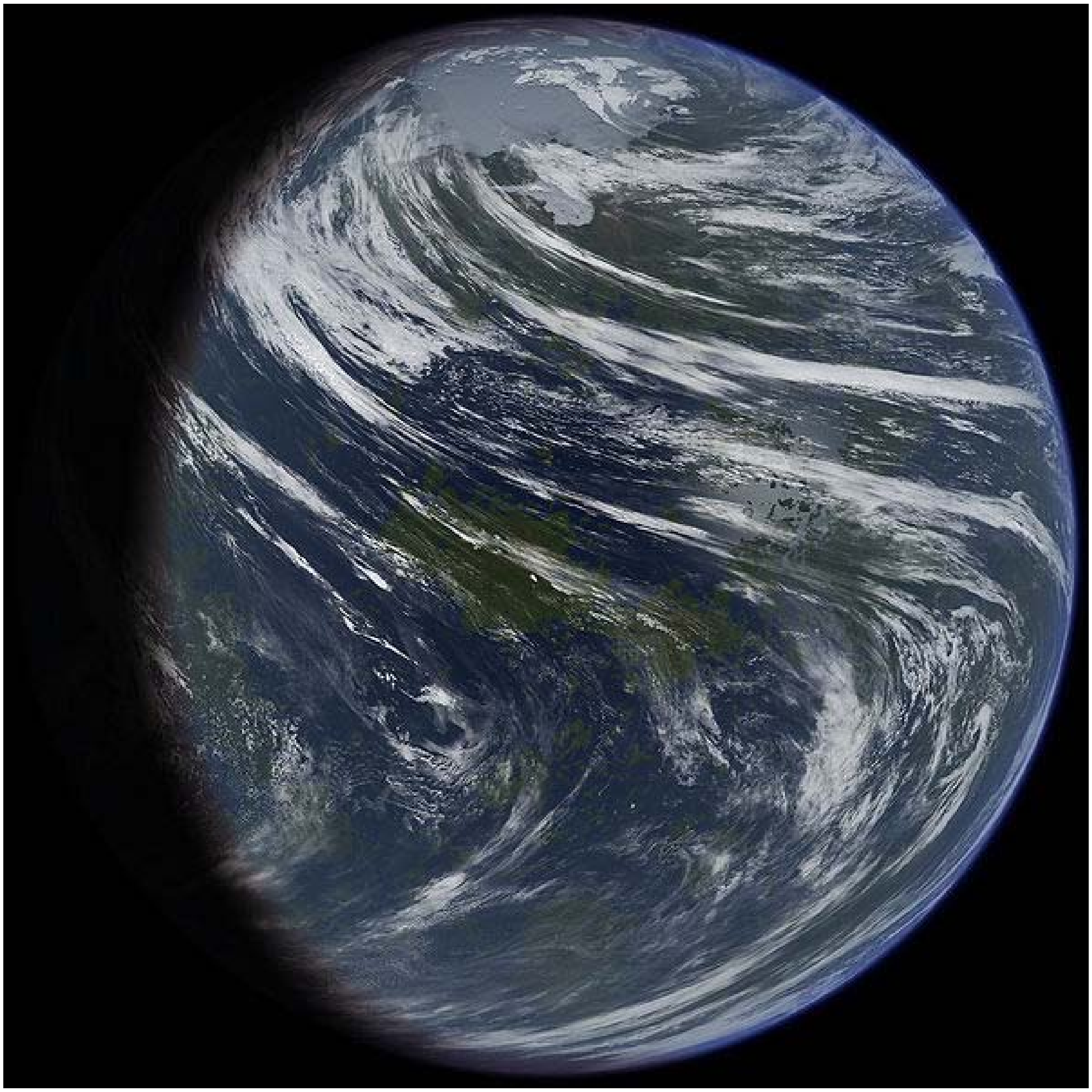
Terraforming Mars would make life outside of pressure vessels on the surface possible. There is some discussion of it actually being done.

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.

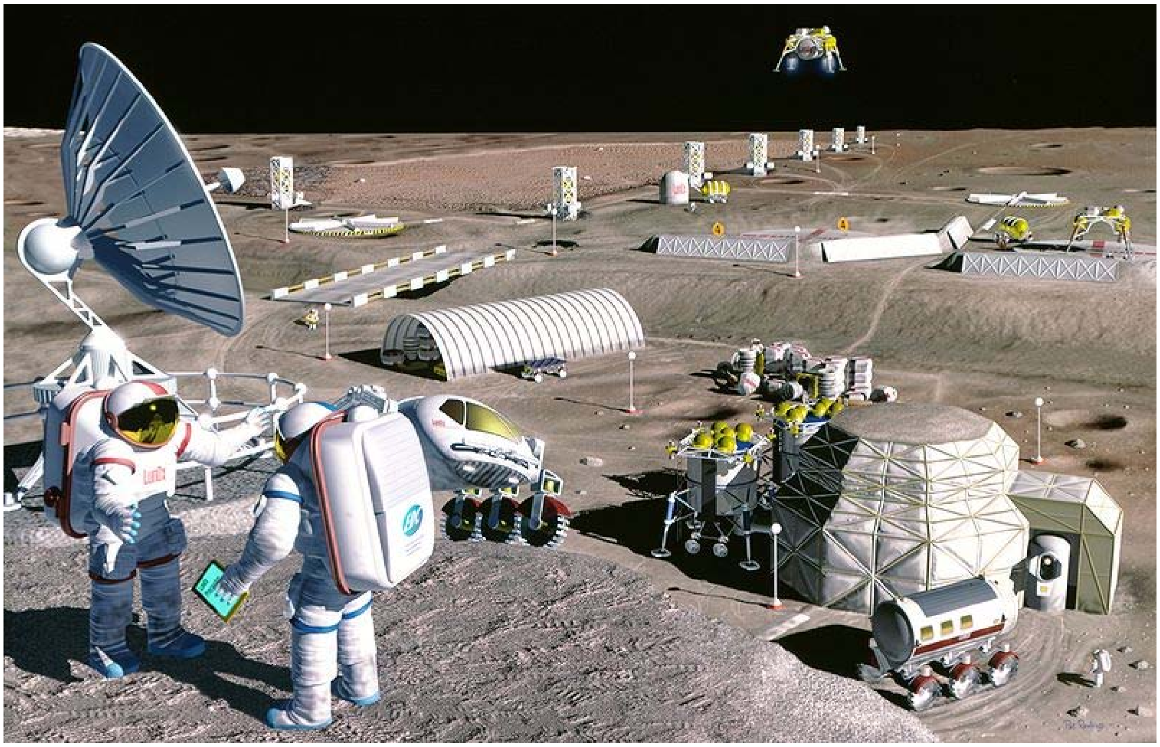
Gas giants

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 consisting of an orbital ring 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 colonization, and saying "In certain ways, Titan is the most hospitable extraterrestrial world within our solar system for human colonization".

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

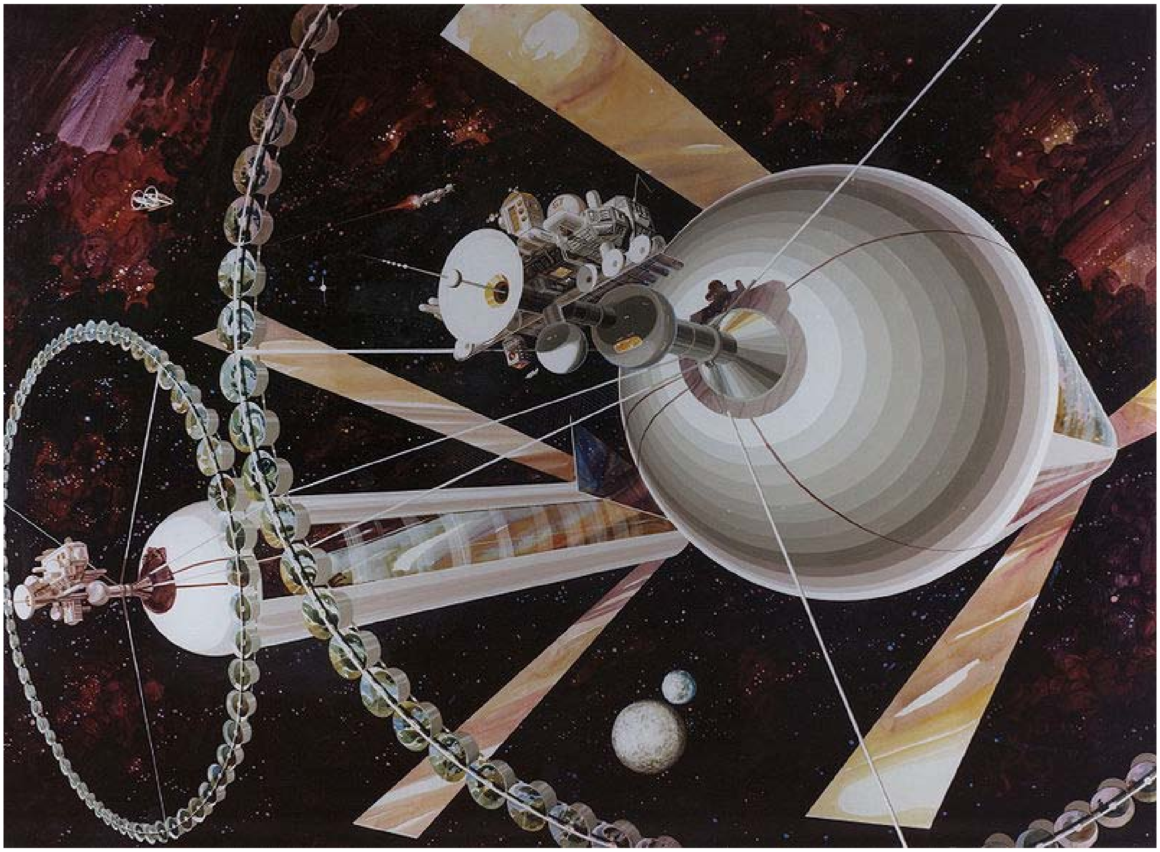
Colonization of asteroids would require space habitats. The asteroid belt has significant overall material available, the largest object being Ceres, although it is thinly distributed as it covers a vast region of space. Unmanned supply craft should be practical with little technological advance, even 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.

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.

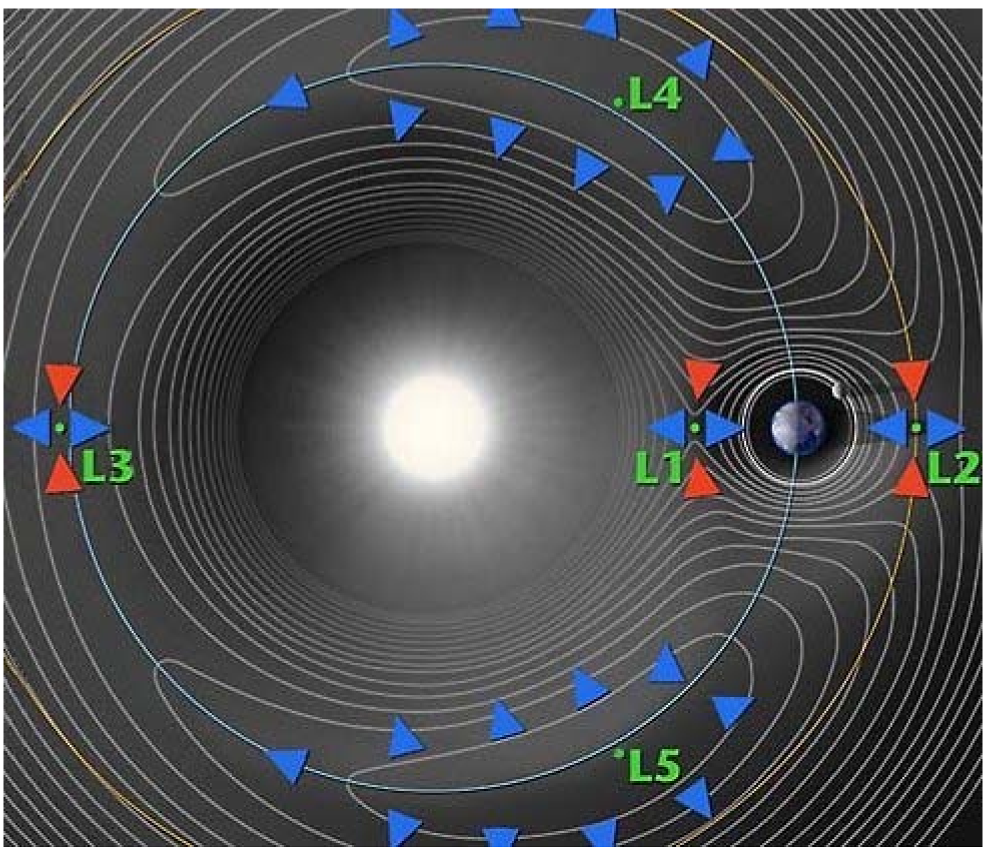
Earth orbit

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 stars 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 through new forms of space commercialization such as 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, space tourism
- 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 Space Studies Institute was founded by Gerard K. O'Neill to fund the study of space habitats.
- The Space Frontier Foundation promotes strong free market, capitalist views about space development.
- 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 Colonize the Cosmos site advocates orbital colonies.
- 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 Settlement Institute is searching for ways to make space colonization happen in our lifetimes.
- 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.

- The Alliance to Rescue Civilization plans to establish backups of human civilization on the Moon and other locations away from Earth.