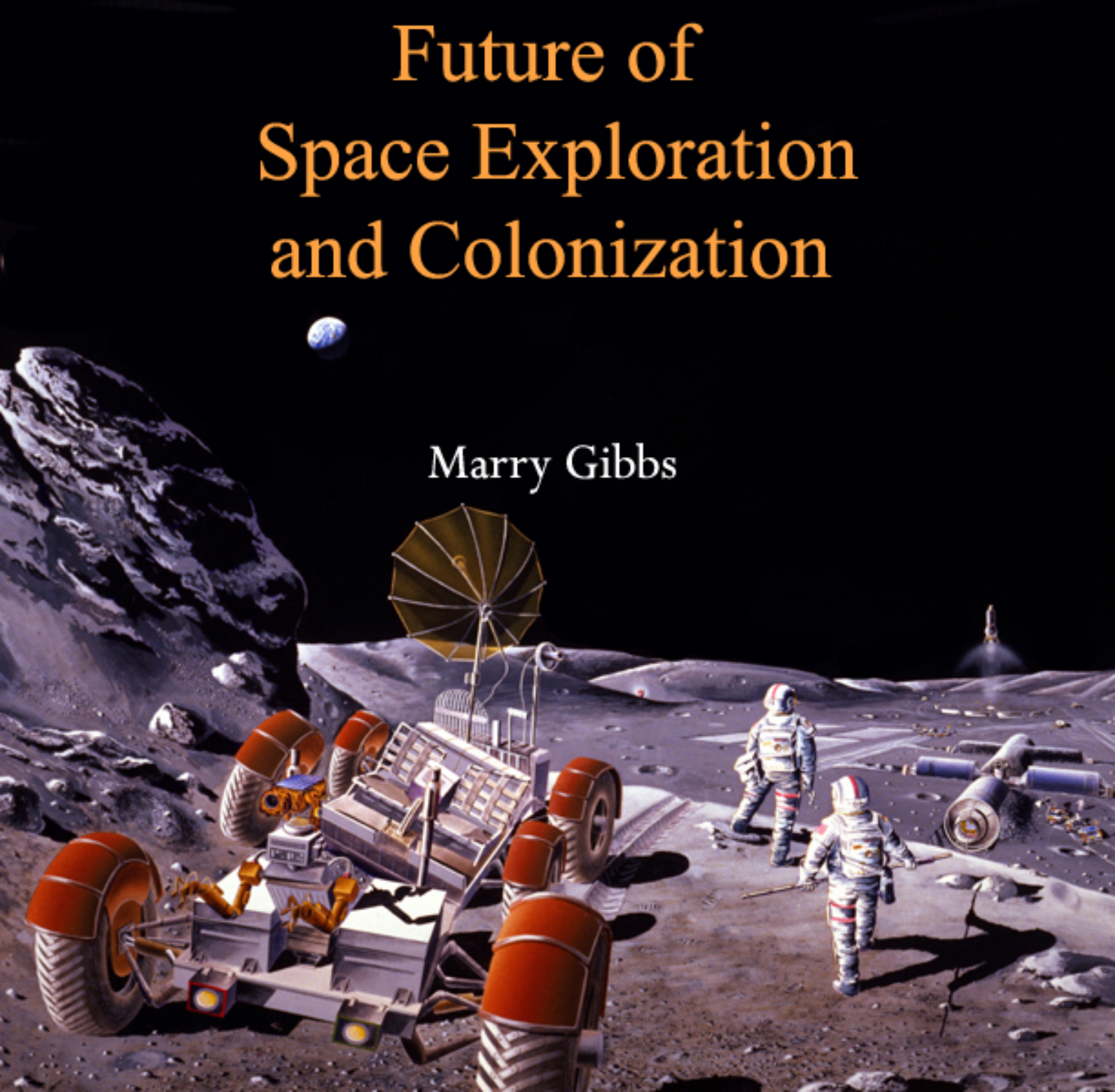
Future of Space Exploration and Colonization

Marry Gibbs



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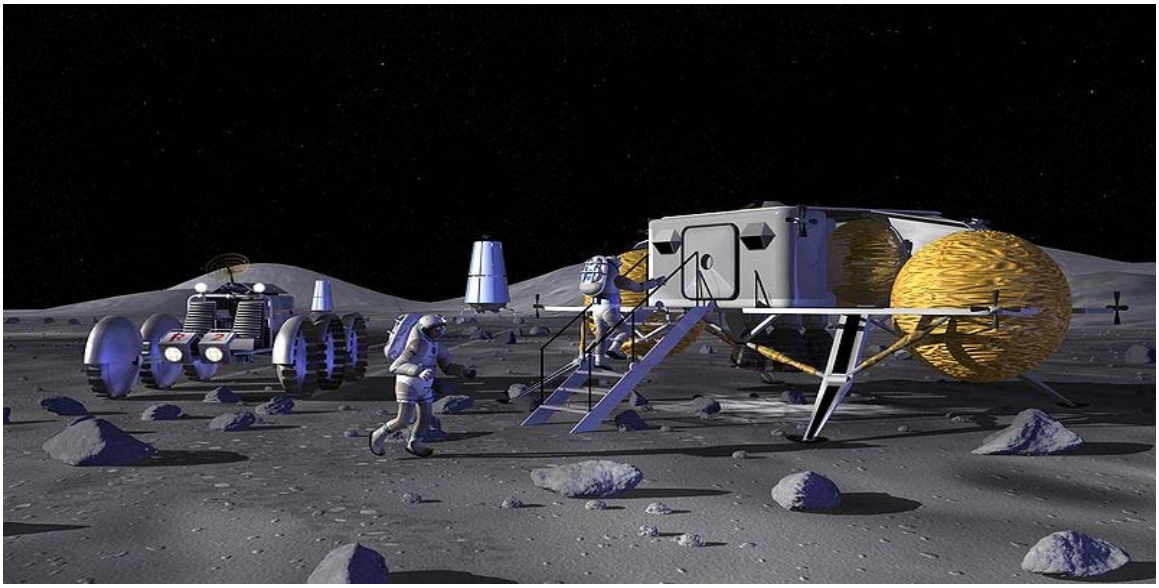
Colonization of the Moon

The **colonization of the Moon** is the proposed establishment of permanent human communities on the Moon. Advocates of space exploration have seen settlement of the Moon as a logical step in the expansion of humanity beyond the Earth. Recent indication that water might be present in quantities at the Lunar poles have increased interest in the Moon. Polar colonies could also avoid the problem of long Lunar nights (about 354 hours, a little more than two weeks) and take advantage of the sun continuously.

Permanent human habitation on a planetary body other than the Earth is one of science fiction's most prevalent themes. As technology has advanced, and concerns about the future of humanity on Earth have increased, the argument that space colonization is an achievable and worthwhile goal has gained momentum. Because of its proximity to Earth, the Moon has been seen as a prime candidate for the location of humanity's first permanently occupied extraterrestrial base.

Proposals



Concept art from NASA showing astronauts entering a Lunar outpost.

The notion of siting a colony on the Moon originated before the space age. In 1638 Bishop John Wilkins wrote *A Discourse Concerning a New World and Another Planet,* in which he predicted a human colony on the Moon. Konstantin Tsiolkovsky (1857–1935), among others, also suggested such a step. From the 1950s onwards, a number of concepts and designs have been suggested by scientists, engineers and others.

In 1954 the noted science-fiction author Arthur C. Clarke proposed a Lunar base of inflatable modules covered in Lunar dust for insulation. A spaceship, assembled in low Earth orbit, would launch to the Moon, and astronauts would set up the igloo-like modules and an inflatable radio mast. Subsequent steps would include the establishment of a larger, permanent dome; an algae-based air purifier; a nuclear reactor for the provision of power; and electromagnetic cannons to launch cargo and fuel to interplanetary vessels in space.

In 1959, John S. Rinehart suggested that the safest design would be a structure that could "[float] in a stationary ocean of dust", since there were, at the time this concept was outlined, theories that there could be mile-deep dust oceans on the Moon. The proposed design consisted of a half-cylinder with half-domes at both ends, with a micrometeoroid shield placed above the base.

Project Horizon

Project Horizon was a 1959 study regarding the U.S. Army's plan to establish a fort on the Moon by 1967. H. H. Koelle, a German rocket engineer of the Army Ballistic Missile Agency (ABMA) led the Project Horizon study. The first landing would be carried out by two "soldier-astronauts" in 1965 and more construction workers would soon follow. Through numerous launches (61 Saturn I and 88 Saturn II), 245 tons of cargo would be transported to the outpost by 1966.

Lunar ark

In 2007 Jim Burke of the International Space University in France said people should plan to preserve humanity's culture in the event of a civilization stopping asteroid impact with Earth. A Lunar ark was proposed. Subsequent planning may be taken up by the International Lunar Exploration Working Group (ILEWG).

Moon exploration

Exploration of the Lunar surface by spacecraft began in 1959 when the Soviet Luna 2 mission crash-landed into the surface. The same year, the Luna 3 mission radioed photographs to Earth of the Moon's hitherto unseen far side, marking the beginning of a decade-long series of unmanned Lunar explorations.

Responding to the Soviet program of space exploration, US President John F. Kennedy in 1961 told the U.S. Congress on May 25: "I believe that this nation should commit itself to achieving the goal before this decade is out of landing a man on the moon and returning

him safely to the Earth." The same year the Soviet leadership made some of its first public pronouncements about landing a man on the Moon and establishing a Lunar base.

In 1962, John DeNike and Stanley Zahn published their idea of a sub-surface base located at the Sea of Tranquility. This base would house a crew of 21, in modules placed 4 meters below the surface, which was believed to provide radiation shielding as well as the Earth's atmosphere does. They favored nuclear reactors for energy production, because they are more efficient than solar panels, and would also overcome the problems with the long Lunar nights. For life support system, an algae-based gas exchanger was proposed.

Manned exploration of the Lunar surface began in 1968 when the Apollo 8 spacecraft orbited the Moon with three astronauts on board. This was mankind's first direct view of the far side. The following year, the Apollo 11 Lunar module landed two astronauts on the Moon, proving the ability of humans to travel to the Moon, perform scientific research work and bring back sample materials.

Additional missions to the Moon continued this exploration phase. In 1969 the Apollo 12 mission landed next to the Surveyor 3 spacecraft, demonstrating precision landing capability. Following the near-disaster of Apollo 13, Apollo 14 was the last mission on which astronauts were quarantined on their return from the Moon. The use of a manned vehicle was demonstrated in 1971 with the Lunar Rover during Apollo 15. Apollo 16 made the first landing within the rugged Lunar highlands. However, interest in further exploration of the Moon was beginning to wane among the American public. In 1972 Apollo 17 was the final Apollo Lunar mission, and further planned missions were scrapped at the directive of President Nixon. Instead, focus was turned to the Space Shuttle and manned missions in near Earth orbit.

The Soviet Luna program failed to send a manned mission to the Moon. However, in 1966 Luna 9 was the first probe to achieve a soft landing and return close-up shots of the Lunar surface. Luna 16 in 1970 returned the first Soviet Lunar soil samples, while in 1970 and 1973 during the Lunokhod program two robotic rovers landed on the Moon. Lunokhod 1 explored the Lunar surface for 322 days, but the contact with Lunokhod 2 was lost after about 4 months of its operation. 1974 saw the end of the Soviet Moonshot, two years after the last American manned landing.

In the decades following, interest in exploring the Moon faded considerably, and only a few dedicated enthusiasts supported a return. However, evidence of Lunar ice at the poles gathered by NASA's Clementine (1994) and Lunar Prospector (1998) missions rekindled some discussion, as did the potential growth of a Chinese space program that contemplated its own mission to the Moon. Subsequent research suggested that there was far less ice present (if any) than had originally been thought, but that there may still be some usable deposits of hydrogen in other forms. However, in September 2009, the Chandrayaan probe, carrying a NASA instrument, discovered that the Lunar regolith contains 0.1% water by weight, overturning theories that had stood for 40 years.

In 2004, U.S. President George W. Bush called for a plan to return manned missions to the Moon by 2020. Propelled by this new initiative, NASA issued a new long-range plan that includes building a base on the Moon as a staging point to Mars. This plan envisions a Lunar outpost at one of the moon's poles by 2024 which, if well-sited, might be able to continually harness solar power; at the poles, temperature changes over the course of a Lunar day are also less extreme, and reserves of water and useful minerals may be found nearby. In addition, the European Space Agency has a plan for a permanently manned Lunar base by 2025. Russia has also announced similar plans to send a man to the moon by 2025 and establish a permanent base there several years later.

A Chinese space scientist has said that the People's Republic of China could be capable of landing a human on the moon by 2022, and Japan and India also have plans for a Lunar base by 2030. Neither of these plans involves permanent residents on the Moon. Instead they call for sortie missions, in some cases followed by extended expeditions to the Lunar base using rotating crew members, as is currently done for the International Space Station.

NASA’s LCROSS/LRO mission had been scheduled to launch in October 2008. The launch was delayed until the 18th of June 2009, resulting in LCROSS's impact with the Moon at 11:30 UT on the 9th of October, 2009. The purpose is preparing for future Lunar exploration.

Water discovered on moon

In September 2009 it was announced that NASA's Moon Mineralogy Mapper on India's Chandrayaan-1 had detected water on the moon.
On November 13, 2009 NASA announced that the LCROSS mission had discovered large quantities of water ice on the moon around the LCROSS impact site at Cabeus. "Large" is a relative term. The amount of water discovered is put in perspective by this comment from Robert Zubrin: "The 30 m crater ejected by the probe contained 10 million kilograms of regolith. Within this ejecta, an estimated 100 kg of water was detected. That represents a proportion of 10 parts per million, which is a lower water concentration than that found in the soil of the driest deserts of the Earth. In contrast, we have found continent sized regions on Mars, which are 600,000 parts per million, or 60% water by weight."
In March 2010, NASA reported that the NASA mini-SAR radar aboard Chandrayaan-1 detected ice deposits at the moon's north pole. It is estimated there is at least 600 million tons of ice at the north pole in sheets of relatively pure ice at least a couple of meters thick.

Advantages and disadvantages

Putting aside the general questions of whether a human colony beyond the Earth is feasible or scientifically desirable in light of cost-efficiency, proponents of space colonization point out that the Moon offers both advantages and disadvantages as a site for such a colony.

Advantages

Placing a colony on a natural body would provide an ample source of material for construction and other uses, including shielding from radiation. The energy required to send objects from the Moon to space is much less than from Earth to space. This could allow the Moon to serve as a construction site or fueling station for spacecraft. Some proposals include using electric acceleration devices (mass drivers) to propel objects off the Moon without building rockets. Others have proposed momentum exchange tethers (see below). Furthermore, the Moon does have some gravity, which experience to date indicates may be vital for fetal development and long-term human health. Whether the Moon's gravity (roughly one sixth of Earth's) is adequate for this purpose, however, is uncertain.

In addition, the Moon is the closest large body in the solar system to Earth. While some Earth-crosser asteroids occasionally pass closer, the Moon's distance is consistently within a small range close to 384,400 km. This proximity has several benefits:

- Monetary (including space tourism), security, and technological gains.
- The energy required to send objects from Earth to the Moon is lower than for most other bodies.
- Transit time is short. The Apollo astronauts made the trip in three days and future technologies could improve on this time.
- If the Moon were colonized then it could be tested if humans can survive in low gravity. Those results could be utilized for a viable Mars colony as well.
- The short transit time would also allow emergency supplies to quickly reach a Moon colony from Earth, or allow a human crew to evacuate relatively quickly from the Moon to Earth in case of emergency. This could be an important consideration when establishing the first human colony.

- The round trip communication delay to Earth is less than three seconds, allowing near-normal voice and video conversation, and allowing some kinds of remote control of machines from Earth that are not possible for any other celestial body. The delay for other solar system bodies is minutes or hours; for example, round trip communication time between Earth and Mars ranges from about eight minutes to about forty minutes. This again would be of particular value in an early colony, where life-threatening problems requiring Earth's assistance could occur. (See, for example, Apollo 13.)
- On the Lunar near side, the Earth appears large and is always visible as an object 60 times brighter than the Moon appears from Earth, unlike more distant locations where the Earth would be seen merely as a star-like object, much as the planets appear from Earth. As a result, a Lunar colony might feel less remote to humans living there.
- A Lunar base would provide an excellent site for any kind of observatory. Particular advantages arise from building observatory facilities on the Moon from Lunar materials. As the Moon's rotation is so slow, visible light observatories could perform observations for days at a time. It is possible to maintain near-

constant observations on a specific target with a string of such observatories spanning the circumference of the Moon. The fact that the Moon is geologically inactive along with the lack of widespread human activity results in a remarkable lack of mechanical disturbance, making it far easier to set up interferometric telescopes on the Lunar surface, even at relatively high frequencies such as visible light.

- A Lunar base could also hold a future site for launching rockets, to distant planets such as Mars. Launching rockets from the Moon would be an easier prospect than on Earth due to the Moon's lower gravity requiring a lower escape velocity. A lower escape velocity would require less propellant, but there is no guarantee that less propellant would cost less money is required to launch from Earth.
- A farm at the Lunar North Pole could provide eight hours of sunlight per day for rotating crops, a beneficial temperature, radiation protection, insects for pollination, and all other plant needs artificially during the local summer for a cost. One estimate suggested a 0.5 hectare space farm could feed 100 people.
- A moon colony provides us with most of the experiments, skills, and knowledge we need to colonize another planet.
- A moon colony can easily be seen from the Earth, and might inspire many more humans to seriously consider the advantages and future of colonization. A clear sign or signal can be made to remind humans on Earth, inspiring future leaders, astronauts, and scientists.

Disadvantages

There are several disadvantages to the Moon as a colony site:

- The long Lunar night would impede reliance on solar power and require a colony to be designed that could withstand large temperature extremes. An exception to this restriction are the so-called "peaks of eternal light" located at the Lunar north pole that are constantly bathed in sunlight. The rim of Shackleton Crater, towards the Lunar south pole, also has a near-constant solar illumination. Other areas near the poles that get light most of the time could be linked in a power grid.
- The Moon is highly depleted in light elements (volatiles), such as carbon, nitrogen and hydrogen. A number of robot probes including Lunar Prospector gathered evidence of hydrogen generally in the Moon's crust consistent with what would be expected from implantation from the solar wind, and higher concentrations near the poles. There had been some disagreement whether the hydrogen must necessarily be in the form of water. The LCROSS mission has definitely found evidence of water. This water would be in ice form perhaps mixed in small crystals in the regolith in a colder landscape than people have ever mined. Other volatiles containing carbon and nitrogen could conceivably also be in the same cold traps as the ice. If no sufficient means is found for recovering these volatiles on the Moon, they would need to be imported from some other source to support life and industrial processes. Volatiles would need to be stringently recycled. This would limit the colony's rate of growth and keep it dependent on Earth. The transportation cost of importing volatiles from Earth could be reduced by

constructing the upper stage of supply ships using materials high in volatiles, such as carbon fiber and other plastics. The 2006 announcement by the Keck Observatory that the binary Trojan asteroid 617 Patroclus, and possibly large numbers of other Trojan objects in Jupiter's orbit, are likely composed of water ice, with a layer of dust, and the hypothesized large amounts of water ice on the closer, main-belt asteroid 1 Ceres, suggest that importing volatiles from this region via the Interplanetary Transport Network may be practical in the not-so-distant future. However, these possibilities are dependent on complicated and expensive resource utilization from the mid to outer solar system, which are not likely to become available to a Moon colony for a significant period of time.

- It is uncertain whether the low (one-sixth *g*) gravity on the Moon is strong enough to prevent detrimental effects to human health in the long term. Exposure to weightlessness over month-long periods has been demonstrated to cause deterioration of physiological systems, such as loss of bone and muscle mass and a depressed immune system. Similar effects could occur in a low-gravity environment, although virtually all research into the health effects of low gravity has been limited to zero gravity. Countermeasures such as an aggressive routine of daily exercise have proven at least partially effective in preventing the health deterioration that is caused by low gravity.
- The lack of a substantial atmosphere for insulation results in temperature extremes and makes the Moon's surface conditions somewhat like a deep space vacuum. It also leaves the Lunar surface exposed to half as much radiation as in interplanetary space (with the other half blocked by the moon itself underneath the colony) raising the issues of the health threat from cosmic rays and the risk of proton exposure from the solar wind, especially since two-thirds of the Moon's orbit is outside the protection of the Earth's magnetosphere. Although Lunar materials would potentially be useful as a simple radiation shield for living quarters, shielding against solar flares during expeditions outside is more problematic.
- Also, the lack of an atmosphere increases the chances of the colonial site being hit by meteors, which would impact upon the surface directly, as they have done throughout the Moon's history. Even small pebbles and dust (micrometeoroids) have the potential to damage or destroy insufficiently protected structures.
- Moon dust is an extremely abrasive glassy substance formed by micrometeorites and unrounded due to the lack of weathering. It sticks to everything, can damage equipment, and it may be toxic.
- Growing crops on the moon faces many difficult challenges due to the long Lunar night (354 hour), extreme variation in surface temperature, exposure to solar flares, and lack of insects for pollination. (Due to the lack of any atmosphere on the Moon, plants would need to be grown in sealed chambers, though experiments have shown that plants can thrive at pressures much lower than those on Earth.) The use of electric lighting to compensate for the 354 hour night might be difficult: a single acre of plants on Earth enjoys a peak 4 megawatts of sunlight power at noon. Experiments conducted by the Soviet space program in the 1970s suggest it is possible to grow conventional crops with the 354 hour light, 354 hour dark cycle. A variety of concepts for Lunar agriculture have been proposed,

including the use of minimal artificial light to maintain plants during the night and the use of fast growing crops that might be started as seedlings with artificial light and be harvestable at the end of one Lunar day.

Locations

Three criteria that a Lunar outpost should meet are:

- good conditions for transport operations;
- a great number of different types of natural objects and features on the Moon of scientific interest; and
- natural resources, such as oxygen. The abundance of certain minerals, such as iron oxide, varies dramatically over the Lunar surface.

While a colony might be located anywhere, potential locations for a Lunar colony fall into three broad categories.

Polar regions

There are two reasons why the Lunar poles might be attractive as locations for a human colony. First, there is evidence that water may be present in some continuously shaded areas near the poles. Second, because the Moon's axis of rotation is almost perfectly perpendicular to the ecliptic plane, it may be possible to power polar colonies exclusively with solar energy. Power collection stations can be located so that at least one is in sunlight at all times. Some sites have nearly continuous sunlight. For example, Malapert mountain, located near the Shackleton crater at the Lunar south pole, offers several advantages as a site:

- It is exposed to the sun most of the time; two closely spaced arrays of solar panels would receive nearly continuous power.
- Its proximity to Shackleton Crater (116 km, or 69.8 mi) means that it could provide power and communications to the crater. This crater is potentially valuable for astronomical observation. An infrared instrument would benefit from the very cold temperatures. A radio telescope would benefit from being shielded from Earth's broad spectrum radio interference.
- The nearby Shoemaker and other craters are in constant deep shadow, and might contain valuable concentrations of hydrogen and other volatiles.
- At around 5,000 meters (16,500 ft) elevation, it offers line of sight communications over a large area, as well as to Earth.
- The South Pole-Aitken basin is located at the south Lunar pole. This is the second largest known impact basin in the solar system, as well as the oldest and biggest impact feature on the Moon, and should provide geologists access to deeper layers of the Moon's crust.

NASA chose to use a south-polar site for the Lunar outpost reference design in the Exploration Systems Architecture Study chapter on Lunar Architecture.

At the north pole, the rim of Peary crater has been proposed as a favorable location for a base. Examination of images from the Clementine mission appear to show that parts of the crater rim are permanently illuminated by sunlight (except during Lunar eclipses). As a result, the temperature conditions are expected to remain very stable at this location, averaging −50 °C (−58 °F). This is comparable to winter conditions in Earth's Poles of Cold in Siberia and Antarctica. The Peary crater interior may also harbor hydrogen deposits.

Although hydrogen appears to be concentrated at the poles, the presence of Lunar ice has not yet been confirmed. A bistatic radar experiment performed during the Clementine mission suggested the presence of water ice around the south pole. The Lunar Prospector spacecraft reported enhanced hydrogen abundances not only at the south pole, but also at the north pole — actually more so. On the other hand, results reported using the Arecibo radio telescope have been interpreted by some to indicate that the anomalous Clementine radar signatures are not indicative of ice, but surface roughness. This interpretation, however, is not universally agreed upon.

A potential limitation of the polar regions is that the inflow of solar wind can create an electrical charge on the leeward side of crater rims. The resulting voltage difference can affect electrical equipment, change surface chemistry, erode surfaces and levitate Lunar dust.

Equatorial regions

The Lunar equatorial regions are likely to have higher concentrations of helium-3 (rare on Earth but much sought after for use in nuclear fusion research) because the solar wind has a higher angle of incidence. They also enjoy an advantage in extra-Lunar traffic: The rotation advantage for launching material is slight due to the Moon's slow rotation, but the corresponding orbit coincides with the ecliptic, nearly coincides with the Lunar orbit around Earth and nearly coincides with the equatorial plane of Earth.

Several probes have landed in the Oceanus Procellarum area. There are many areas and features that could be subject to long-term study, such as the Reiner Gamma anomaly and the dark-floored Grimaldi crater.

Far side

The Lunar far side lacks direct communication with Earth, though a communication satellite at the L_2 Lagrangian point, or a network of orbiting satellites, could enable communication between the far side of the Moon and Earth. The far side is also a good location for a large radio telescope because it is well shielded from the Earth. Due to the lack of atmosphere, the location is also suitable for an array of optical telescopes, similar to the Very Large Telescope in Chile. To date, there has been no ground exploration of the far side.

Scientists have estimated that the highest concentrations of helium-3 will be found in the maria on the far side, as well as near side areas containing concentrations of the titanium-based mineral ilmenite. On the near side the Earth and its magnetic field partially shields the surface from the solar wind during each orbit. But the far side is fully exposed, and thus should receive a somewhat greater proportion of the ion stream.

Lunar lava tubes

Lunar lava tubes form a potentially important location for constructing a future Lunar base, which may be used for local exploration and development, or as a human outpost to serve exploration beyond the Moon. Any intact lava tube on the moon could serve as a shelter from the severe environment of the Lunar surface, with its frequent meteorite impacts, high-energy ultra-violet radiation and energetic particles, and extreme diurnal temperature variations.; March 5, 2010; Discover Magazine; Phil Plait Astronomy The second lunar lava tube was discovered by LRO.

Structure

Habitat

A NASA model of a proposed inflatable module

There have been numerous proposals regarding habitat modules. The designs have evolved throughout the years as mankind's knowledge about the Moon has grown, and as the technological possibilities have changed. The proposed habitats range from the actual spacecraft landers or their used fuel tanks, to inflatable modules of various shapes. Early on, some hazards of the Lunar environment such as sharp temperature shifts, lack of atmosphere or magnetic field (which means higher levels of radiation and micrometeoroids) and long nights, were recognized and taken into consideration.

Some suggest building the Lunar colony underground, which would give protection from radiation and micrometeoroids. This also greatly reduce the risk of air leakage, as the colony will be fully sealed from the outside except for a few exits to the surface. This is not the only advantage to this option. The average temperature on the moon is about −5 °C. The day period (about 354 hours) has an average temperature of about 107 °C (225 °F), although it can rise as high as 123 °C (253 °F). The night period (also 354 hours) has an average temperature of about −153 °C (−243 °F). Underground, both periods would be around -23 °C (-9 °F), and humans could install ordinary air conditioners.

The construction of such a base would probably be more complex; one of the first machines from Earth might be a remote controlled excavating machine to excavate living quarters. Once created, some sort of hardening would be necessary to avoid collapse, possibly a spray-on concrete-like substance made from available materials. A more porous insulating material also made *in-situ* could then be applied. Mining methods such as the room and pillar might also be used. Inflatable self-sealing fabric habitats might then be put in place to retain air. Eventually an underground city similar to The Forum Shops at Caesars and Underground City, Montreal can be constructed. Farms setup underground would need artificial sunlight. As an alternative to excavating, a lava tube could be covered and insulated, thus solving the problem of radiation exposure. One such lava tube has been discovered in early 2009.

A possibly easier solution would be to build the Lunar base on the surface, and cover the modules with Lunar soil. The Lunar regolith is composed of a unique blend of silica and iron-containing compounds that may be fused into a glass-like solid using microwave energy. This may allow for the use of "Lunar bricks" in structural designs, or the "glassing" of loose dirt to form a hard, ceramic crust. Others have put forward the idea that the Lunar base could be built on the surface and protected by other means, such as improved radiation and micrometeoroid shielding. Building the Lunar base inside a deep crater would provide at least partial shielding against radiation and micrometeoroids. Artificial magnetic fields have been proposed as a means to provide radiation shielding for long range deep space manned missions, and it might be possible to use similar technology on a Lunar colony. Some regions on the Moon possess strong local magnetic fields that might partially mitigate exposure to charged solar and galactic particles.

Moon Capital

The Moon Capital Competition will be offering a prize for an architectural design of a Lunar habitat intended to be an underground international commercial center capable of

supporting a residential staff of 60 people and their families. The Moon Capital is intended to be self-sufficient with respect to food and other material required for life support. Prize money will be provided primarily by the Boston Society of Architects and The New England Council of the American Institute of Aeronautics and Astronautics.

Energy

A Lunar base would need power for its operations — from fuel production and communications to life support systems and scientific research.

Nuclear power

A nuclear fission reactor might fulfill most of the base's power requirements. Fission reactors can also overcome the difficulty of the 354 hour Lunar night. Radioisotope thermoelectric generators could be used as backup and emergency power sources for solar powered colonies.

Solar energy

Solar energy is a possible source of power for a Lunar base. Many of the raw materials needed for solar panel production can be extracted on site. However, the long Lunar night (354 hours) is a drawback for solar power on the Moon's surface. This might be solved by building several power plants, so that at least one of them is always in daylight. Another possibility would be to build such a power plant where there is constant or near-constant sunlight, such as at the Malapert mountain near the Lunar south pole, or on the rim of Peary crater near the north pole. A third possibility would be to leave the panels in orbit, and beam the power down as microwaves.

The solar energy converters need not be silicon solar panels. It may be more advantageous to use the larger temperature difference between sun and shade to run heat engine generators. Concentrated sunlight could also be relayed via mirrors and used in Stirling engines or solar trough generators, or it could be used directly for lighting, agriculture and process heat. The focused heat might also be employed in materials processing to extract various elements from Lunar surface materials.

Energy storage

In the early days, a combination of solar panels for 'day-time' operation and fuel cells for 'night-time' operation could be used.

Fuel cells on the Space Shuttle have operated reliably for up to 17 Earth days at a time. On the Moon, they would only be needed for 354 hours — the length of the Lunar night. Fuel cells produce water directly as a waste product. Current fuel cell technology is more advanced than the Shuttle's cells — PEM (Proton Exchange Membrane) cells produce considerably less heat (though their waste heat would likely be useful during the Lunar

night) and are physically lighter, not to mention the reduced mass of the smaller heat-dissipating radiators. This makes PEMs more economical to launch from Earth than the shuttle's cells, but PEMs have not yet been proven in space.

Combining fuel cells with electrolysis would provide a 'perpetual' source of electricity - solar energy could be used to provide power during the Lunar day, and fuel cells at night. During the Lunar day, solar energy would also be used to electrolyze the water created in the fuel cells - although there would be small losses of gases that would have to be replaced.

Transport

Earth to Moon

Conventional rockets have been used for most Lunar exploration to date. The ESA's SMART-1 mission from 2003 to 2006 used Hall effect thrusters. NASA will use chemical rockets on its Ares V booster and Lunar Surface Access Module, being developed for a planned return to the Moon around 2019. The construction workers, location finders, and other astronauts vital to building, will be taken in NASA's Orion spacecraft.

On the surface

A Lunar rover being unloaded from a cargo spacecraft. Conceptual drawing.

Within the colony it will be difficult to set up a public transport system. However a system of Escalators, moving walkways and elevator can be used to quickly transport people and cargo around.

Lunar colonists will also want the ability to move over long distances, to transport cargo and people to and from modules and spacecraft, and to carry out scientific study of a larger area of the Lunar surface for long periods of time. Proposed concepts include a variety of vehicle designs, from small open rovers to large pressurised modules with lab equipment, and also a few flying or hopping vehicles.

Rovers could be useful if the terrain is not too steep or hilly. The only rovers to have operated on the surface of the Moon (as of 2008) are the three Apollo Lunar Roving Vehicles (LRV), developed by Boeing, and the two robotic Soviet Lunokhods. The LRV was an open rover for a crew of two, and a range of 92 km during one Lunar day. One NASA study resulted in the Mobile Lunar Laboratory concept, a manned pressurised rover for a crew of two, with a range of 396 km. The Soviet Union developed different rover concepts in the Lunokhod series and the L5 for possible use on future manned

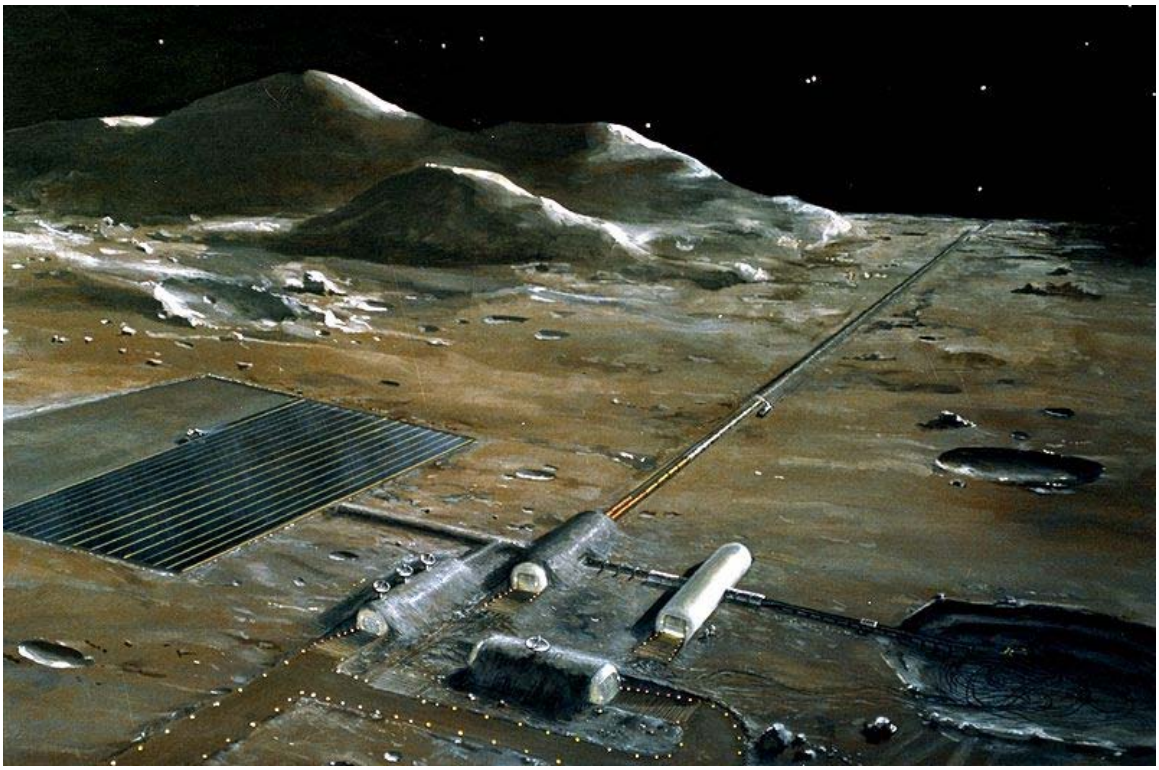
missions to the Moon or Mars. These rover designs were all pressurised for longer sorties.

If multiple bases were established on the Lunar surface, they could be linked together by permanent railway systems. Both conventional and magnetic levitation (Mag-Lev) systems have been proposed for the transport lines. Mag-Lev systems are particularly attractive as there is no atmosphere on the surface to slow down the train, so the vehicles could achieve velocities comparable to aircraft on the Earth. In addition achieving the extremely cold temperatures necessary for the superconducting magnets that levitate and drive the Mag-Lev trains would be much easier to achieve than on Earth due to the lack of an atmosphere. One significant difference with Lunar trains, however, is that the cars would need to be individually sealed and possess their own life support systems. The trains would also need to be highly resistant to derailment, as a punctured car could lead to rapid loss of life.

For difficult areas, a flying vehicle may be more suitable. Bell Aerosystems proposed their design for the Lunar Flying Vehicle as part of a study for NASA. Bell also developed the Manned Flying System, a similar concept.

Surface to space

Launch technology



A Lunar base with a mass driver (the long structure that goes toward the horizon.) NASA conceptual illustration.

A Lunar base will need efficient ways to transport people and goods of various kinds between the Earth and the Moon and, later, to and from various locations in interplanetary space. One advantage of the Moon is its relatively weak gravity field, making it easier to launch goods from the Moon than from the Earth. The lack of a Lunar atmosphere is both an advantage and a disadvantage; while it is easier to launch from the Moon because there is no drag, aerobraking is not possible, which makes it necessary to bring extra fuel in order to land. An alternative, which may work for supplies, is to surround the payload with impact-absorbing materials, something that was tried in the Ranger program. This can be efficient if the impact protection is made of needed lighter elements that are absent from the Moon (Ranger used balsa wood)

One way to get materials and products from the Moon to an interplanetary waystation might be with a mass driver, a magnetically accelerated projectile launcher. Cargo would be picked up from orbit or an Earth-Moon Lagrangian point by a shuttle craft using ion propulsion, solar sails or other means and delivered to Earth orbit or other destinations such as near-Earth asteroids, Mars or other planets, perhaps using the Interplanetary Transport Network. If a Lunar space elevator is ever built, it could transport people, raw materials and products to and from an orbital station at Lagrangian points L_1 or L_2.

Launch costs

- Estimates of the cost per pound of launching cargo or people from the Moon vary and the cost impacts of future technological improvements are difficult to predict. An upper bound on the cost of launching material from the Moon might be about $40,000,000 per kilogram, based on dividing the Apollo program costs by the amount of material returned. At the other extreme, the incremental cost of launching material from the moon using an electromagnetic accelerator could be quite low. The efficiency of launching material from the Moon with a proposed electric accelerator is suggested to be about 50%. If the carriage of a mass driver weighs the same as the cargo, two kilograms must be accelerated to orbital velocity for each kilogram put into orbit. The overall system efficiency would then drop to 25%. So 1.4 kilowatt-hours would be needed to launch an incremental kilogram of cargo to low orbit from the Moon. At $0.1/kilowatt-hour, a typical cost for electrical power on Earth, that amounts to $0.16 for the energy to launch a kilogram of cargo into orbit. For the actual cost of an operating system, energy loss for power conditioning, the cost of radiating waste heat, the cost of maintaining all systems, and the interest cost of the capital investment are considerations. David R. Criswell believes that there is a potential for the cost of electrical power on the Moon to become enough less than the cost on Earth for electrical power to be exported from the Moon to Earth by microwave.
- Passengers cannot be divided into the parcel size suggested for the cargo of a mass driver, nor subjected to hundreds of gravities acceleration. However, technical developments could also affect the cost of launching passengers to orbit from the Moon. Instead of bringing all fuel and oxidizer from Earth, liquid oxygen could be produced from Lunar materials and hydrogen should be available from the Lunar poles. The cost of producing these on the Moon is yet

unknown, but they will be more expensive than on Earth. The situation of the local hydrogen is most open to speculation. As a rocket fuel, hydrogen could be extended by combining it chemically with silicon to form silane, which has yet to be demonstrated in an actual rocket engine. In the absence of more technical developments, the cost of transporting people from the Moon will be an impediment to colonization.

Surface to and from cis-Lunar space

A cis-Lunar transport system has been proposed using tethers to achieve momentum exchange. This system requires zero net energy input, and could not only retrieve payloads from the Lunar surface and transport them to Earth, but could also soft land payloads on to the Lunar surface.

Economic development

For long term sustainability, a space colony should be close to self sufficient. On site mining and refining of the Moon's materials could provide an advantage over deliveries from Earth – for use both on the Moon and elsewhere in the solar system – as they can be launched into space at a much lower energy cost than from Earth. It is possible that vast sums of money will be spent in interplanetary exploration in the 21st century, and the cost of providing goods from the Moon might be attractive.

Space-based materials processing

In the long term, the Moon will likely play an important role in supplying space-based construction facilities with raw materials. Zero gravity allows for the processing of materials in ways impossible or difficult on Earth, such as "foaming" metals, where a gas is injected into a molten metal, and then the metal is annealed slowly. On Earth, the gas bubbles rise and burst, but in a zero gravity environment, that does not happen. Annealing is a process that requires large amounts of energy, as a material is kept very hot for an extended period of time. (This allows the molecular structure to realign.) Materials which cannot be alloyed or mixed on Earth because of gravity-field effects on density differences could be combined in space, resulting in composites which could have exceptional qualities. No one knows, because no one has been able to experiment along these lines on any scale. However, it is possible that materials or processes will be identified which will be highly valuable on Earth, but impossible to make here. (This is the foundation of the free MoonBaseOne game made by a non-profit that teaches children about space.)

Exporting material to Earth

Exporting material to Earth in trade from the Moon is more problematic due to the cost of transportation which will vary greatly if the Moon is industrially developed (see above). One suggested candidate is Helium-3 from the solar wind, which is thought to have

accumulated on the Moon's surface over billions of years, and which is rare on Earth. Helium might be present in the Lunar regolith in quantities of 0.01 ppm to 0.05 ppm (depending on soil). 2006 market price for He-3 was about $46,500 per troy ounce ($1500/gram, $1.5M/kg), more than 120 times the value per unit weight of Gold and over eight times the value of Rhodium.

In the long term future He-3 may prove to be a desirable fuel in thermonuclear fusion reactors.

Solar power satellites

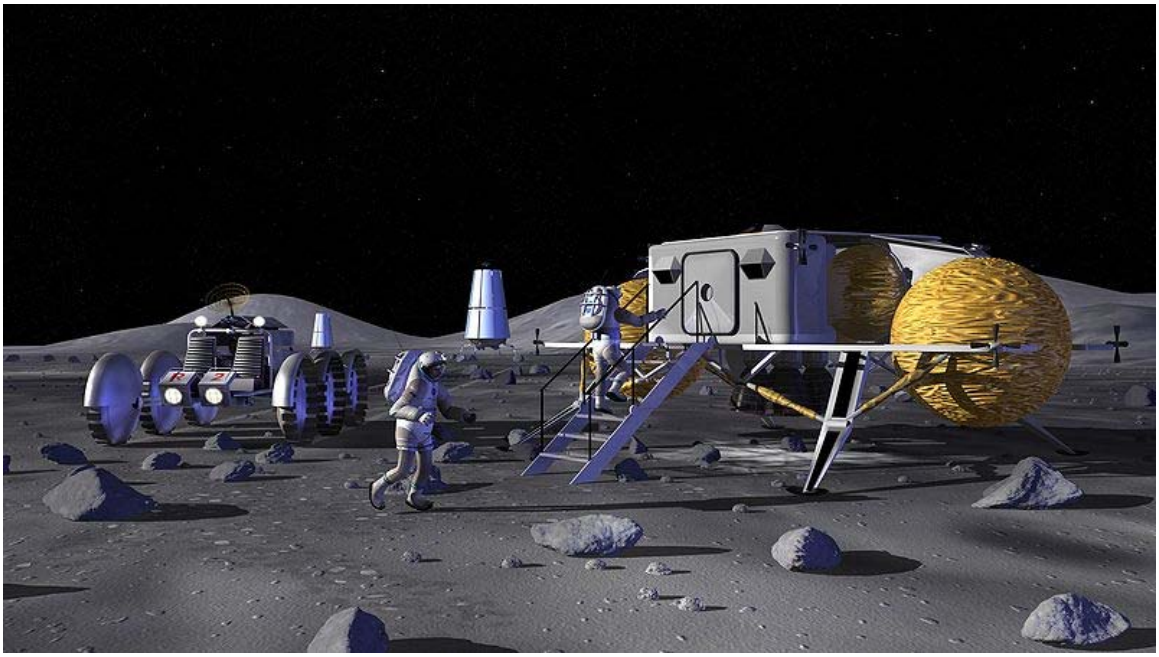
Gerard K. O'Neill, noting the problem of high launch costs in the early 1970s, came up with the idea of building Solar Power Satellites in orbit with materials from the Moon. Launch costs from the Moon will vary greatly if the Moon is industrially developed (see above). This 1970s proposal was predicated on the then advertised future launch costs of NASA's space shuttle.

On 30 April 1979 the Final Report "Lunar Resources Utilization for Space Construction" by General Dynamics Convair Division under NASA contract NAS9-15560 concluded that use of Lunar resources would be cheaper than terrestrial materials for a system comprising as few as thirty Solar Power Satellites of 10 GW capacity each.

In 1980, when it became obvious NASA's launch cost estimates for the space shuttle were grossly optimistic, O'Neill et al. published another route to manufacturing using Lunar materials with much lower startup costs. This 1980s SPS concept relied less on human presence in space and more on partially self-replicating systems on the Lunar surface under telepresence control of workers stationed on Earth.

Chapter- 2

Lunar Outpost



Concept art from NASA showing astronauts entering a lunar outpost. (2006)

A **lunar outpost** is an element of the Vision for Space Exploration. The outpost would be an inhabited facility on the surface of the Moon. At the time it was proposed, NASA was to construct the outpost over the five years between 2019 and 2024. The United States Congress directed that the U.S. portion, "shall be designated the ***Neil A. Armstrong Lunar Outpost***".

On December 4, 2006, NASA announced the conclusion of its Global Exploration Strategy and Lunar Architecture Study. The Lunar Architecture Study's purpose was to "define a series of lunar missions constituting NASA's Lunar campaign to fulfill the Lunar Exploration elements" of the Vision for Space Exploration. What resulted was a basic plan for a lunar outpost near one of the poles of the Moon, which would permanently house astronauts in six-month shifts. These studies were made before the

discovery of large quantities of water ice in a polar crater, which may substantially affect plans.

Reference architecture

A reference architecture has been established for this outpost, based on a location on the rim of the Shackleton crater, located in the immense South Pole-Aitken basin, near the Moon's south pole. At a presentation on December 4, 2006, Doug Cooke (Deputy Associate Administrator, NASA Exploration Systems Mission Directorate) described an area "that is ... sunlit ... 75 to 80 percent of the time, and it is adjacent to a permanently dark region in which there are potentially volatiles that we can extract and use. ... This sunlit area is about the size of the Washington Mall." (approximately 1.25 km²). The Indian Chandrayaan orbiter will assist in the determination of the precise location of the outpost.

Other locations considered for possible lunar outposts include the rim of Peary crater near the lunar north pole and the Malapert Mountain region on the rim of Malapert crater.

The current outpost design includes:

- Habitation modules
- Solar power units
- Unpressurized rovers
- In-Situ Resource Utilization (ISRU) unit
- Surface mobility carrier

The outpost would be supplied by a mixed crew and cargo Altair lander, capable of bringing four astronauts and a payload of six tons to the Moon's surface.

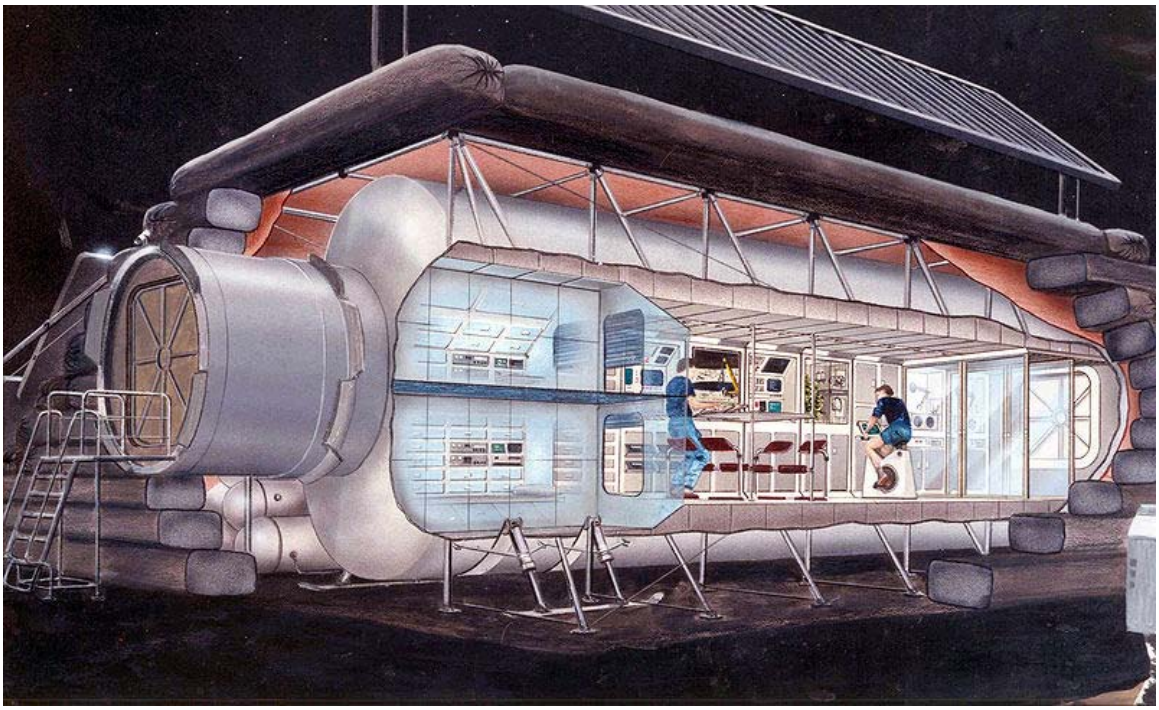
As currently planned, an incremental buildup would begin with four-person crews making several seven-day visits to the moon until their power supplies, rovers and living quarters were operational. The first mission would begin by 2020. This would be followed by 180-day missions to prepare for journeys to Mars.

History

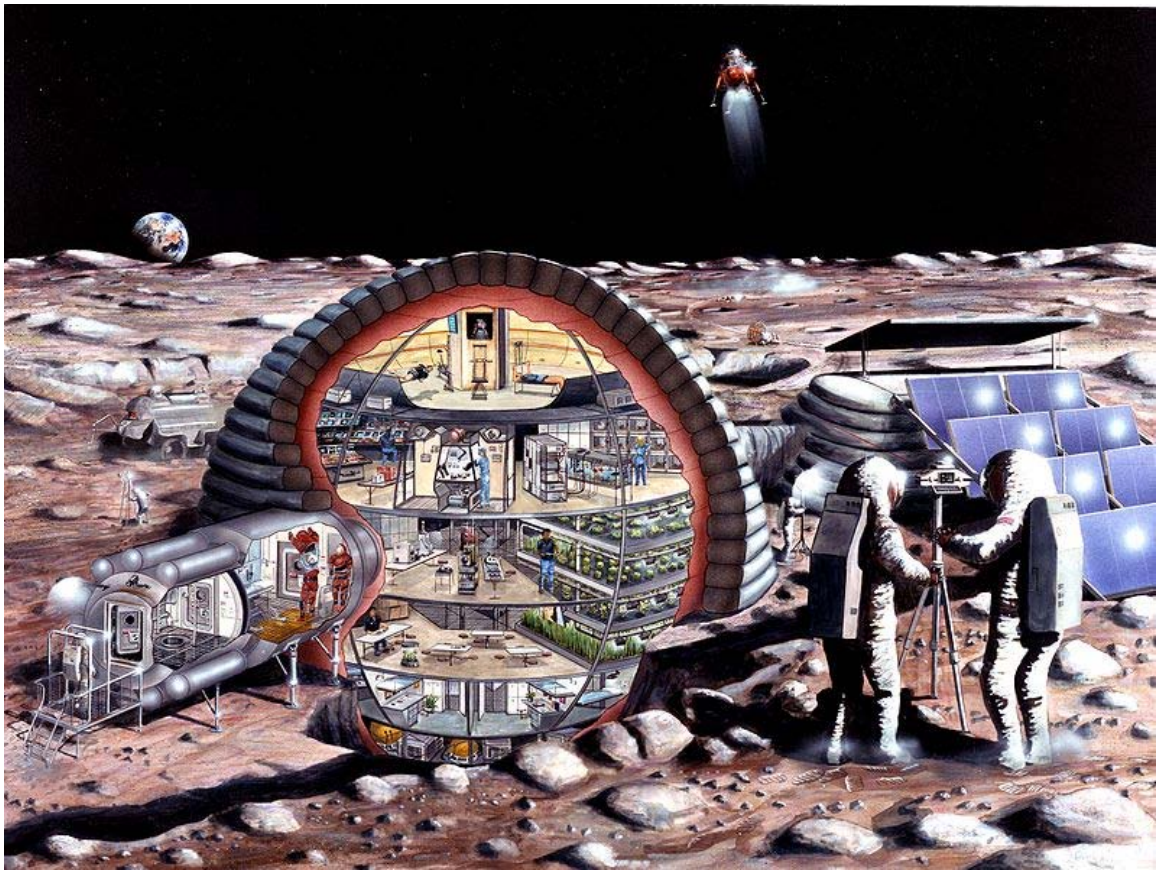
The concept of establishing a long-term human presence on the Moon can be traced back to the late 1950s. The Lunex Project, conceptualized in 1958, was a US Air Force plan to construct an underground Air Force Base on the Moon. On June 8, 1959, the US Army's Ballistic Missile Agency (ABMA) organized a task force called Project Horizon to assess the feasibility of constructing a Military base on the Moon.

Project Horizon proposed using a series of Saturn launches to pre-construct an outpost while in Earth orbit, with the intention of subsequently delivering and landing the

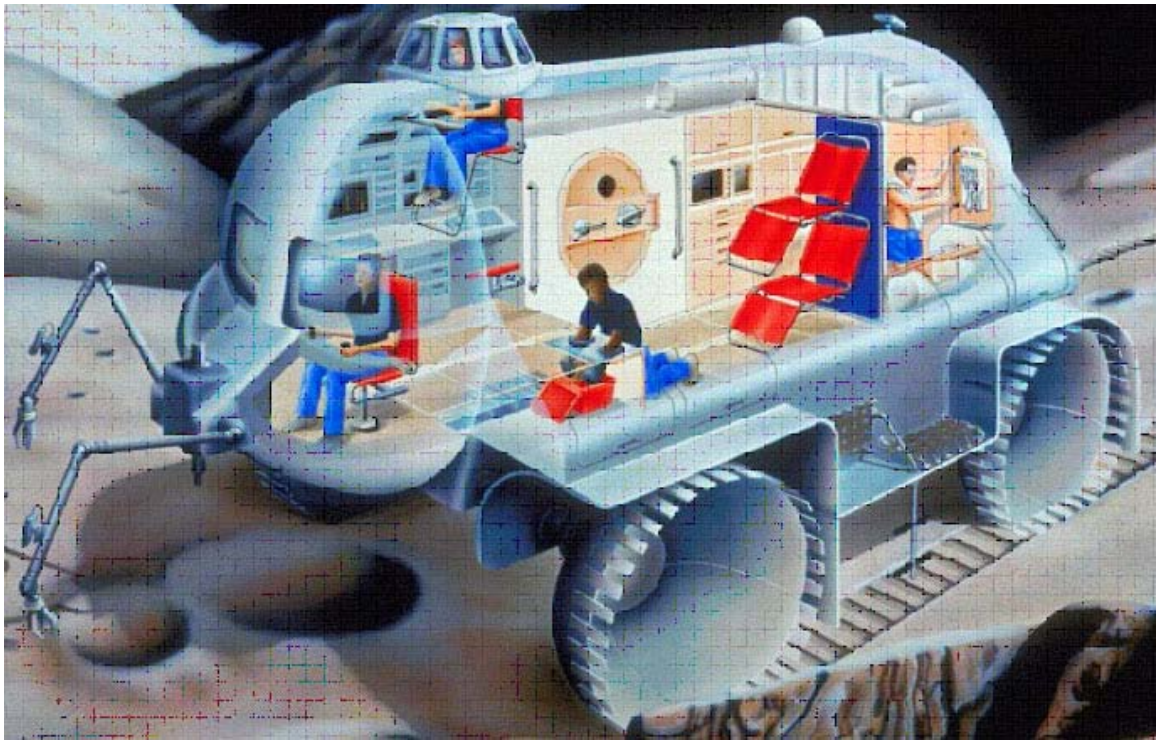
completed assembly on the Moon. Additional Saturn launches each month would then ship supplies to the inhabitants.



An early lunar outpost design based on a module design. A connecting tunnel to the left permits the outpost module to connect to landers, rovers or other modules. Much of the equipment is built into standardized racks. Much of the hardware in the early outpost will be dedicated to crew health. Concept: NASA (1990)



A lunar base for six to twelve people, built into an inflatable spherical habitat. Proportions of interior volume devoted to different systems equipment is relatively accurate. The heaviest equipment such as for environmental control, and areas in which the crew spends the most time, such as their personal sleep quarters are lowest in the habitat. Work areas for lunar sample analysis, for hydroponics, and even for small animals are located in the middle areas. The top deck in this view is a running track on which the sloped surface permits the crew member to use centripetal force rather than gravity to permit running in 1/6 G. Concept: NASA (1989)



Heavy, pressurized lunar rover for long duration treks across the moon's surface. The rover contains all facilities and supplies to house approx 4 crew for up to 2 weeks. A crew airlock permits crew to exit and enter the rover and may double as a docking port to the lunar base. A smaller sample airlock permits the crew, using remote manipulators mounted on the rover front to select, pick-up and retrieve samples without exiting the rover. Wheel design is based on one of the more favorable flex wheels developed during Apollo. Cupola on top is important for viewing the terrain at a much greater distance and along 360 degrees of the horizon, and is based on the ISS cupola design. Concept: NASA (1990)

Other countries' plans

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

China National Space Administration (CNSA) has commenced the Chang'e program for exploring the Moon to investigate the prospect of lunar mining, specifically for mining isotope helium-3 for use as an energy source on Earth. CNSA director Luan Enjie has stated, humans must learn to leave Earth and "set up self-sufficient extraterrestrial homeland." China launched the Chang'e 1 robotic lunar orbiter on October 10, 2007.

Justification

In the words of former NASA Administrator, Michael D. Griffin,

> *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.*

NASA proposes six "Lunar exploration themes" to answer the question, *"Why should we return to the Moon?"*

1. **Human Civilization:** Extend human presence to the Moon to enable eventual settlement.
2. **Scientific Knowledge:** Pursue scientific activities that address fundamental questions about the history of Earth, the solar system and the universe; and therefore, about our place in them.

3. **Exploration Preparation:** Test technologies, systems, flight operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.
4. **Global Partnerships:** Provide a challenging, shared and peaceful activity that unites nations in pursuit of common objectives.
5. **Economic Expansion:** Expand Earth's economic sphere, and conduct lunar activities with benefits to life on the home planet.
6. **Public Engagement:** Use a lively space exploration program to engage the public, encourage students and help develop the high-technology workforce that will be required to address the challenges of tomorrow.

According to retired NASA Office of Inspector General Senior Special Agent Joseph Richard Gutheinz, Jr., if "NASA succeeds, we may very well see the first permanent manned presence on the moon in 2024." Gutheinz, who teaches risk management, once investigated the Mir Space Station fire and collision and frequently speaks out against unnecessary risks in space, although he considers settling the moon to be an acceptable risk.

Criticism

Criticisms come from groups that want the manned exploration money diverted to Mars, from those who prefer unmanned exploration, and from those who simply want the money spent elsewhere. The criticisms listed here mostly predate the discovery of significant amounts of polar water ice. Jeff Foust, writing for *The Space Review*, called the six themes that NASA released too "broad" and the explanations supporting them "shallow." He also argues that a Moon base is a poor use of resources, since "science can be done for far less money by robotic missions—which also don't put human lives at risk." The *Los Angeles Times* seconded that in an editorial, saying "Manned moon flight may appeal to baby boomers, but it makes little scientific sense for most space missions these days. Robots can now perform, or be developed to perform, most of the tasks people would do at a moon station."

Columnist Gregg Easterbrook, who has reported on the space program for decades, has criticized the plans as a poor use of resources. He writes that

Although, of course, the base could yield a great discovery, its scientific value is likely to be small while its price is extremely high. Worse, moon-base nonsense may for decades divert NASA resources from the agency's legitimate missions, draining funding from real needs in order to construct human history's silliest white elephant.

According to Easterbrook, the billions of dollars that a lunar colony might cost should instead be devoted to exploring the solar system with space probes; space observatories; and protecting the Earth from near-Earth asteroids.

Buzz Aldrin, the second of twelve men to have walked on the Moon, disagrees with NASA's current goals and priorities, including their plans for a lunar outpost. While not

necessarily opposed to sending people back to the Moon, Aldrin argues that NASA should concentrate on a crewed mission to Mars and leave further lunar exploration and the establishment of a base there to a consortium of other countries under U.S. leadership. In a July 2009 editorial in the *Washington Post*, he said that NASA's Vision for Space Exploration "is not visionary; nor will it ultimately be successful in restoring American space leadership. Like its Apollo predecessor, this plan will prove to be a dead end littered with broken spacecraft, broken dreams and broken policies." He continued by saying that

the lunar surface ... is a poor location for homesteading. The moon is a lifeless, barren world, its stark desolation matched by its hostility to all living things. And replaying the glory days of Apollo will not advance the cause of American space leadership or inspire the support and enthusiasm of the public and the next generation of space explorers.

2008 concepts study

On June 6, 2008 NASA announced a set of six research opportunities and requested proposals for research funding in response to the announcement. The overall budget for research conducted as part of this "Lunar Surface Systems Concepts Study" is anticipated to be $2 million. Proposals will be selected and contracts awarded in August 2008 by the NASA Constellation Lunar Surface Systems Project Office (LSSPO).

2010/2011 surface system concept review

The LSSPO was established at the Johnson Space Center in August 2007. The LSSPO is studying lunar surface systems such as "habitation systems", ISRU, rovers, power production and storage, systems to meet science and exploration objectives and safety systems. The LSSPO currently expects to conduct a surface system concept review in the 2010 or 2011 timeframe.

Future Lunar Missions

Currently, there are several **future lunar missions** scheduled by various nations and organisations.

Unmanned missions

Recent impacts

– Within a year – Earlier

Country	Name	Launch date	Landing date	Area	Mission type
India	*MIP*	October 22, 2008	November 14, 2008	LQ30	Impactor

Japan	*Okina (RSAT)*	September 14, 2007	February 12, 2009	LQ08	Orbiter (crashed at mission end)
China	*Chang'e 1*	October 24, 2007	March 1, 2009	LQ21	Orbiter (systematically crashed at mission end)
Japan	*Kaguya*	September 14, 2007	June 10, 2009	LQ30	Orbiter (systematically crashed at mission end)
USA	*LCROSS*	June 18, 2009	October 9, 2009	LQ30	Impactor (Centaur) Impactor (Shepherding Spacecraft)

In flight

– En route – Under main mission – Mission complete

Country	Name	Launch date	Mission life time
Japan	*Ouna (VSAT)*	September 14, 2007	1 year (mission complete at 29 June 2009)
India	*Chandrayaan-1*	October 22, 2008	2 years intended (Achieved only 315 days - Mission abruptly terminated due to malfunction and lost contact)
USA	*Lunar Reconnaissance Orbiter*	June 19, 2009	1 year (extended mission of up to 5 years)
USA	*ARTEMIS*	February 17, 2007	until 2012
China	*Chang'e 2*	October 1, 2010	6 months

Under development

Country	Name	Launch due
USA	*GRAIL*	September 6 2011
USA	*LADEE*	2012
Russia	*Luna-Glob 1*	2012
Russia	*Luna-Glob 2*	2012
China	*Chang'e 3*	2013
India	*Chandrayaan-2*	2013
USA	*ILN Node 1*	2013
USA	*ILN Node 2*	2014

Proposal phase

Country	Name	Launch due
Japan	*SELENE-2*	2012 / 2013
UK	*MoonLITE*	2014
	MoonRaker	2014
Russia	*Luna-Grunt 1*	2014
	Luna-Grunt 2	2015
India	Chandrayaan III	2015
(Private)	*Google Lunar X Prize*	Before 2015
USA	*ILN Node 3*	2016
	ILN Node 4	2017
China	*Chang'e 4*	2017
Europe	*MoonNext*	2015-2018
Russia	*Luniy-Poligon*	2020
South Korea	*Moon Orbiter*	2020
	Moon Lander	2025

Cancelled or indefinitely postponed

Country	Name	Launch due	
Japan	*LUNAR-A*	August 2004	Integrated into Russia's *Luna-Glob 1* mission
Germany	*LEO*	2012	Mission postponed indefinitely due to budgetary constraints
USA	*Constellation Program*	2020	Mission Cancellation Pending Congressional Approval Due To Budget

Manned missions

Country	Name	Currently proposed launch date
India		2020; proposed by ISRO (2009).
Japan		2020, moonbase 2030; proposed by JAXA (2006).
China	*CLEP*	2025 suggested by various scientists.
Europe	*Aurora programme*	2024; proposed by ESA.
Russia		2025, moonbase 2027–32; proposed by RFSA (2007).

NB. Launch dates are aspirational and may change drastically as the planning and preparation progresses.

Chapter- 3

Colonization of Venus

Venus

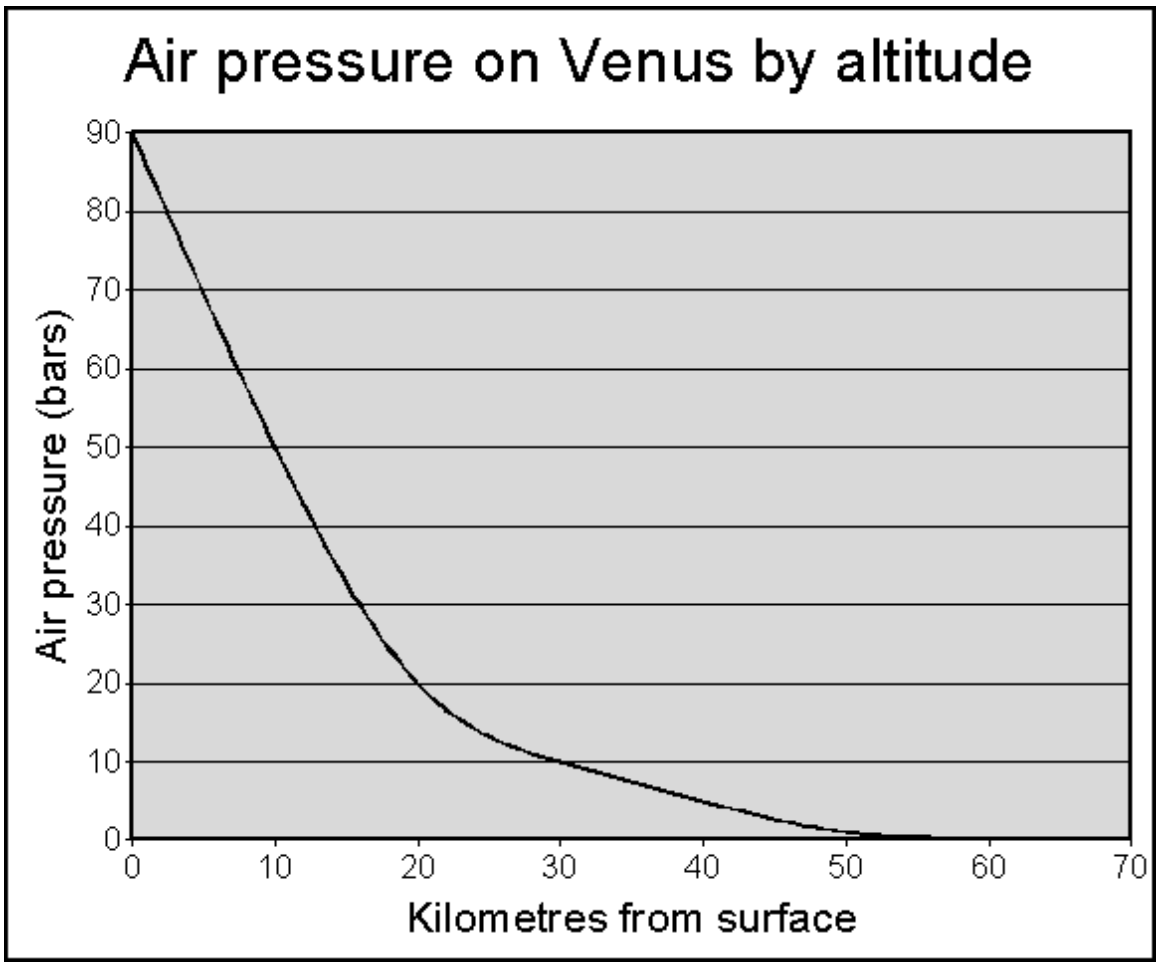
The **colonization of Venus** has been a subject of much speculation and many works of science fiction since before the dawn of spaceflight, and is still much discussed. With the discovery of Venus' hostile surface environment, attention has largely shifted towards the colonization of the Moon and the colonization of Mars.

Reasons for colonization

Space colonization is a step beyond space exploration, and implies the permanent or long-term presence of humans in an environment outside Earth. Colonization of space is arguably the best way to ensure the survival of humans as a species. Other reasons for colonizing space include economic interests, long-term scientific research best carried out by humans, and sheer curiosity. Venus is the second largest terrestrial planet and Earth's closest neighbour, which makes it a potential target.

Advantages

Scale representations of Venus and the Earth shown next to each other. Venus is only slightly smaller.



Air pressure on Venus, beginning at a pressure on the surface 90 times that of Earth and reaching a single bar by 50 kilometres.

Venus has certain similarities to Earth which might make colonization easier in many respects in comparison with other possible destinations. These similarities, and its proximity, have led Venus to be called Earth's "sister planet".

At present it has not been established whether the gravity of Mars, 0.38 times that of the Earth, would be sufficient to avoid bone decalcification and loss of muscle tone experienced by astronauts living in an environment of microgravity (the probe Mars Gravity Biosatellite was going to be the first probe to investigate this, however it has since been canceled due to lack of funding). In contrast, Venus is close in size and mass to the Earth, resulting in a similar surface gravity (0.904 *g*). Most other space exploration and colonization plans face concerns about the damaging effect of long-term exposure to fractional *g* or zero gravity on the human musculoskeletal system. Humans born on Venus would probably have little difficulty adapting to Earth gravity should there be a reason to visit or return; contrasted to return trips from Mars where humans would likely need rehabilitation or the use of an exoskeleton.

Venus's relative proximity makes transportation and communications easier than for most other locations in the solar system. With current propulsion systems, launch windows to Venus occur every 584 days, compared to the 780 days for Mars. Flight time is also somewhat shorter; the probe Venus Express which recently arrived at Venus spent slightly over five months en route, compared to nearly six months for Mars Express. This is because at closest approach, Venus is 45 million km from Earth compared to 56 million km for Mars, making Venus the closest planet to the Earth.

Difficulties

Venus also presents several significant challenges to human colonization. Surface conditions on Venus are practically impossible to deal with: the temperature at the equator averages around 500 °C (932 °F), higher than the melting point of lead. The atmospheric pressure on the surface is also at least ninety times greater than on Earth, which is equivalent to the pressure experienced under a kilometer of water. These conditions have caused missions to the surface to be extremely brief: the probes Venera 5 and Venera 6 for example were crushed by high pressure whilst still 18 km above the surface. Following landers such as Venera 7 and Venera 8 succeeded in transmitting data after reaching the surface, but these missions were brief as well, surviving no more than a single hour on the surface.

Furthermore, water, in any form, is almost entirely absent from Venus. The atmosphere is devoid of molecular oxygen and is primarily carbon dioxide in poisonously high concentrations. In addition, the visible clouds are composed partly of corrosive sulfuric acid and sulfur dioxide vapor.

Methods of colonization and exploration

Given the hostile conditions of Venus, a colony on the Venusian surface in its present form is far beyond current technological capabilities.

This has not prevented some science-fiction authors from speculating on ways of overcoming this by, for example, terraforming Venus – making the planet more earth-like. The energy requirements for all terraforming plans are daunting when compared with our current technology, and the time required could possibly span hundreds of years. Other authors speculate that, if a large portion or the entire planet could be shaded, Venus would cool to a useful temperature in mere decades. Such authors postulate methods which would include placing sails (Solar shades) between Venus and the sun at the Lagrange point between the two, controlled dust clouds in space, and a large number of other ideas.

Others suggest a different approach, however, claiming that rather than attempting to colonize Venus' hostile surface, humans might attempt to colonize the Venusian atmosphere (the most habitable known part of any planet outside Earth). This is because

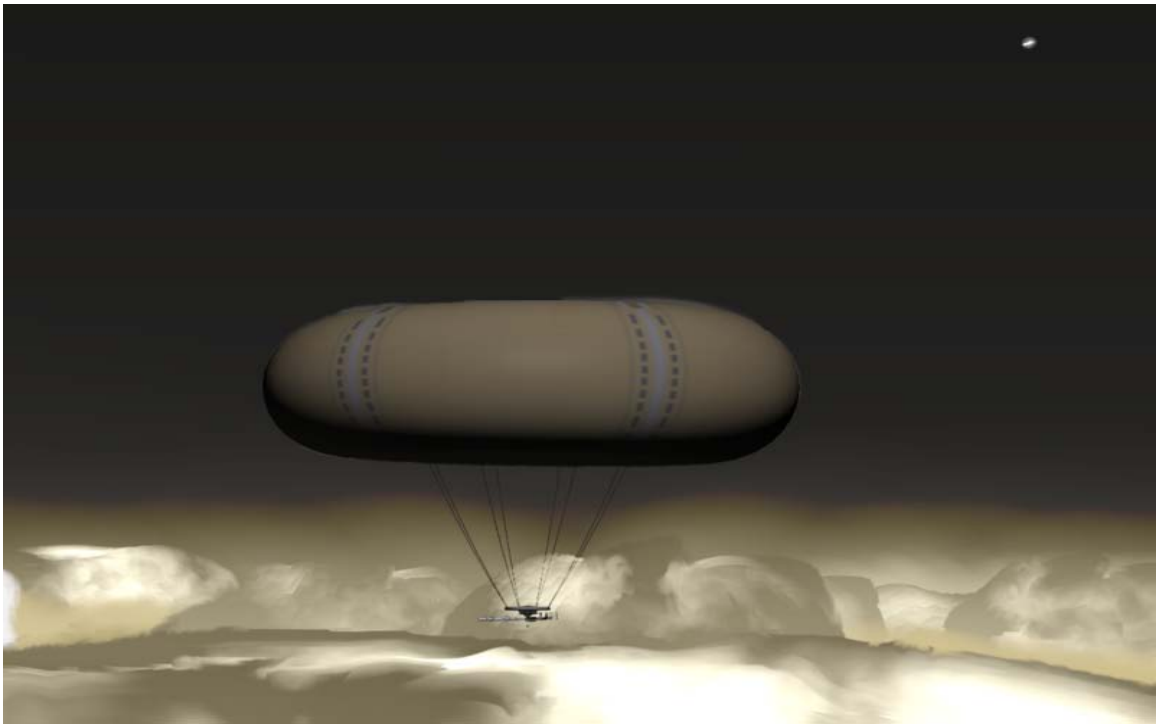
at an altitude of approximately 50 kilometers (in Venus's upper atmosphere), the pressure and temperature are Earth-like (1 bar and 0-50 degrees Celsius).

Exploration and research

As Venus has not been studied as much as objects such as the moon and Mars have, further research would have to be conducted on the planet before a human-powered mission could be approved. The probe Venus Express is currently in orbit around the planet, but other low-cost missions have been proposed to further explore the planet's atmosphere, as the area 50 kilometres above the surface where air pressure is at the same level as Earth has not yet been explored.

It is currently possible to successfully land a robot on the surface. The Soviet Venera program succeeded in doing so – the Venera 13 lander survived for 127 minutes, and the Venera 14 lander for 57 minutes. It is not inconceivable that this survival time could be extended. Improved materials and technology designed to work at the high temperatures and pressures would be necessary. As the survival times of the robotic probes grows longer, enhanced missions might be feasible, including the establishment of a robotic base at locations where important (perhaps fissionable) compounds might be found. The technology for operating under such conditions is at the current time so exotic as to be difficult to conceive, and funding is likely to go elsewhere.

Aerostat habitats and floating cities



Hypothetical prototype floating outpost studying colonization of Venus around 50 km above the surface supported by a torus full of hydrogen.

Geoffrey A. Landis has summarized the perceived difficulties in colonizing Venus as being merely from the assumption that a colony would need to be based on the surface of a planet:

> "However, viewed in a different way, the problem with Venus is merely that the ground level is too far below the one atmosphere level. At cloud-top level, Venus is the paradise planet."

He has proposed aerostat habitats followed by floating cities, based on the concept that breathable air (21:79 Oxygen-Nitrogen mixture) is a lifting gas in the dense Venusian atmosphere, with over 60% of the lifting power that helium has on Earth. In effect, a balloon full of human-breathable air would sustain itself and extra weight (such as a colony) in midair. At an altitude of 50 km above Venusian surface, the environment is the most Earth-like in the solar system – a pressure of approximately 1 bar and temperatures in the 0°C–50°C range. Because there is not a significant pressure difference between the inside and the outside of the breathable-air balloon, any rips or tears would cause gases to diffuse at normal atmospheric mixing rates, giving time to repair any such damages. In addition, humans would not require pressurized suits when outside, merely air to breathe and a protection from the acidic rain. Alternatively, two-part domes could contain a lifting gas like hydrogen or helium (extractable from the atmosphere) to allow a higher mass density.

Cloud-top colonization also offers a way to avoid the issue of slow Venusian rotation. At the top of the clouds the wind speed on Venus reaches up to 95 m/s (approximately 212 mph), circling the planet approximately every four Earth days in a phenomenon known as "super-rotation". Colonies floating in this region could therefore have a much shorter day length by remaining untethered to the ground and moving with the atmosphere. While a space elevator extending to the surface of Venus is impractical due to the slow rotation, constructing a skyhook that extended into the upper atmosphere and rotated at the wind speed would not be difficult compared to constructing a space elevator on Earth.

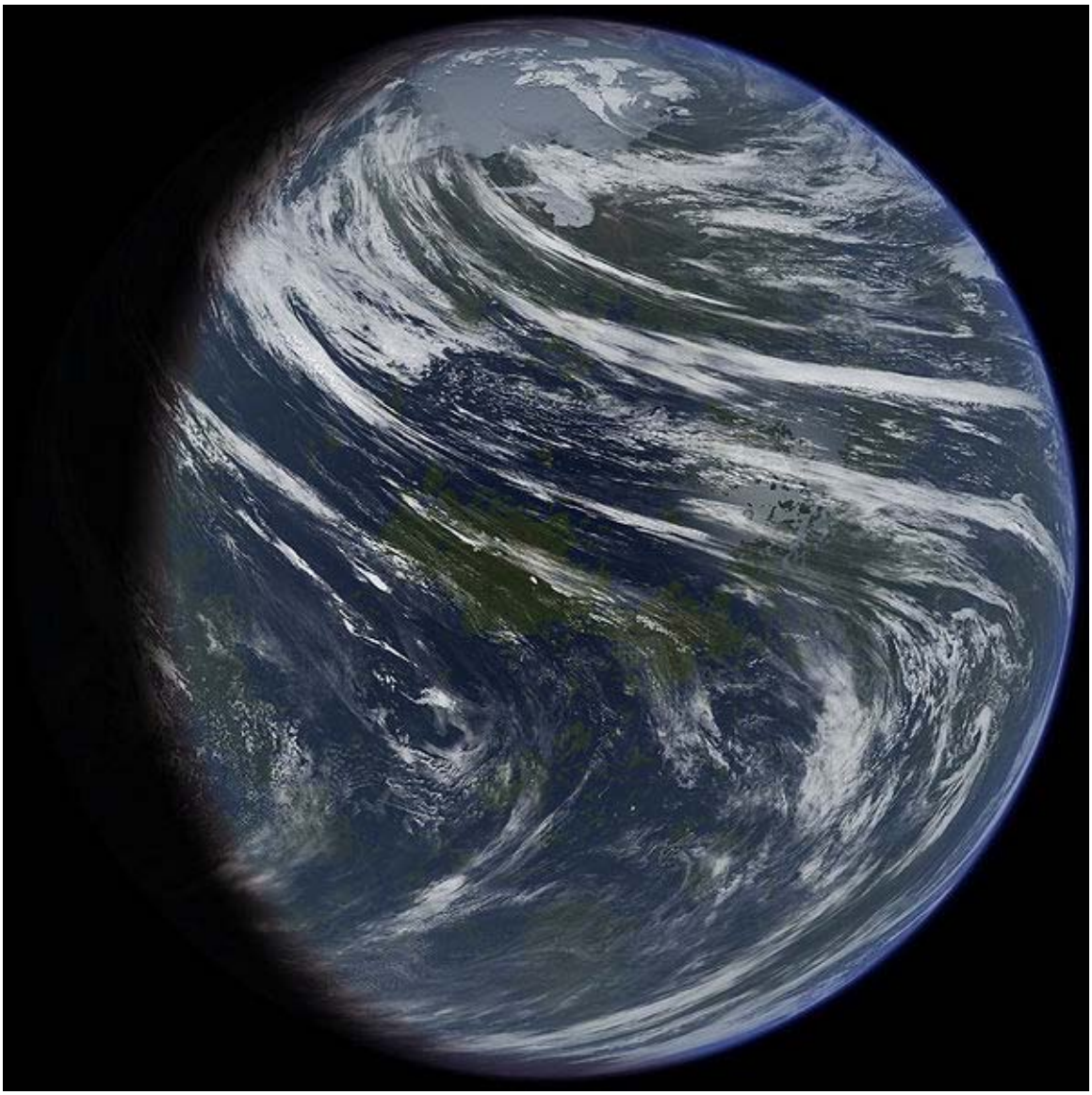
Since such colonies would be viable in current Venusian conditions, this allows a dynamic approach to colonization instead of requiring extensive terraforming measures in advance. The main challenge would be using a substance resistant to sulfuric acid to serve as the structure's outer layer; ceramics or metal sulfates could possibly serve in this role. Dyneema, Polyethene and Polypropylene would be well usable for the skin of the balloon.

Landis has suggested that as more floating cities were built, they could form a solar shield around the planet, and could simultaneously be used to process the atmosphere into a more desirable form. If made from carbon nanotubes (recently fabricated into sheet form) or graphene (a sheet-like carbon allotrope), the major structural materials can be produced using carbon dioxide gathered in situ from the atmosphere. The recently synthesised amorphous carbonia might prove a useful structural material if it can be quenched to STP conditions, perhaps in a mixture with regular silica glass. According to

Birch's analysis such colonies and materials would provide an immediate economic return from colonizing Venus, funding further terraforming efforts.

In remarking that the ground is too far below the one-atmosphere level, Landis echoes the descriptions of the planets Rustum, in the novel *Orbit Unlimited* by Poul Anderson, and Plateau, in *A Gift from Earth* by Larry Niven. Each has a dense poisonous atmosphere, with a small region of land rising to a habitable level.

Terraforming



Artist's conception of a terraformed Venus.

Terraforming (literally, "Earth-shaping") is the theoretical process of modifying a planet, moon, or other body to a more habitable atmosphere, temperature, or ecology. Venus has

been the subject of a number of terraforming proposals. The proposals seek to remove or convert the dense carbon dioxide atmosphere, reduce Venus's 500 °C (770 K) surface temperature, and establish a day/night light cycle closer to that of Earth's.

Most proposals involve deployment of a solar shade and/or a system of orbital mirrors, for the purpose of reducing insolation and providing light to the dark side of Venus. Another common thread in most proposals involves some introduction of large quantities of hydrogen or water. Proposals also involve either freezing most of Venus's atmospheric CO_2, or converting it to carbonates, urea or other forms.

Colonies in Venus Orbit

Another promising pathway to colonization is the use of near-Venus space for the orbital capture and development of comets and asteroids. Although Venus currently has no moons, in the near future it may be practical to nudge smaller bodies into orbit around the inner planets. Venus is especially good for this because aerobraking in its thick atmosphere can be used to slow these bodies down. Unlike near-Earth space where the danger of hitting the Earth would have severe effects on the civilization, near-Venus space does not suffer from this problem. The available free solar energy from the Sun makes Venus a desirable location for industrial development.

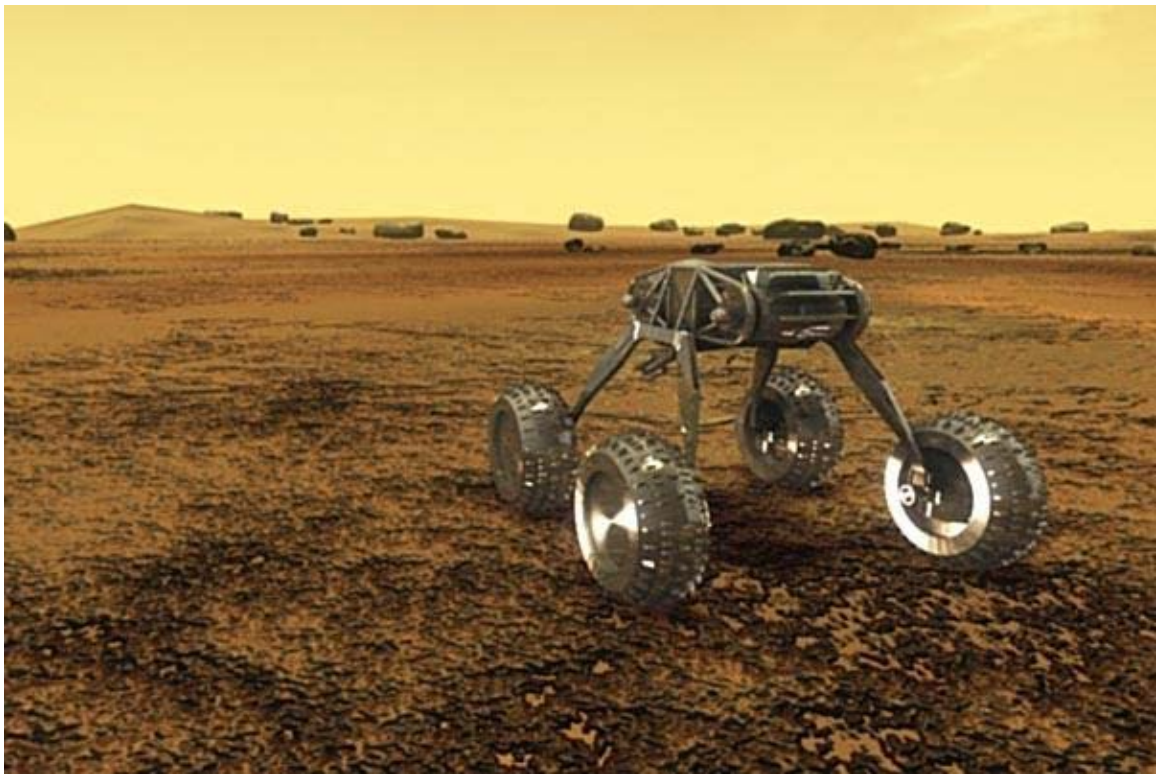
It is also a likely precursor to any serious attempt to develop economic activity in the gravity well of Venus. Resources in Venus orbit would be used to extend activity downward. A space elevator would likely not be feasible, given Venus' slow rotation (243 Earth days), but a skyhook into the atmosphere is possible.

Chapter- 4

Future Missions to Venus

NASA's MESSENGER mission to Mercury performed two flybys of Venus in October 2006 and June 2007, to slow its trajectory for an eventual orbital insertion of Mercury in March 2011. MESSENGER collected scientific data on both those flybys.

The Venus Express probe was designed and built by the European Space Agency. Launched on November 9, 2005 by a Russian Soyuz-Fregat rocket procured through Starsem, it successfully assumed a polar orbit around Venus on April 11, 2006. The probe is undertaking a detailed study of the Venusian atmosphere and clouds, including mapping of the planet's plasma environment and surface characteristics, particularly temperatures. One of the first results emerging from Venus Express is the discovery that a huge double atmospheric vortex exists at the south pole of the planet.



Artist's impression of a Stirling cooled Venus Rover devised by NASA.

The Japan Aerospace Exploration Agency (JAXA) devised a Venus orbiter, Akatsuki (formerly "Planet-C"), which was launched on May 20, 2010 but the craft failed to enter orbit in December 2010. Hopes remain that the probe can successfully hibernate and make another insertion attempt in six years, however. Planned investigations included surface imaging with an infrared camera and experiments designed to confirm the presence of lightning as well as the determination of the existence of current surface volcanism.

The European Space Agency (ESA) hopes to launch a mission to Mercury in 2014, called BepiColombo, which will perform two flybys of Venus before it reaches Mercury orbit in 2020.

Under its New Frontiers Program, NASA has proposed a lander mission called the Venus In-Situ Explorer to land on Venus to study surface conditions and investigate the elemental and mineralogical features of the regolith. The probe would be equipped with a core sampler to drill into the surface and study pristine rock samples not weathered by the very harsh surface conditions. The Venera-D (Russian: Венера-Д) probe is a proposed Russian space probe to Venus, to be launched around 2016 with its goal to make remote-sensing observations around the planet Venus and deploying a lander, based on the Venera design, capable of surviving for a long duration on the planet's surface. Other proposed Venus exploration concepts include rovers, balloons, and airplanes.

Manned Venus flyby

A manned Venus flyby mission, using Apollo program hardware, was proposed in the late 1960s. The mission was planned to launch in late October or early November 1973, and would have used a Saturn V to send three men to fly past Venus in a flight lasting approximately one year. The spacecraft would have passed approximately 5,000 kilometres from the surface of Venus about four months later.

Background

The proposed mission would use a Saturn V to send three men to fly past Venus in a flight which would last approximately one year. The S-IVB stage would be a 'wet workshop' similar to Skylab, first using the S-IVB engine to launch the mission on course to Venus, and then vented of any remaining fuel to serve as home for the crew for the duration of the mission. The Apollo SM engine would be used for course corrections on the way to Venus and back to Earth, and for a braking burn before the Command Module re-entered Earth's atmosphere. In order to free up more space in the Spacecraft Lunar Module Adapter for the docking tunnel connecting the CSM to the S-IVB, the SPS engine on the Service Module would be replaced by two LM engines. These would provide similar thrust with shorter nozzles, and would also give the mission the added safety of redundant engines.

Precursors to the Venus flyby would include an initial orbital test flight with an S-IVB 'wet workshop' and basic docking adapter, and a year-long test flight taking the S-IVB to a near-geostationary orbit around the Earth.

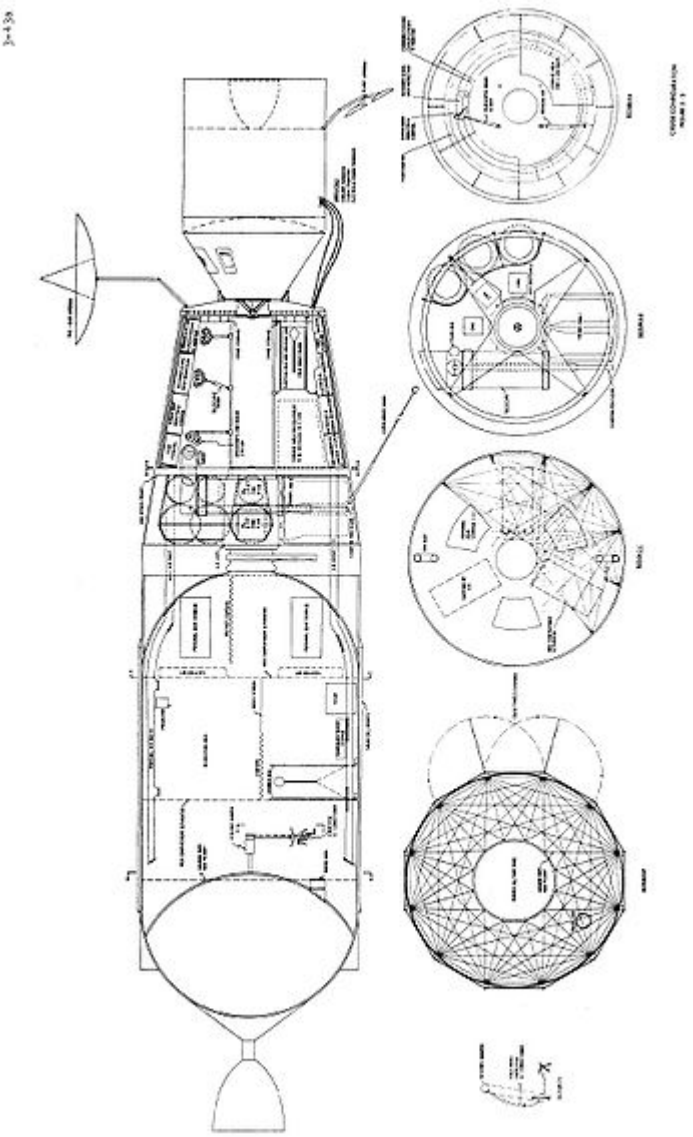
One oddity of the Venus flyby mission is that, unlike trips to the Moon, the CSM would separate and dock with the S-IVB stage before the S-IVB burn, so the astronauts would fly 'eyeballs-out', the thrust of the engine pushing them out of their seats rather than into them. This was required because there was only a short window for an abort burn by the CSM to return to Earth after a failure in the S-IVB, so all spacecraft systems needed to be operational and checked out before leaving the parking orbit around Earth to fly to Venus.

Science

The mission would measure:

- Atmospheric density, temperature and pressure as functions of altitude, latitude and time.
- Definition of the planetary surface and its properties.
- Chemical composition of the low atmosphere and the planetary surface.
- Ionospheric data such as radio reflectivity and electron density and properties of cloud layers.
- Optical astronomy - UV and IR measurements above the Earth's atmosphere to aid in the determination of the spatial distribution of hydrogen.
- Solar astronomy - UV, X-ray and possible infrared measurements of the solar spectrum and space monitoring of solar events.
- Radio and radar astronomy - radio observations to map the brightness of the radio sky and to investigate solar, stellar and planetary radio emissions; radar measurements of the surface of Venus and Mercury
- X-ray astronomy - measurements to identify new X-ray sources in the galactic system and to obtain additional information on sources previously identified.
- Data on the Earth-Venus interplanetary environment, including particulate radiation, magnetic fields and meteoroids.
- Data on the planet Mercury, which will be in mutual planetary alignment with Venus approximately two weeks after the Venus flyby

Mission



Cutaway diagram of the Venus flyby spacecraft.

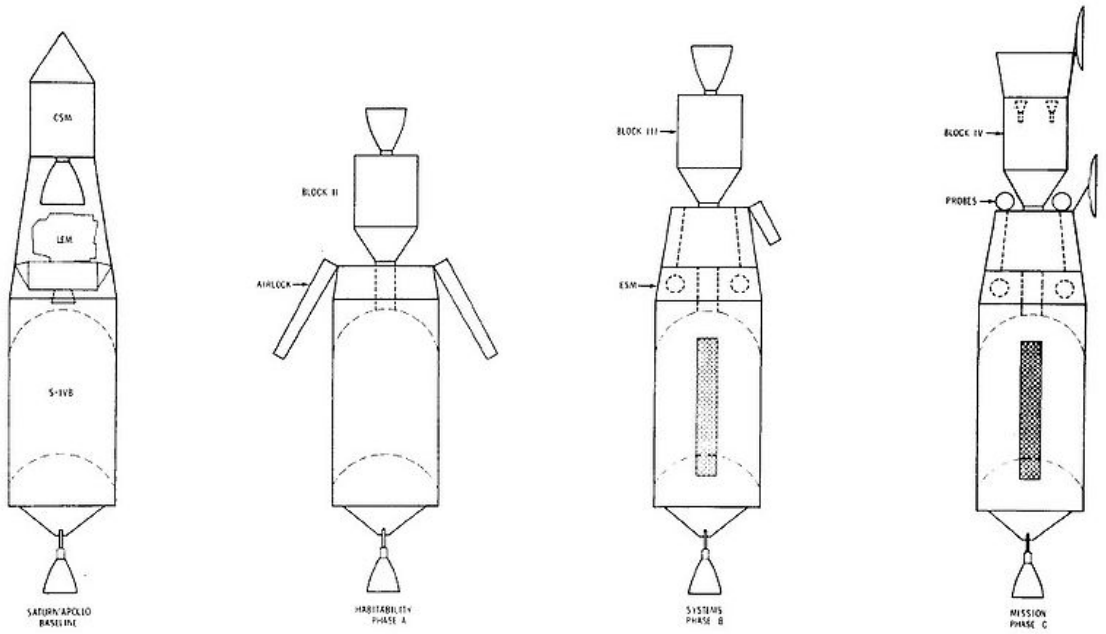


Figure 3-4 - Development Steps

Diagram of the planned development phases of the Venus flyby spacecraft.

Mockup of Phase-A test, in an 'eyeballs-out' burn. (From Orbiter Space Flight Simulator)

Phase A

Phase A of the plan would have launched a 'wet workshop' S-IVB and a standard Block II Apollo CSM into orbit on a Saturn V. The crew would separate the CSM from the S-IVB by blowing off the SLA panels, then perform a Transposition and Docking maneuver similar to that conducted on the lunar flights, in order to dock with the docking module attached to the front of the S-IVB. Optionally they could then use the S-IVB engine to launch them into a high orbit before they vented any remaining fuel into space and entered the S-IVB fuel tanks to conduct experiments for a few weeks. After evaluating the use of the S-IVB as a long-term habitat for astronauts, they would separate the CSM from the S-IVB and return to Earth.

Phase B

Phase B would test the Venus flyby spacecraft in a long duration mission in high orbit. A Saturn V would launch a Block III CSM designed for long-term spaceflight and a modified S-IVB with the Environmental Support Module required for the real Venus flyby, and following the transposition and docking maneuver the S-IVB engine would carry the spacecraft to a circular orbit at an altitude of about 25,000 miles around the Earth. This altitude would be high enough to be clear of Earth's radiation belts while

exposing the spacecraft to an environment similar to that of a trip to Venus, yet close enough to Earth that the astronauts could use the CSM to return in a few hours in an emergency.

Power would probably be provided by solar panels similar to those used on Skylab, as fuel cells would require a very large amount of fuel to operate for a year. Similarly the fuel cells in the SM used to provide power on lunar flights would be replaced by batteries which would provide enough power for the duration of launch and re-entry operations.

Phase C

Phase C would be the actual manned flyby, using a Block IV CSM and an updated version of the Venus flyby S-IVB which would carry a large radio antenna for communication with Earth and two or more small probes which would be released shortly before the flyby to enter the atmosphere of Venus. The Block IV CSM has LM engines replacing the Service Propulsion System engines, batteries to replace the fuel cells, and other modifications to support long-range communication with Earth and the higher re-entry velocities required for the return trajectory compared to a return from lunar orbit.

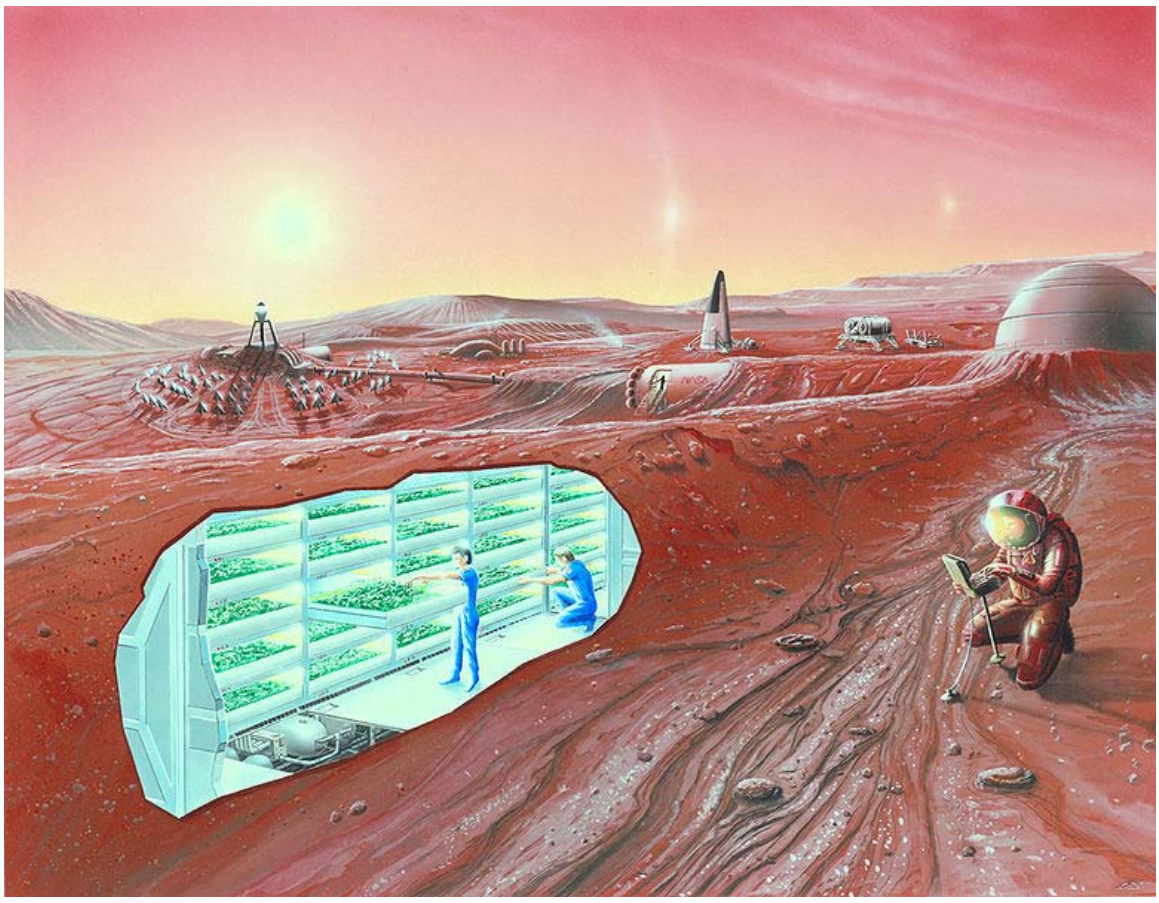
The Phase C mission was planned to launch in late October or early November 1973, when the velocity requirements required to reach Venus and the duration of the resulting mission would be at their lowest. After a brief stay in Earth parking orbit to check out the spacecraft the crew would head for Venus: in the event of a major problem during the Trans-Venus Injection burn, they would have roughly an hour to separate the CSM from the S-IVB and use the SM engine to cancel out most of the velocity they gained from the burn. This would put them into a highly elliptical orbit which would typically bring them back to Earth for a re-entry two to three days later. Beyond that time the SM engine would not have enough fuel to bring the CSM back to Earth before the SM batteries ran out of power: it would literally be 'Venus or Bust'.

After a successful S-IVB burn, the spacecraft would pass approximately 3000 miles from the surface of Venus about four months later. The flyby velocity would be so high that the crew would only have a few hours for detailed study of the planet. At this point, one or more unmanned probe landers would separate from the main craft and land on Venus.

During the rest of the mission the crew would perform astronomical studies of the Sun, the sky and Mercury, which they would approach within 0.3 Astronomical Units.

Chapter- 5

Colonization of Mars



An artist's conception of the colonization of Mars, with a cutaway showing part of the interior (NASA Ames, 2005)

The **colonization of Mars** by humans is the focus of speculation and serious study because the surface conditions and availability of water on Mars make it arguably the most hospitable planet in the solar system other than Earth. The Moon has been proposed as the first location for human colonization but Mars has an atmosphere, giving it the potential capacity to host human and other organic life.

Relative similarity to Earth

The Earth is very like its "sister planet" Venus in bulk composition, size and surface gravity but Mars' similarities to Earth are arguably more compelling when considering colonization. These include:

- The Martian day (or **sol**) is very close to Earth's. A Mars solar day is 24 hours 39 minutes 35.244 seconds.
- Mars has a surface area that is 28.4% of Earth's, only slightly less than the amount of dry land on Earth (which is 29.2% of Earth's surface). Mars has half the radius of Earth and only one-tenth the mass. This means that it has a smaller volume (~15%) and lower average density than Earth.
- Mars has an axial tilt of 25.19°, compared with Earth's 23.44°. As a result, Mars has seasons much like Earth, though they last nearly twice as long because the Martian year is about 1.88 Earth years. The Martian north pole currently points at Cygnus, not Ursa Minor.
- Mars has an atmosphere. Although it is very thin (about 0.7% of Earth's atmosphere) it provides some protection from solar and cosmic radiation and has been used successfully for aerobraking of spacecraft.
- Recent observations by NASA's Mars Exploration Rovers, ESA's Mars Express and NASA's Phoenix Lander confirm the presence of water ice on Mars. Mars appears to have significant quantities of all the elements necessary to support Earth-based life.

Differences from Earth

- The surface gravity on Mars is 0.38 of that on Earth. It is not known if this is enough to prevent the health problems associated with weightlessness.
- Mars is much colder than Earth, with a mean surface temperature of -63°C and a low of -140°C. The lowest temperature ever recorded on Earth was −89.2°C, in Antarctica.
- There are no standing bodies of liquid water on the surface of Mars.
- Because Mars is further from the Sun, the amount of solar energy reaching the upper atmosphere (the solar constant) is less than half of what reaches the Earth's upper atmosphere or the Moon's surface. However, the solar energy that reaches the surface of Mars is not impeded by a thick atmosphere like on Earth.

- Mars' orbit is more eccentric than Earth's, exacerbating temperature and solar constant variations.

- The atmospheric pressure on Mars is ~6 mbar, far below the Armstrong Limit (61.8 mbar) at which people can survive without pressure suits. Since terraforming cannot be expected as a near-term solution, habitable structures on Mars would need to be constructed with pressure vessels similar to spacecraft, capable of containing a pressure between a third and a whole bar.

- The Martian atmosphere consists mainly of carbon dioxide. Because of this, even with the reduced atmospheric pressure, the partial pressure of CO_2 at the surface of Mars is some 52 times higher than on Earth. It also has significant levels of carbon monoxide.

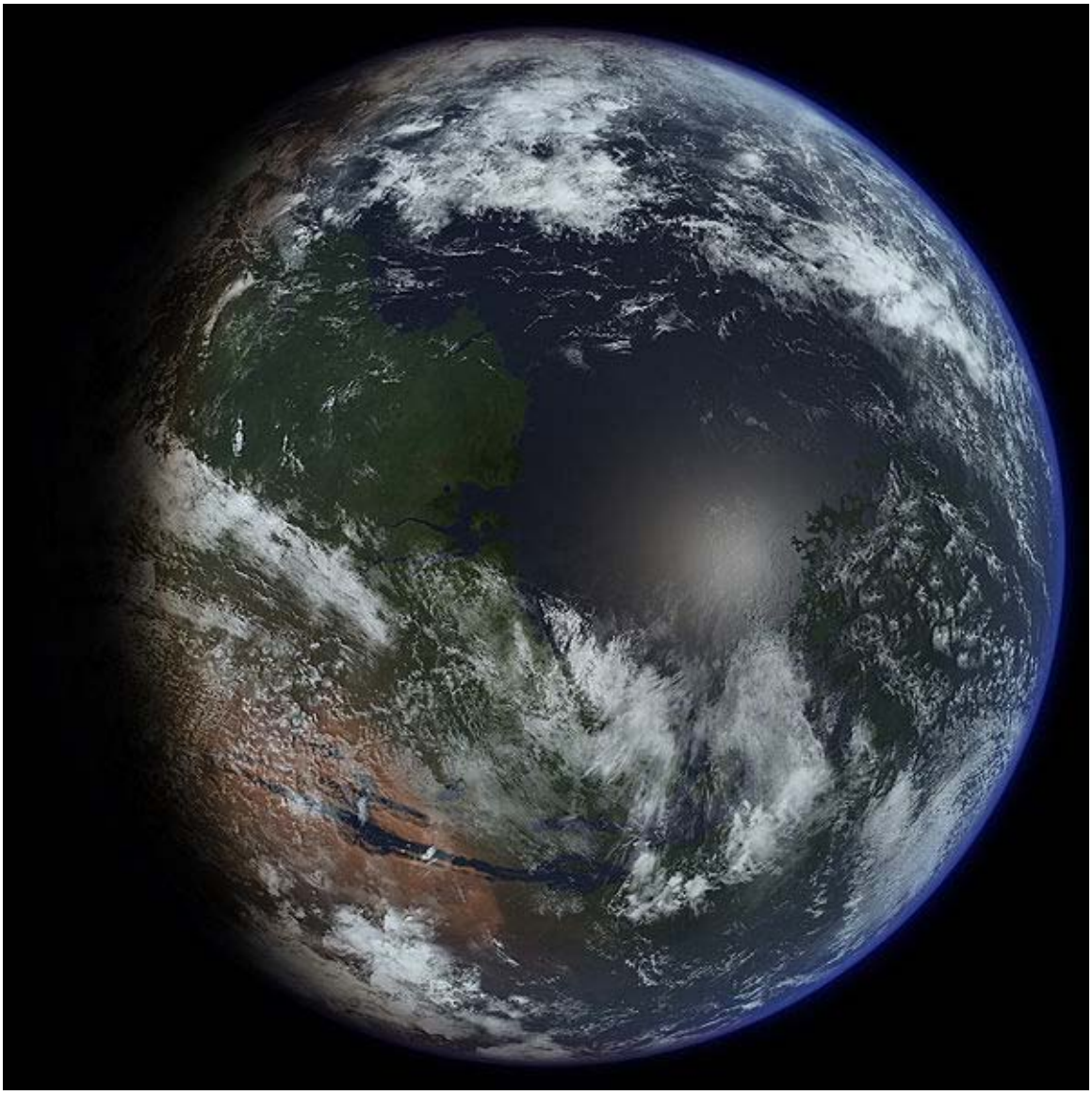
- Mars has a very weak magnetosphere, so it deflects solar winds poorly.

Habitability

Conditions on the surface of Mars are much closer to habitability than the surface of any other known planet or moon, as seen by the extremely hot and cold temperatures on Mercury, the furnace-hot surface of Venus, or the cryogenic cold of the outer planets and their moons. Only the cloud tops of Venus are closer in terms of habitability to Earth than Mars is. There are natural settings on Earth where humans have explored that match most conditions on Mars. The highest altitude reached by a manned balloon ascent, a record set in May 1961, was 34,668 meters (113,740 feet). The pressure at that altitude is about the same as on the surface of Mars. Extreme cold in the Arctic and Antarctic match all but the most extreme temperatures on Mars.

NASA Deputy Administrator Shana Dale said, "We also hope to discover if Mars can provide a second home for humans—an extension of our civilization—40 million miles from Earth."

Terraforming



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

It may be possible to terraform Mars to allow a wide variety of living things, including humans, to survive unaided on Mars' surface.

Radiation

Mars has no global magnetic field comparable to Earth's geomagnetic field. Combined with a thin atmosphere, this permits a significant amount of ionizing radiation to reach the Martian surface. The Mars Odyssey spacecraft carried an instrument, the Mars Radiation Environment Experiment (MARIE), to measure the dangers to humans.

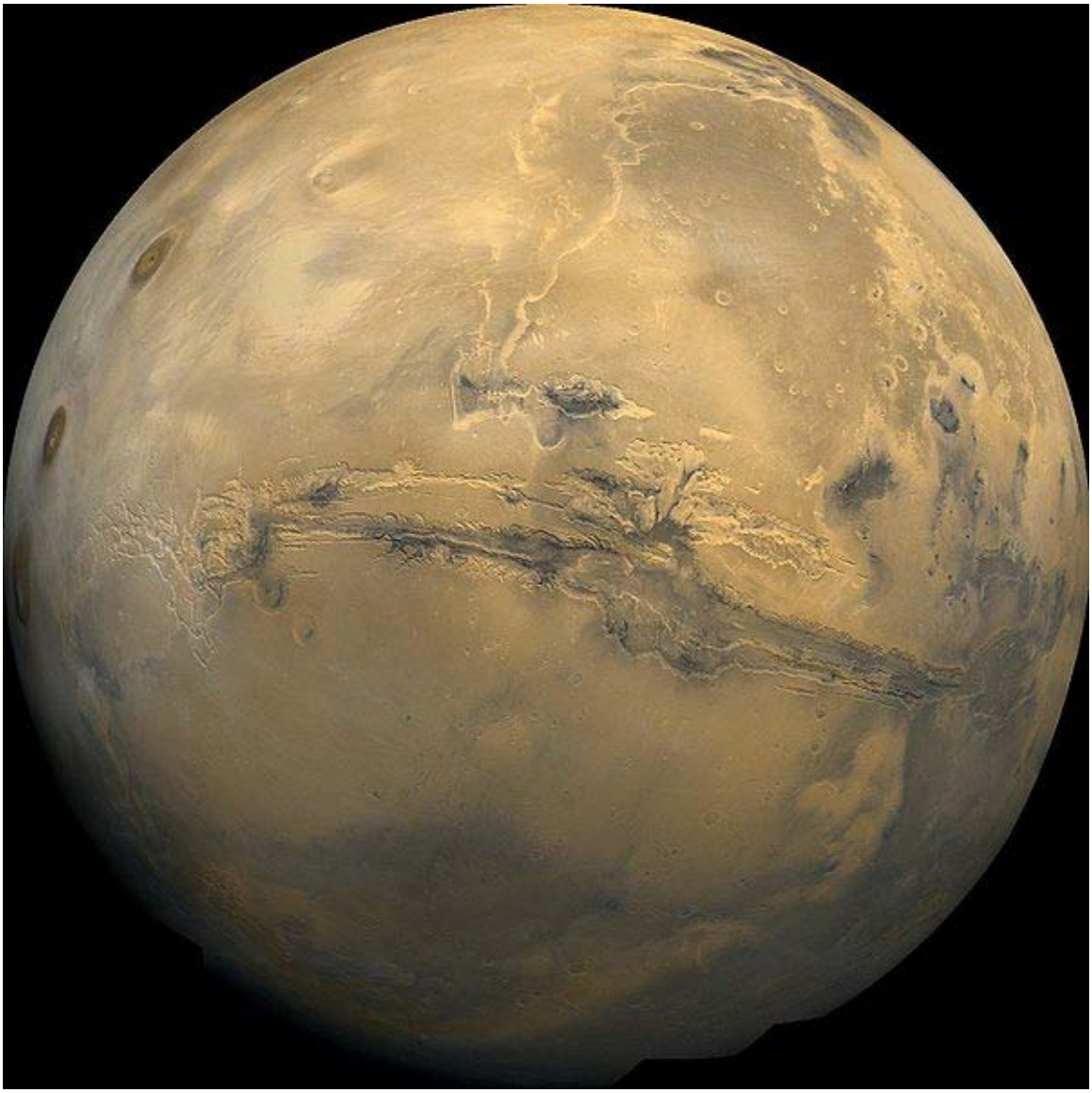
MARIE found that radiation levels in orbit above Mars are 2.5 times higher than at the International Space Station. Average doses were about 22 millirads per day (220 micrograys per day or 0.08 gray per year.) A three year exposure to such levels would be close to the safety limits currently adopted by NASA. Levels at the Martian surface would be somewhat lower and might vary significantly at different locations depending on altitude and local magnetic fields.

Occasional solar proton events (SPEs) produce much higher doses. Some SPEs were observed by MARIE that were not seen by sensors near Earth due to the fact that SPEs are directional, making it difficult to warn astronauts on Mars early enough.

Much remains to be learned about space radiation. In 2003, NASA's Lyndon B. Johnson Space Center opened a facility, the NASA Space Radiation Laboratory, at Brookhaven National Laboratory that employs particle accelerators to simulate space radiation. The facility will study its effects on living organisms along with shielding techniques. There is some evidence that this kind of low level, chronic radiation is not quite as dangerous as once thought; and that radiation hormesis occurs. The consensus among those that have studied the issues is that radiation levels, with the exception of the SPEs, that would be experienced on the surface of Mars, and while journeying there, are certainly a concern, but are not thought to prevent a trip from being made with current technology.

Transportation

Interplanetary spaceflight



Mars (Viking 1, 1980)

Mars requires less energy per unit mass (delta V) to reach from Earth than any planet except Venus. Using a Hohmann transfer orbit, a trip to Mars requires approximately nine months in space. Modified transfer trajectories that cut the travel time down to seven or six months in space are possible with incrementally higher amounts of energy and fuel compared to a Hohmann transfer orbit, and are in standard use for robotic Mars missions. Shortening the travel time below about six months requires higher delta-v and an exponentially increasing amount of fuel, and is not feasible with chemical rockets, but

would be perfectly feasible with advanced spacecraft propulsion technologies, some of which have already been tested, such as VASIMR, and nuclear rockets, in the formers case, a trip time of forty days could be attainable, and in the latter, a trip time down to about two weeks. Another possibility is constant-acceleration technologies such as space proven solar sails and ion drives which permits passage times at close approaches on the order of several weeks. Both of these propulsion systems have been deployed and could readily obtain a constant acceleration of 0.1g.

During the journey the astronauts are subject to radiation, which requires a means to protect them. Cosmic radiation and solar wind cause DNA damage, which increases the risk of cancer significantly. The effect of long term space travel in the interplanetary space is unknown, but scientists estimate up to 19% probability for male persons to die of cancer because of the radiation during the journey to Mars and back to Earth. Together with the base probability of 20% for a male person on Earth to die from cancer this gives a probability of 39%. For women the probability is even higher due to their larger glandular tissues.

Landing on Mars

Mars has a gravity 0.38 times that of the Earth and the density of its atmosphere is 1% of that on Earth. The relatively strong gravity and the presence of aerodynamic effects makes it difficult to land heavy, crewed spacecraft with thrusters only as was done with the Apollo moon landings, yet the atmosphere is too thin for aerodynamic effects to be of much help in braking and landing a large vehicle. Landing piloted missions on Mars will require braking and landing systems different from anything used to land crewed spacecraft on the Moon or robotic missions on Mars.

If one assumes carbon nanotube construction material will be available with a strength of 130 GPa then a space elevator could be built to land men and material on Mars. A space elevator on Phobos has also been proposed.

Communication

Communications with Earth are relatively straightforward during the half-sol when the Earth is above the Martian horizon. NASA and ESA included communications relay equipment in several of the Mars orbiters, so Mars already has communications satellites. While these will eventually wear out, additional orbiters with communication relay capability are likely to be launched before any colonization expeditions are mounted.

The one-way communication delay due to the speed of light ranges from about 3 minutes at closest approach (approximated by perihelion of Mars minus aphelion of Earth) to 22 minutes at the largest possible superior conjunction (approximated by aphelion of Mars plus aphelion of Earth). Telephone conversations or Internet Relay Chat between Earth and Mars would be highly impractical due to the long time lags involved. NASA has found that direct communication can be blocked for about two weeks every synodic period, around the time of superior conjunction when the Sun is directly between Mars

and Earth, although the actual duration of the communications blackout varies from mission to mission depending on various factors - such as the amount of link margin designed into the communications system, and the minimum data rate that is acceptable from a mission standpoint. In reality most missions at Mars have had communications blackout periods of the order of a month.

A satellite at either of the Earth-Sun L_4/L_5 Lagrange points could serve as a relay during this period to solve the problem; even a constellation of communications satellites would be a minor expense in the context of a full colonization program. However the size and power of the equipment needed for these distances make the L4 and L5 locations unrealistic for relay stations, and the inherent stability of these regions, while beneficial in terms of station-keeping, also attracts asteroids, which could pose a severe risk to any satellite.

Recent work by the University of Strathclyde's Advanced Space Concepts Laboratory, in collaboration with the European Space Agency, has suggested an alternative relay architecture based on highly non-Keplerian orbits. These are a special kind of orbit produced when continuous low-thrust propulsion, such as that produced from an ion engine or solar sail, modifies the natural trajectory of a spacecraft. Such an orbit would enable continuous communications during solar conjunction by allowing a relay spacecraft to "hover" above Mars, out of the orbital plane of the two planets. Such a relay avoids the problems of satellites stationed at either L4 or L5 by being significantly closer to the surface of Mars while still maintaining continuous communication between the two planets.

Robotic precursors

The path to a human colony could be prepared by robotic systems such as the Mars Exploration Rovers *Spirit* and *Opportunity*. These systems could help locate resources, such as ground water or ice, that would help a colony grow and thrive. The lifetimes of these systems would be measured in years and even decades, and as recent developments in commercial spaceflight have shown, it may be that these systems will involve private as well as government ownership. These robotic systems also have a reduced cost compared with early crewed operations, and have less political risk.

Wired systems might lay the groundwork for early crewed landings and bases, by producing various consumables including fuel, oxidizers, water, and construction materials. Establishing power, communications, shelter, heating, and manufacturing basics can begin with robotic systems, if only as a prelude to crewed operations.

Early human missions

Early human missions to Mars, such as those being tentatively planned by NASA, FKA and ESA would not be direct precursors to colonization. They are intended solely as

exploration missions, as the *Apollo* missions to the Moon were not planned to be sites of a permanent base.

Colonization requires the establishment of permanent bases that have potential for self-expansion. A famous proposal for building such bases is the Mars Direct plan, advocated by Robert Zubrin. The Mars Society has established the Mars Analogue Research Station Programme at sites Devon Island in Canada and in Utah, United States, to experiment with different plans for human operations on Mars, based on Mars Direct. Modern Martian architecture concepts often include facilities to produce oxygen and propellant on the surface of the planet.

Economics

As with early colonies in the New World, economics would be a crucial aspect to a colony's success. The reduced gravity well of Mars and its position in the solar system may facilitate Mars-Earth trade and provide the rationalization for continued settlement of the planet.

Mars' reduced gravity together with its rotation rate makes it possible for the construction of a space elevator with today's materials, although the low orbit of Phobos could present engineering challenges. If constructed, the elevator could transport minerals and other natural resources extracted from the planet.

A major economic problem is the enormous up-front investment required to establish the colony and perhaps also terraform the planet.

Some early Mars colonies might specialize in developing local resources for Martian consumption, such as water and/or ice.

Another main inter-Martian trade good during early colonization could be manure. Assuming that life doesn't exist on Mars, the soil is going to be very poor for growing plants, so manure and other fertilizers will be valued highly in any Martian civilization until the planet changes enough chemically to support growing vegetation on its own.

Solar power is a candidate for power for a Martian colony. Solar insolation (the amount of solar radiation that reaches Mars) is about 42% of that on Earth, since Mars is about 52% farther from the Sun and insolation falls off as the square of distance. But the thin atmosphere would allow almost all of that energy to reach the surface as compared to Earth, where the atmosphere absorbs roughly a quarter of the solar radiation.

Nuclear power is also a good candidate, since the fuel is very dense for cheap transportation from Earth. Nuclear power also produces heat, which would be extremely valuable to a Mars colony.

Heating requirements could be lowered if the colonists use domes to trap solar heat, especially for greenhouses.

Possible locations for colonies

Mars can be considered in broad regions for discussion of possible colony sites.

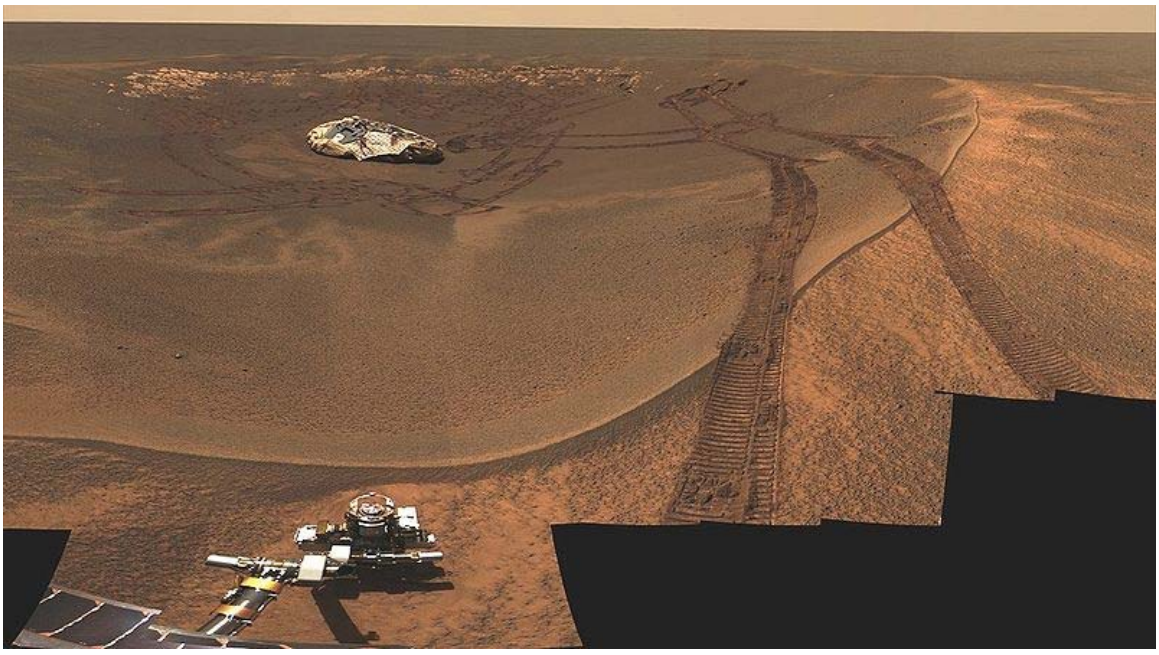
Polar regions

Mars' north and south poles once attracted great interest as colony sites because seasonally-varying polar ice caps have long been observed by telescope from Earth. Mars Odyssey found the largest concentration of water near the north pole, but also showed that water likely exists in lower latitudes as well, making the poles less compelling as a colony locale. Like Earth, Mars sees a midnight sun at the poles during local summer and polar night during local winter.

Equatorial regions

Mars Odyssey found what appear to be natural caves near the volcano Arsia Mons. It has been speculated that colonists could benefit from the shelter that these or similar structures could provide from radiation and micrometeroids. Geothermal energy is also suspected in the equatorial regions.

Midlands



Eagle Crater, as seen from *Opportunity* (2004)

The exploration of Mars' surface is still underway. The two Mars Exploration Rovers, *Spirit* and *Opportunity*, have encountered very different soil and rock characteristics. This suggests that the Martian landscape is quite varied and the ideal location for a colony

would be better determined when more data becomes available. As on Earth, seasonal variations in climate become greater with distance from the equator.

Valles Marineris

Valles Marineris, the "Grand Canyon" of Mars, is over 3,000 km long and averages 8 km deep. Atmospheric pressure at the bottom would be some 25% higher than the surface average, 0.9 kPa vs 0.7 kPa. The canyon runs roughly east-west, so shadows from its walls should not interfere too badly with solar power collection. River channels lead to the canyon, indicating it was once flooded.

Lava Tubes

Several lava tube skylights on Mars have been located. Earth based examples indicate that some should have lengthy passages offering complete protection from radiation and be relatively easy to seal using on site materials, especially in small subsections.

Advocacy

Making Mars colonization a reality is advocated by several groups with different reasons and proposals. One of the oldest is the Mars Society. They promote a NASA program to accomplish human exploration of Mars and have set up Mars analog research stations in Canada and the United States. Another group is Marsdrive, which is dedicated to private initiatives for the exploration and settlement of Mars.

Concerns

Besides the general criticism of human colonization of space, there are specific concerns about a colony on Mars:

- Mars has a gravity 0.38 times that of the Earth and a density of the atmosphere of 1% that on Earth. The stronger gravity than the Moon and the presence of aerodynamic effects makes it more difficult to land heavy, crewed spacecraft with thrusters only, yet the atmosphere is also too thin to get very much use out of aerodynamic effects for braking and landing. Landing piloted missions on Mars will require a braking and landing system different from anything used to land crewed spacecraft on the Moon or robotic missions on Mars.

- The question of whether life once existed or exists now on Mars has not been settled, raising concerns about possible contamination of the planet with Earth life.

- Advocates of a return to the Moon say the Moon is a more logical first location for a first planetary colony, perhaps using it as practice for future manned missions to Mars. However, in several ways experience gained on the moon

would not be applicable to the task of colonizing Mars. The moon has no atmosphere, no analogous geology and a much greater temperature range and rotational period. These differences make Mars more in common with Earth than the Moon. Antarctica or desert areas of Earth provide much better training grounds at vastly lesser cost. Also, the Moon is extremely poor in several of the key elements required for life, most notably hydrogen, nitrogen and carbon (50 – 100 ppm), and has only 47.2% of the delta-v requirement for launching to orbit that Mars has.

- It is unknown whether Martian gravity can support human life in the long term (all experience is at either ~1g or zero gravity). Space medicine researchers have theorized on whether the health benefits of gravity rise slowly or quickly between weightlessness and full Earth gravity. One theory is that sleeping chambers built inside centrifuges would minimize the health problems. The Mars Gravity Biosatellite experiment was due to become the first experiment testing the effects of partial gravity, artificially generated at 0.38 *g* to match Mars gravity, on mammal life, specifically on mice, throughout the life cycle from conception to death. However, in 2009 the Biosatellite project was cancelled due to lack of funds.

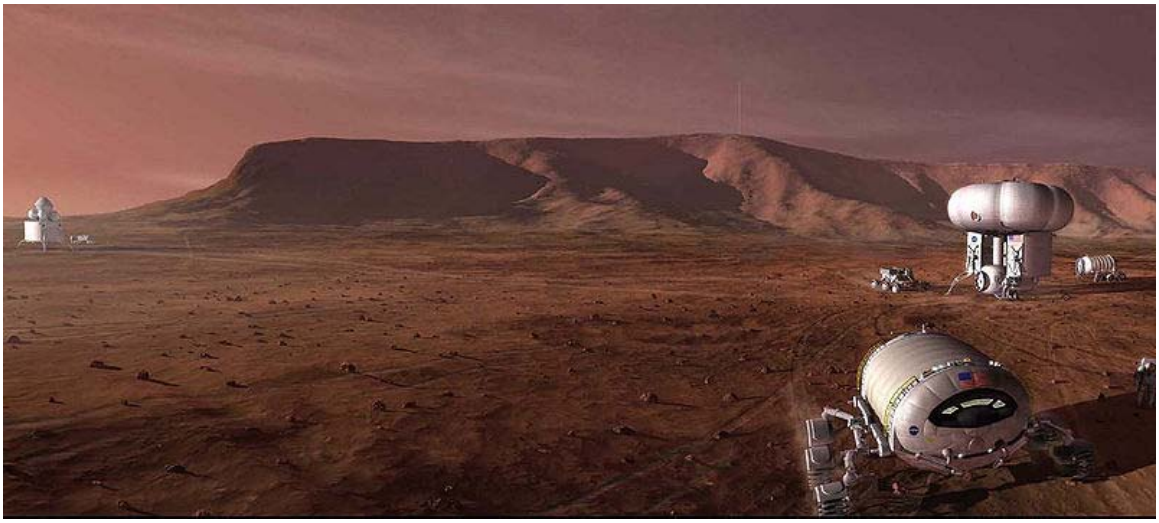
- Mars' escape velocity is 5 km/s, which, though less than half that for Earth, is reasonably high compared to the Moon's 2.38 km/s or the negligible escape velocity of most asteroids. This could make physical export trade from Mars to other planets and habitats less viable economically.

- There is likely to be little economic return from the colonization of Mars while Lunar and Near Earth Asteroid industry is likely to be exporting to Earth.

- Mars has dust storms which can reduce solar power. The largest of these storms can cover much of the planet.

Chapter- 6

Manned Mission to Mars



Concept for NASA Design Reference Mission Architecture 5.0 (2009)

A **manned mission to Mars** has been the subject of science fiction, engineering, and scientific proposals throughout the 20th century and into the 21st century. The plans comprise proposals not only to land on, but eventually also settle the planet Mars, its moons, Phobos & Deimos and terraform the planet.

Preliminary work for missions has been undertaken since the 1950s, with planned missions typically taking place 10 to 30 years in the future. The list of manned Mars mission plans in the 20th century shows the various mission proposals that have been put forth by multiple organizations and space agencies in this field of space exploration.

In 2004 the U.S. administration announced a new Vision for Space Exploration naming a manned Mars mission as one of its milestones. No concrete plan has been decided upon, and the proposal is currently being discussed between politicians, scientists, space advocates and in the public. In 2010, a new bill was signed allowing for a manned Mars mission by the 2030s.

Challenges

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

There are several key challenges that a human mission to Mars must overcome:

1. physical effects of exposure to high-energy cosmic rays and other ionizing radiation
2. physical effects of a prolonged low-gravity environment
3. physical effects of a prolonged low-light environment
4. psychological effects of isolation from Earth
5. psychological effects of lack of community due to lack of real-time connections with Earth
6. social effects of several humans living under crowded conditions for over one Earth year
7. inaccessibility of terrestrial medical facilities

Some of these issues were estimated statistically in the HUMEX study. Ehlmann and others have reviewed political and economic concerns, as well as technological and biological feasibility aspects.

While fuel for roundtrip travel could be a challenge, methane and oxygen can be produced utilizing Martian H_2O (preferably as water ice instead of chemically bound water) and atmospheric CO_2 with mature technology.

One of the main considerations for traveling to Mars from Earth or vice versa is the energy needed to transfer between their orbits. Every 26 Earth months a lower energy transfer from Earth to Mars opens, so missions are typically planned to coincide with one of these windows. In addition, the low-energy windows varies higher or lower on roughly a 15 year cycle. For example, there was a minimum in the 1969 and 1971 launch windows, rising to a peak in the late 70s, and hitting another low in 1986 and 1988, and then repeating on the same interval.

20th century proposals

Over the last century, a number of mission concepts for such an expedition have been proposed. David Portree's history volume *Humans to Mars: Fifty Years of Mission Planning, 1950 - 2000* discusses many of these.

Wernher von Braun proposal (1947 through 1950s)

Wernher von Braun was the first person to make a detailed technical study of a Mars mission. Details were published in his book *Das Marsprojekt* (1952); published in English as *The Mars Project* (1962) and several subsequent works, and featured in *Collier's magazine* in a series of articles beginning March 1952. A variant of the Von Braun mission concept was popularized in English by Willy Ley in the book *The Conquest of Space* (1949), featuring illustrations by Chesley Bonestell. Von Braun's Mars project envisioned nearly a thousand three-stage vehicles launching from Earth to ferry parts for the Mars mission to be constructed at a space station in Earth orbit. The mission itself featured a fleet of ten spacecraft heading to Mars, each one carrying 70 people, bringing three winged surface excursion ships that would land horizontally on the surface of Mars. (Winged landing was considered possible because at the time of his proposal, the Martian atmosphere was believed to be much denser than was later found to be the case.)

In the 1956 revised vision of the Mars Project plan, published in the book *The Exploration of Mars* by Wernher Von Braun and Willy Ley, the size of the mission was trimmed, requiring only 400 launches to put together two ships, still carrying a winged landing vehicle. Later versions of the mission proposal, featured in the Disney "Man In Space" film series, showed nuclear powered ion propulsion vehicles for the interplanetary cruise.

U.S. proposals (1950s and 1960s)

Artist's depiction of Mars Excursion Module landed on Mars, from a 1963 NASA study

In 1962, Aeronutronic Ford, General Dynamics and the Lockheed Missiles and Space Company made studies of Mars mission designs as part of NASA Marshall Spaceflight Center "Project EMPIRE". These studies indicated that a Mars mission (possibly including a Venus fly-by) could be done with a launch of eight Saturn V boosters and assembly in low Earth orbit, or possibly with a single launch of a hypothetical "post Saturn" heavy-lift vehicle. Although the EMPIRE missions were only studies, and never proposed as funded projects, these were the first detailed analyses of what it would take to accomplish a human voyage to Mars using data from the actual NASA spaceflight, and laid much of the basis for future studies, including significant mission studies by TRW, North American, Philco, Lockheed, Douglas, and General Dynamics, along with several in-house NASA studies.

Following the success of the Apollo Program, von Braun advocated a manned mission to Mars as a focus for NASAs manned space program. Von Braun's proposal used Saturn V boosters to launch nuclear-powered (NERVA) upper stages that would power two six-crew spacecraft on a dual mission in the early 1980s. The proposal was considered by (then president) Richard Nixon but passed over in favor of the Space Shuttle.

Soviet mission proposals (1956 through 1970)

The Martian Piloted Complex or "'MPK'" was a proposal by Mikhail Tikhonravov of the Soviet Union for a manned Mars expedition, using the (then proposed) N-1 rocket, in studies from 1956 to 1962.

Artist's depiction of TMK-MAVR

Heavy Piloted Interplanetary Spacecraft (known by the Russian acronym **TMK**) was the designation of a Soviet Union space exploration proposal in the 1960s to send a manned flight to Mars and Venus (TMK-MAVR design) without landing. The TMK spacecraft was due to launch in 1971 and make a three-year long flight including a Mars fly-by at which time probes would have been dropped. The TMK project was planned as an answer from the Soviet Union to the United States manned moon landings. The project was never completed because the required N1 rocket never flew successfully.

The *Mars Expeditionary Complex*, or "'MEK'" (1969) was another Soviet proposal for a Mars expedition that would take a crew from three to six to Mars and back with a total mission duration of 630 days.

Case for Mars (1981–1996)

Following the Viking missions to Mars, between 1981 and 1996 a series of conferences named The Case for Mars were held at the University of Colorado at Boulder. These conferences advocated human exploration of Mars, presented concepts and technologies, and held a series of workshops to develop a baseline concept for the mission. The baseline concept was notable in that it proposed use of In Situ Resource Utilization to manufacture rocket propellant for the return trip using the resources of Mars. The mission study was published in a series of proceedings volumes published by the American Astronautical Society. Later conferences in the series presented a number of alternative concepts, including the "Mars Direct" concept of Robert Zubrin and David Baker; the "Footsteps to Mars" proposal of Geoffrey A. Landis, which proposed intermediate steps before the landing on Mars, including human missions to Phobos; and the "Great Exploration" proposal from Lawrence Livermore National Laboratory, among others.

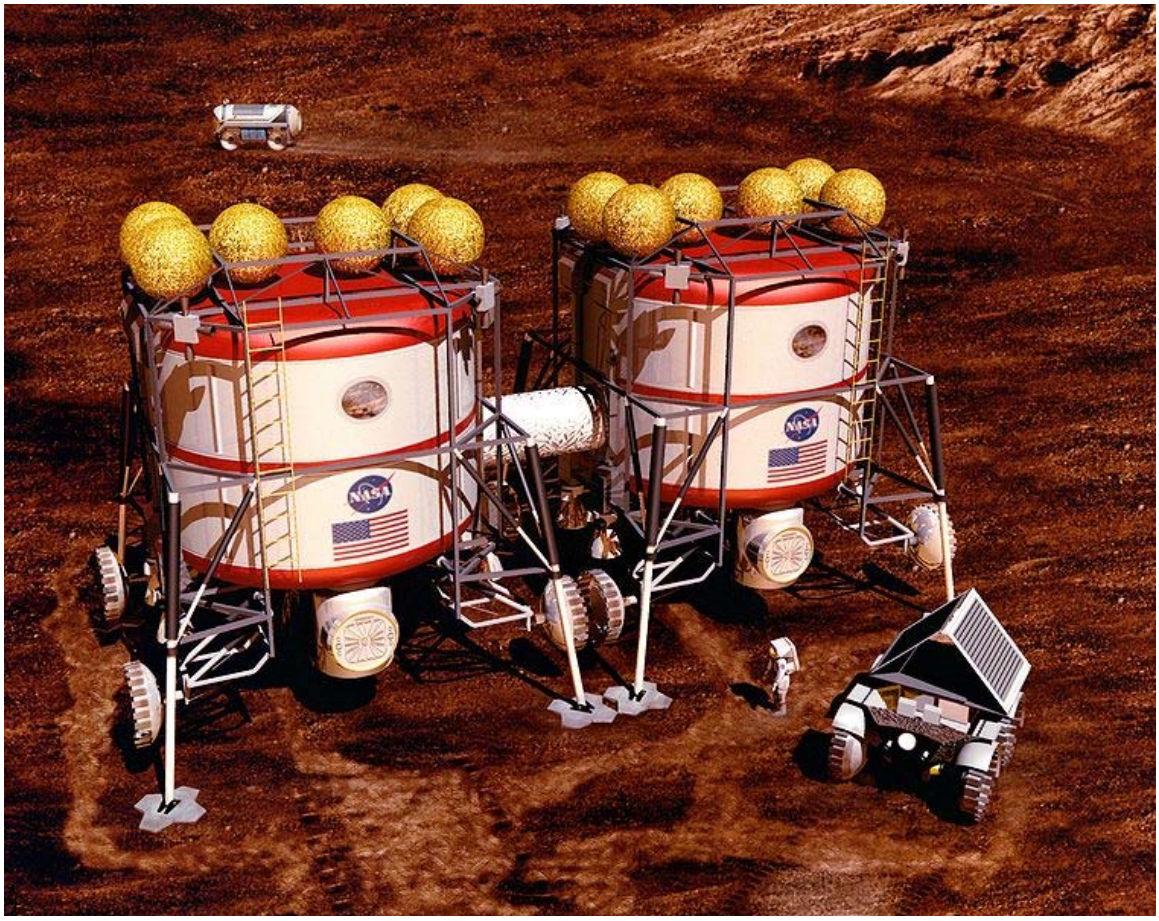
NASA Space Exploration Initiative (1989)

In response to a presidential initiative, NASA made a study of a project for human lunar- and Mars exploration as a proposed follow-on to the International Space Station project. This resulted in a report, called the *90-day study*, in which the agency proposed a long-term plan consisting of completing the Space Station as "a critical next step in all our space endeavors," returning to the moon and establishing a permanent base, and then sending astronauts to Mars. This report was widely criticized as too elaborate and expensive, and all funding for human exploration beyond Earth orbit was canceled by Congress.

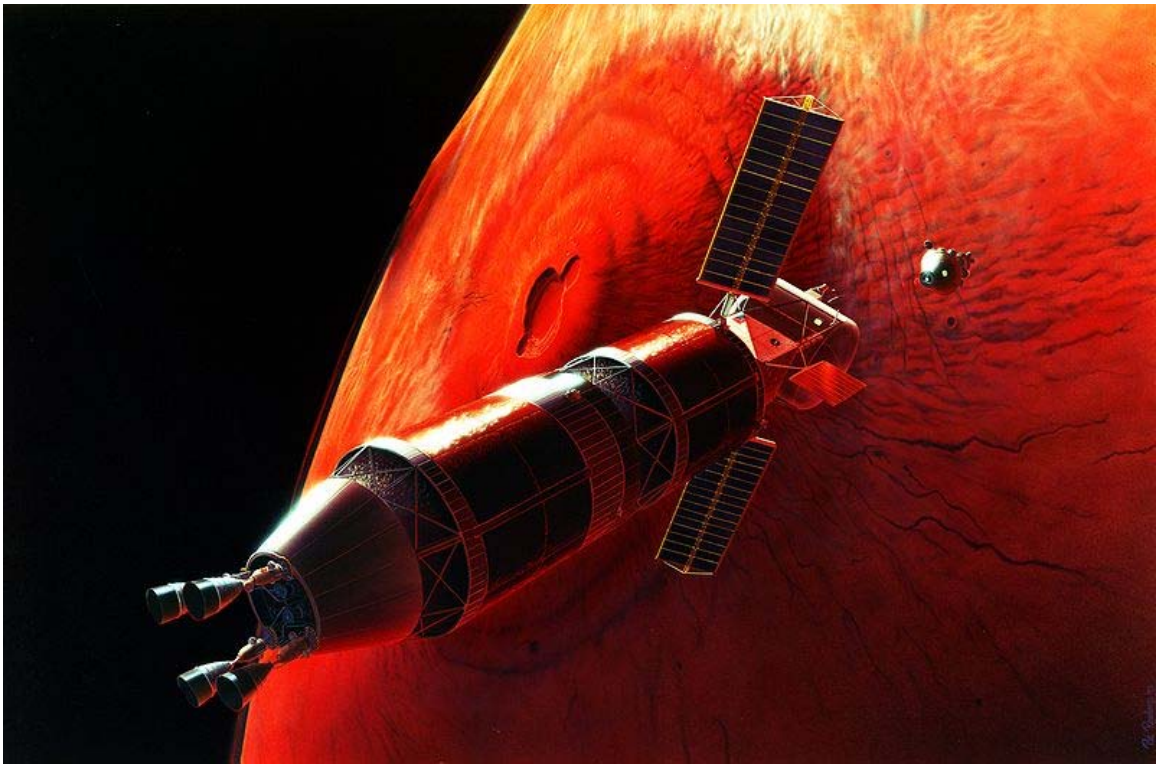
Mars Direct (early 1990s)

Because of the distance between Mars and Earth, the Mars mission would be much more risky and more expensive than past manned flights to the Moon. Supplies and fuel would have to be prepared for a 2-3 year round trip and the spacecraft would have to be designed with at least partial shielding from intense solar radiation. A 1990 paper by Robert Zubrin and David A. Baker, then of Martin Marietta, proposed reducing the mission mass (and hence the cost) with a mission design using In Situ Resource Utilization to manufacture propellant from the Martian Atmosphere. This proposal drew on a number of concepts developed by the former "Case for Mars" conference series. Over the next decade, this proposal was developed by Zubrin into a mission concept, Mars Direct, which he developed in a book, *The Case for Mars* (1996). The mission is advocated by the Mars Society as a practical and affordable plan for a manned Mars mission.

NASA Design reference mission (late 1990s)



Mars design reference mission 3.0



Artist's concept of Mars Orbit Rendezvous between spaceship and Martian ascent stage. Painting by Pat Rawlings (SAIC) for NASA.

In the mid to late 1990s NASA developed several conceptual level human Mars exploration architectures. One of the most notable and often quoted was the NASA Design reference mission 3.0 (DRM 3.0). The study was performed by the NASA Mars Exploration Team at the NASA's Johnson Space Center (JSC) in the 1990s. Personnel representing several NASA field centers formulated a "Reference Mission" addressing human exploration of Mars. The plan describes the first human missions to Mars with concept of operations and technologies to be used as a first cut at an architecture. The architecture for the Mars Reference Mission builds on previous work, principally on the work of the Synthesis Group (1991) and Zubrin's (1991) concepts for the use of propellants derived from the Martian atmosphere. The primary purpose of the Reference Mission was to stimulate further thought and development of alternative approaches, which can improve effectiveness, reduce risks, and reduce cost. Improvements can be made at several levels; for example, in the architectural, mission, and system levels.

21st century proposals

Vision for Space Exploration (2004)

United States President George W. Bush announced an initiative of manned space exploration on January 14, 2004, known as the Vision for Space Exploration. It included developing preliminary plans for a lunar outpost by 2012 and establishing an outpost by

2020. Precursor missions that would help develop the needed technology during the 2010-2020 decade were tentatively outlined by Adringa and others. On September 24, 2007, Michael Griffin, then NASA Administrator, hinted that NASA may be able to launch a human mission to Mars by 2037. The needed funds are to be generated by diverting $11 billion from space science missions to the vision for human exploration.

NASA has also discussed plans to launch Mars missions from the Moon to reduce traveling costs.

Aurora programme (early 2000s)

The European Space Agency has the long-term vision of sending a human mission to Mars by 2030. Laid out in 2001, the project's proposed timeline would begin with robotic exploration, a proof of concept simulation of sustaining humans on Mars, and eventually a manned mission; however, objections from the participating nations of ESA and other delays have put the timeline into question.

Russian mission proposals (current)

A number of Mars mission concepts and proposals have been put forth by Russian scientists. Stated dates were for a launch sometime between 2016 and 2020. The Mars probe would carry a crew of four to five cosmonauts, who would spend close to two years in space.

In 2011, Russian and European space agencies will have successfully completed the ground-based MARS-500. The biomedical experiment simulating manned flight to Mars was completed in Russia in July 2009.

Mars Society Germany - European Mars Mission (EMM) (2005)

The Mars Society Germany proposed a manned mars mission using several launches of an improved heavy-lift version of the Ariane 5. Roughly 5 launches would be required to send a crew of 5 on a 1200 days mission, with a payload of 120,000 kg (260,000 lb)

The one-person, one-way option (2006)

In 2006, former NASA engineer James C. McLane III proposed a scheme to initially colonize Mars via a one way trip by only one human. Papers discussing this concept appeared in The Space Review, Harper’s and SEARCH magazine.

NASA Design Reference Mission 5.0 (2007)

NASA released initial details of the latest version conceptual level human Mars exploration architecture in this presentation. The study further developed concepts developed in previous NASA DRM and updated it to more current launchers and technology.

MarsDrive mission design (2008)

The MarsDrive Organization has been working at a series of new human mission designs starting with Mars for Less. Their current design program under Director of Engineering Ron Cordes has discarded many of the Mars for Less elements and is a work in progress as of June 2008. Some of their design philosophy is focused on using current or near term existing launch vehicle systems, permanent human settlement, conceptual EDL systems and enhanced surface ISRU. Their proposed methods of funding the mission are also an alternative to the current plans with a private consortium approach being investigated.

ESA plans

Another proposal for a joint ESA mission with Russia is based on two spacecraft being sent to Mars, one carrying a six-person crew and the other the expedition's supplies. The mission would take about 440 days to complete with three astronauts visiting the surface of the planet for a period of two months. The entire project would cost $20 billion and Russia would contribute 30% of these funds.

Chinese Mars exploration program

Little is known of the **Chinese Mars exploration program**. While the Moon is the first priority, there are plans for Martian exploration that follow upon the work done in the Chinese Lunar Exploration Program. China has been studying the necessity and feasibility of Mars exploration since early 1990s as part of the national "863 Planetary Exploration" project, according to Liu Zhenxing, a researcher from the CAS Center for Space Science and Applied Research (CSSAR).

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 notable Mars to Stay advocates, former Apollo astronaut Buzz Aldrin has been a particularly outspoken promoter, suggesting in numerous forums "Forget the Moon, Let’s Head to Mars!" . 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.

NASA Design Reference Mission Architecture 5.0 (2009)

DRMA 5.0 Mars ascent stage (2009)

NASA released an updated version of NASA DRM 5.0 in early 2009, featuring use of the Ares V launcher, Orion CEV, and updated mission planning. In this document.

Mars by the mid-2030s

In a major space policy speech at Kennedy Space Center on April 15, 2010, U.S. President Barack Obama predicted a manned Mars mission to orbit the planet by the mid-2030s, followed by a landing:

> “By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it.”

The United States Congress has approved manned missions to the Moon, followed by Asteroid exploration in 2025 and Mars in the 2030s.

Preparedness

A number of nations and organizations have long-term intentions to send humans to Mars. The state of their readiness is summarized below.

- The United States has a number of missions currently exploring Mars, with a sample-return planned in the near future. The US does not have a launcher capable of sending humans to Mars, although the Orion spacecraft, currently under development by NASA, could ferry astronauts from the surface of Earth to join a Mars-bound expedition in Earth orbit and then back to Earth's surface once the expedition has returned from Mars. NASA has used the Haughton impact crater on Devon Island as a proving ground due to the crater's similarity with Martian geology. According to *New Scientist*, an argon plasma-based VASIMR rocket could reduce the transit time to less than 40 days.
- The European Space Agency has sent robotic probes, and has long-term plans to send humans but has not yet built a human-capable launcher. There is a proposal to convert ESA's existing Automated Transfer Vehicle (ATV) for crewed launches.
- Russia (and previously the Soviet Union) has sent a large number of probes. It can send humans into Earth-Orbit and has extensive experience with long-term manned orbital space flight due to its space station programs. Russia does not have a launcher capable of sending humans to Mars, although the Kliper program was proposed as the Russian-European counterpart to the United States' Orion Spacecraft. A simulation of a manned Mars mission, called Mars-500, was completed in Russia in July 2009.
- Japan's robotic missions to Mars have so far failed.
- China plans to cooperate with Russia in sending robotic sample return mission to Phobos. China was the third country after Russia and the USA to launch humans into Earth orbit.

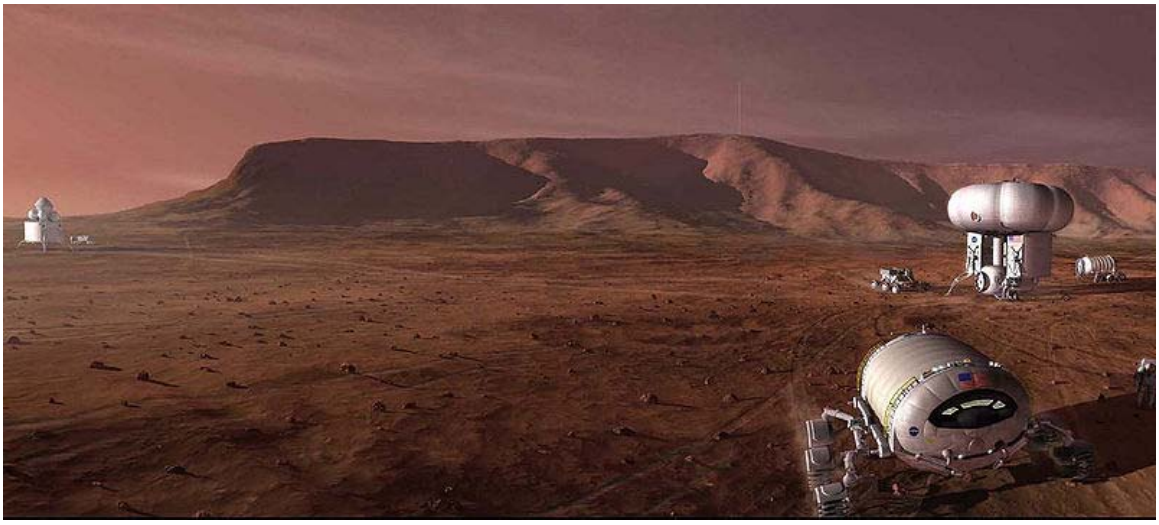
Criticism

Some scientists have argued that attempting manned flight to Mars would actually be counterproductive for science. In 2004, the Special committee on the funding of Astrophysics, a committee of the American Physical Society, stated that "shifting NASA priorities toward risky, expensive missions to the Moon and Mars will mean neglecting the most promising space science efforts".

Chapter- 7

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

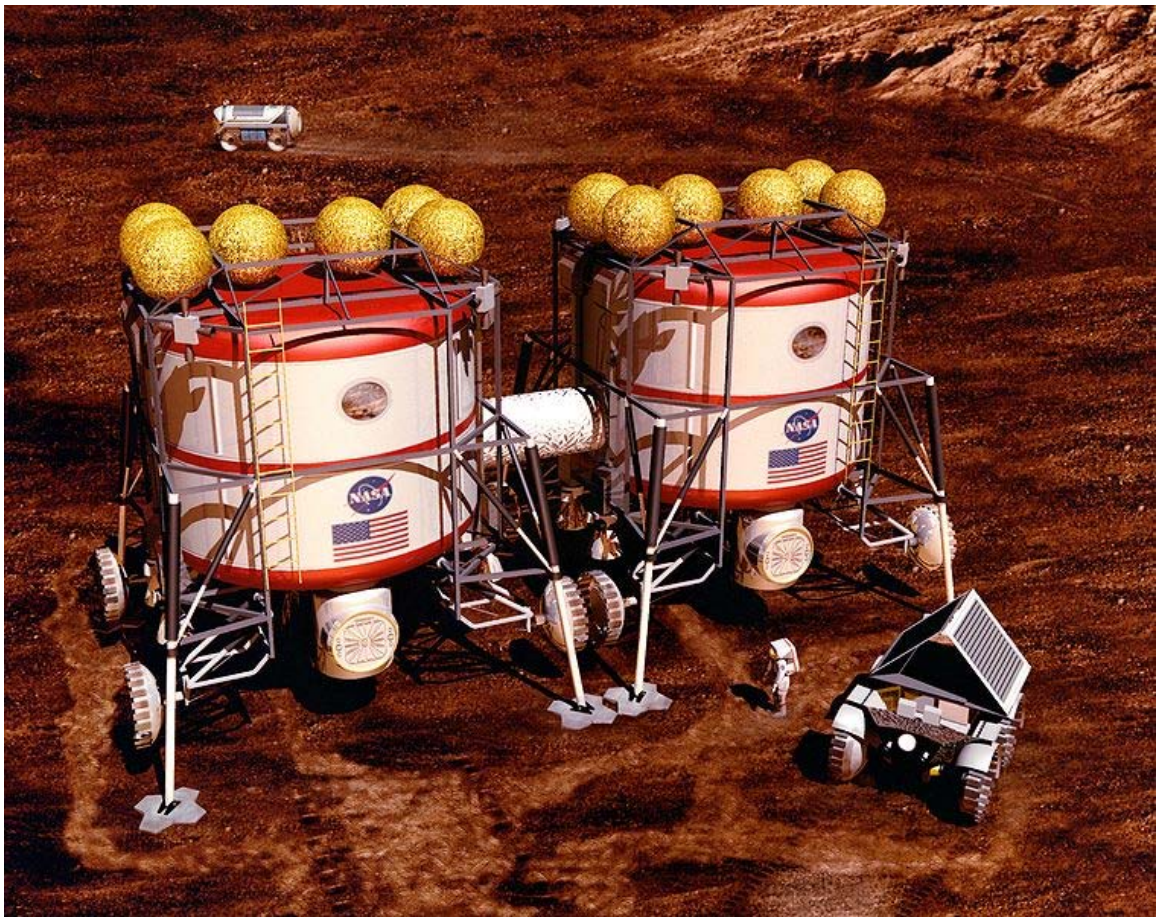
Artist's conception of a human mission on Mars
1989 painting by Les Bossinas of Lewis Research Center for NASA

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?"

In October 2009, Eric Berger of the Houston Chronicle wrote of 'Mars to Stay' as perhaps the only program which can revitalize America's space program:

"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- 8

Colonization of the Outer Solar System

Some of the moons of the outer planets of the solar system are large enough to be suitable places for colonization. Many of the larger moons contain water ice, liquid water, and organic compounds that might be useful for sustaining human life . Colonies in the outer solar system could also serve as centers for long term investigation of the planet and the other moons. In particular, robotic devices could be controlled by humans without the very long time delays needed to communicate with Earth. There have also been proposals to place robotic aerostats in the upper atmospheres of the gas giant planets for exploration and possibly mining of helium-3, which could have a very high value per unit mass as a thermonuclear fuel.

The Jovian system

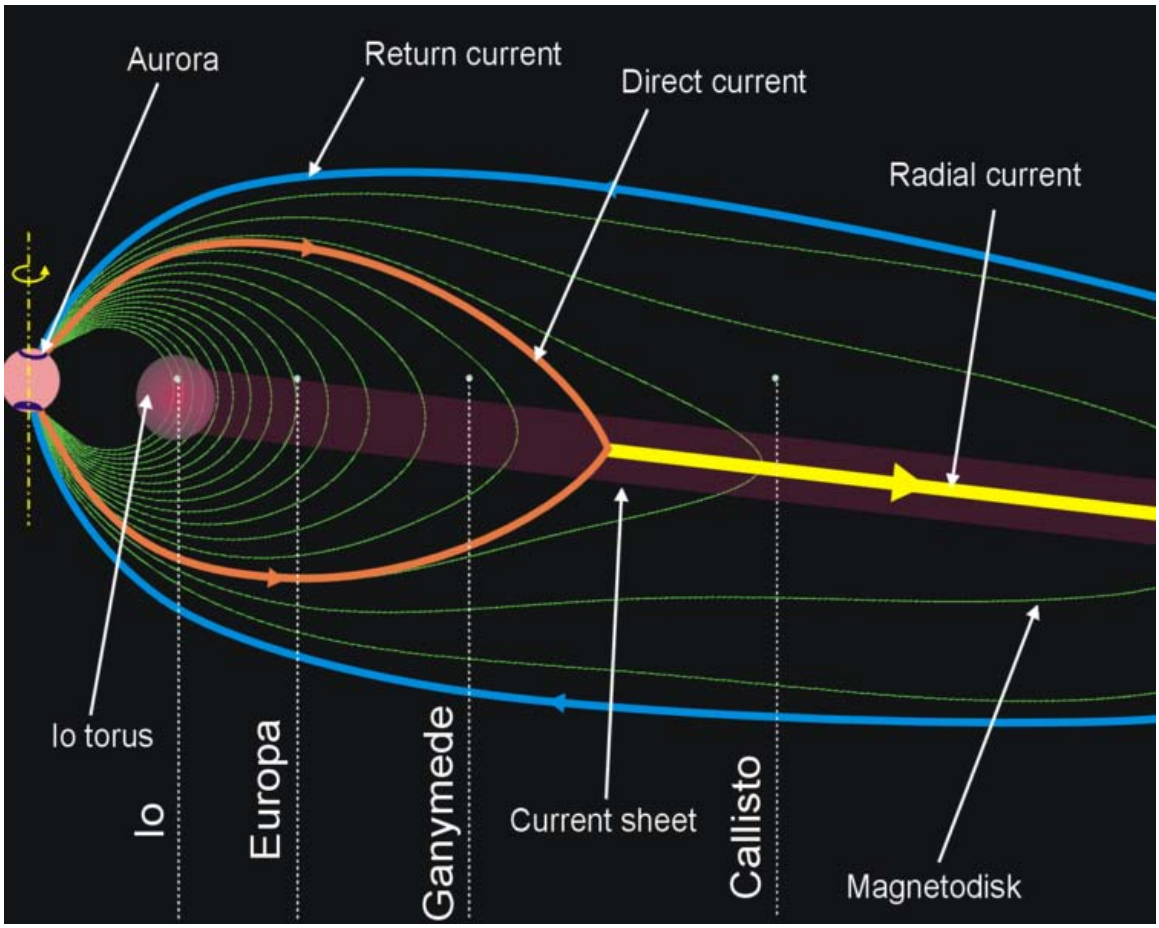
The Jovian system in general poses particular disadvantages for colonizing because of its severe radiation environment and its particularly deep gravity well. Its radiation would deliver about 3,600 rems per day to unshielded colonists at Io and about 540 rems per day to unshielded colonists at Europa. Exposure of approximately 75 rems over a period of a few days is enough to cause radiation poisoning, and about 500 rems over a few days is fatal.

Jupiter

Orbiting colonies could exist around Jupiter, as around any body in the solar system, but artificial gravity (such as through rotation of the structure) would need to be employed. These bases would also need to withstand radiation from all angles. This type of structure could also serve as a dock for ships visiting other parts of the Jovian system. Additionally, science fiction writers have sometimes proposed that Jupiter could be the site of airborne colonies such as floating cities, assuming the radiation and gravity issues in traveling to and from the atmosphere are properly addressed. So far no serious proposals or studies have been made of such a colony within Jupiter's atmosphere. However, there does exist a depth within Jupiter's atmosphere at which the pressure is the same as Earth's at sea level, and where there is a blue sky, although it is colder than on Earth; further down, there is a location that has the same average temperature as the surface of the Earth, although the pressure is about five bars.

One significant challenge to overcome in colonizing Jupiter would be the intense radiation in the planet's magnetosphere.

Europa



The magnetic field of Jupiter and co–rotation enforcing currents

The Artemis Project designed a plan to colonize Europa. Scientists are to inhabit igloos and drill down into the Europan ice crust, exploring any sub-surface ocean. It also discusses use of air pockets for human inhabitation.

Europa, the fourth-largest moon of Jupiter, is a subject in both science fiction and scientific speculation for future human colonization. Europa's geophysical features, including a possible subglacial water ocean, make it a strong possibility that human life could be sustained on or beneath the surface.

Feasibility

Europa as a target for human colonization has several benefits compared to other bodies in the outer solar system, but is not without challenges.

Possible advantages

Europa is thought to have a liquid water ocean underneath its icy exterior. The access to this liquid water ocean is a major difficulty. But the abundance of water on Europa is a benefit to any considerations for colonization. Not only can water provide for colonists' drinking needs, it also can be broken down to provide breathable oxygen. Oxygen is also believed to have accumulated from the radiolysis of the ice on the surface that has been convected into the subsurface ocean and may prove sufficient for oxygen-using marine life.

Possible problems

The colonization of Europa presents numerous difficulties. One is the high level of radiation from Jupiter's radiation belt, which is about 10 times as strong as Earth's Van Allen radiation belts. As Europa receives 540 rem of radiation per day (500 rem is a fatal dose), a human would not survive at or near the surface of Europa for long without significant radiation shielding. Colonists on Europa would have to descend beneath the surface when Europa is not protected by Jupiter's magnetotail, and stay in subsurface habitats. This would allow colonists to use Europa's ice sheet to shield themselves from radiation.

Another problem is that the surface temperature of Europa normally rests at −170 °C (103 K) (-275°F). However, the fact that liquid water is believed to exist below Europa's icy surface, along with the fact that colonists would spend much of their time under the ice sheet in order to shield themselves from radiation, may somewhat mitigate the problems associated with low surface temperatures.

The low gravity of Europa may also present challenges to colonization efforts. The effects of low gravity on human health are still an active field of study, but can include symptoms such as loss of bone density, loss of muscle density, and a weakened immune system. Astronauts in Earth orbit have remained in microgravity for up to a year and more at a time. Effective countermeasures for the negative effects of low gravity are well-established, particularly an aggressive regimen of daily physical exercise. The variation in the negative effects of low gravity as a function of different levels of low gravity are not known, since all research in this area is restricted to humans in zero gravity. The same goes for the potential effects of low gravity on fetal and pediatric development. It has been hypothesized that children born and raised in low gravity would not be well adapted for life under the higher gravity of Earth.

It is also speculated that alien organisms may exist on Europa, possibly in the water underlying the moon's ice shell. If this is true, human colonists may come into conflict

with harmful microbes, or aggressive native life forms. More recent studies have indicated that the action of solar radiation on the surface of Europa might produce oxygen, which could be pulled down into the subsurface ocean by upwellings of the interior. If this process occurs, Europa's subsurface ocean could have an oxygen content equal to or greater than that of the Earth's, possibly providing a home to more complex life, which could create additional problems. Regardless of the form of life (if any) that is found on Europa, human colonization raises ethical questions of ecocide.

Artemis Project Colonization Plan

In 1997, the Artemis Project produced a plan to colonize Europa. According to this plan, explorers would first establish a small base on the surface. From there, they would drill down into the Europan ice crust, entering the postulated subsurface ocean. The colonists would then create (or, possibly, find) a pocket between the icy surface and the liquid interior in which to establish a base. This location would be protected from radiation by the ice overhead, and would be at a more reasonable temperature than the surface, as indicated by the presence of liquid water.

Ganymede

Ganymede is the largest moon in the Solar System. Ganymede is the only moon with a magnetosphere but it is overshadowed by Jupiter's magnetic field. Ganymede receives about 8 rem of radiation per day. Callisto being further from Jupiter's powerful radiation belt is subject to only 0.01 rem a day.

Callisto

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.

Trojan asteroids

The 2006 announcement by the Keck Observatory that the binary Trojan asteroid 617 Patroclus, and possibly large numbers of other Trojan objects in Jupiter's orbit, are likely composed of water ice, with a layer of dust, suggests that mining water and other volatiles in this region and transporting them elsewhere in the Solar system, perhaps via the proposed Interplanetary Transport Network, may be feasible in the not-so-distant future. This could make colonization of the Moon, Mercury and main-belt asteroids more practical.

The Saturnian system

Robert Zubrin identified Saturn, Uranus and Neptune as "the Persian Gulf of the solar system", as the largest sources of deuterium and helium-3 to drive the pending fusion economy, with Saturn the most important and most valuable of the three, because of its relative proximity, low radiation, and excellent system of moons.

Titan

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." A widely published expert on terraforming, Christopher McKay, is also a co-investigator on the Huygens probe that landed on Titan in January 2005.

The surface of Titan is mostly uncratered and thus inferred to be very young and active, and probably composed of mostly water ice, and lakes of liquid hydrocarbons (methane/ethane) in its polar regions. While the temperature is cryogenic (95 K) it should be able to support a base, but more information regarding Titan's surface and the activities on it is necessary. The thick atmosphere and the weather, such as potential flash floods, are also factors to consider.

Enceladus

On March 9th, 2006, NASA's Cassini space probe found possible evidence of liquid water on Enceladus. According to that article, "pockets of liquid water may be no more than tens of meters below the surface." If these findings are confirmed, it would mean liquid water could be collected much more easily on Enceladus than on, for instance, Europa (see above). Discovery of water, especially liquid water, generally improves a celestial body's consideration for colonization dramatically. An alternative model of Enceladus' activity is the decomposition of methane/water clathrates - a process requiring lower temperatures than liquid water eruptions. The higher density of Enceladus indicates a larger than Saturnian average silicate core that should provide materials for base operations.

Uranus

Because Uranus has the lowest escape velocity of the four gas giants, it has been proposed as a mining site for helium-3. If human supervision of the robotic activity proved necessary, one of Uranus' natural satellites might serve as a base. An alternative is to place floating cities in its atmosphere, as its surface gravity is only 90% of Earth's. Saturn and Neptune could be suitable as well, but Jupiter would likely not be, due to its high gravity, escape velocity, and radiation.

Neptune

It's hypothesized that one of Neptune's satellites could be used for colonization - Triton's surface shows signs of extensive geological activity implying a sub-surface ocean, perhaps of ammonia/water. If technology advanced to the point that tapping such geothermal energy was possible, it could make colonizing a cryogenic world like Triton feasible, supplemented by nuclear fusion power.

Kuiper Belt and Oort Cloud

The noted physicist Freeman Dyson identified comets, rather than planets, as the major potential *habitat* of life in space.

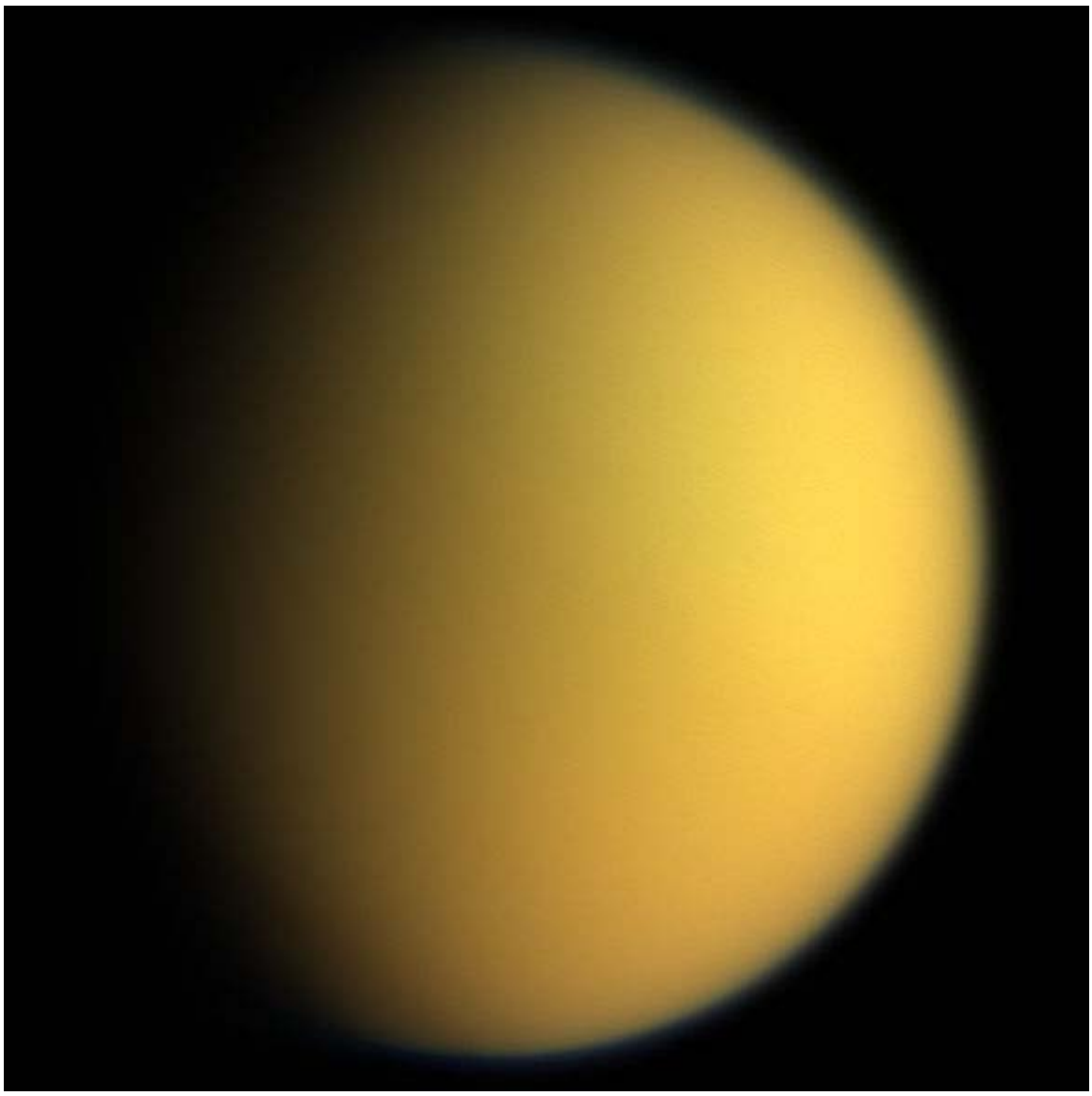
Challenges

There are various difficulties in colonizing the outer solar system. They include:

- Distance from Earth: The outer planets are much further from Earth than inner planets, and would therefore be harder and more time-consuming to reach.
- Planetary conditions: The outer planets have no surface to land on, so any habitation would have to use floating colonies, increasing complexity and decreasing reliability. The moons/comets do not have this problem, although some have specific problems (e.g., Europa is in Jupiter's intense radiation bands).
- Power: Solar power is generally considered unsuitable because of the large distance from the sun. Nuclear power is believed to be the only suitable power source for the colonies.

Chapter- 9

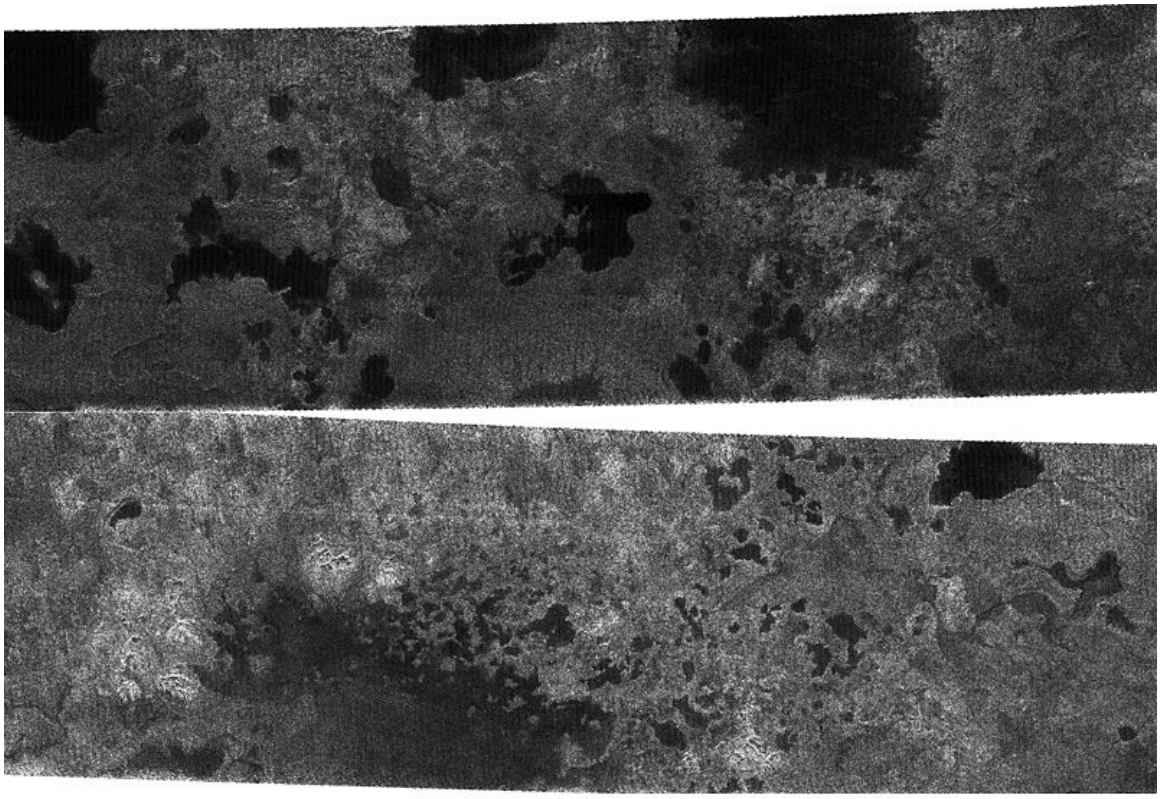
Colonization of Titan



Saturn's moon Titan in natural color.

Saturn’s orange moon Titan is one of several candidates for a possible future colonization of the outer planets in the solar system. There are many possible reasons for colonization, one of which is mining or collecting hydrocarbons which drive Earth's machines.

Natural resources



Lakes of Titan

According to Cassini data from 2008 Titan has hundreds of times more liquid hydrocarbons than all the known oil and natural gas reserves on Earth. These hydrocarbons rain from the sky and collect in vast deposits that form lakes and dunes. "Titan is just covered in carbon-bearing material—it’s a giant factory of organic chemicals," said Ralph Lorenz, who leads the study of Titan based on radar data from Cassini. “This vast carbon inventory is an important window into the geology and climate history of Titan.” Several hundred lakes and seas have been observed, with each of several dozen estimated to contain more hydrocarbon liquid than Earth's oil and gas reserves. The dark dunes that run along the equator contain a volume of organics several hundred times larger than Earth's coal reserves.

Titan 'sea' (left) compared at scale to Lake Superior (right)

Radar images obtained on July 21, 2006 appear to show lakes of liquid hydrocarbon (such as methane and ethane) in Titan's northern latitudes. This is the first discovery of currently-existing lakes anywhere besides Earth. The lakes range in size from about a kilometer to one which is one hundred kilometers across.

On March 13, 2007, JPL announced that it found strong evidence of seas of methane and ethane in the northern hemisphere. At least one of these is larger than any of the Great Lakes in North America.

Suitability

The Jovian system is the least likely to be developed for collecting resources from a gas giant, because of its extraordinary radiation belt. The American aerospace engineer and author Robert Zubrin identified Saturn as the most important and most valuable of the three other gas giants, because of its relative proximity, low radiation, and excellent system of moons. He also named Titan as the most important moon on which to establish a base to develop the resources of the Saturn system.

Habitability

Robert Zubrin has pointed out that Titan possesses an abundance of all the elements necessary to support life, saying "In certain ways, Titan is the most hospitable extraterrestrial world within our solar system for human colonization." The atmosphere contains plentiful nitrogen and methane, and strong evidence indicates that liquid

methane is on the surface and, liquid water, and ammonia are present under the surface and are often delivered to the surface by volcanic activity. Water can easily be used to generate breathable oxygen. Nitrogen is ideal to add buffer gas partial pressure to breathable air; indeed, nitrogen forms about 78% of Earth's atmosphere. Nitrogen, methane and ammonia can all be used to produce fertilizer for growing food.

Atmosphere

Additionally, Titan has an atmospheric pressure one and a half times that of Earth. This means that the interior air pressure of landing craft and habitats could be set equal or close to the exterior pressure, reducing the difficulty and complexity of structural engineering for landing craft and habitats compared with low or zero pressure environments such as on the Moon, Mars, or the asteroids. The thick atmosphere would also make radiation a non-issue, unlike on the Moon, Mars, or the asteroids. While Titan's atmosphere contains trace amounts of hydrogen cyanide, in the event of pressure suit breach, the concentration would not inflict more than a slight headache.

Gravity

Titan has a surface gravity of 0.14 *g*, slightly less than that of the Moon. Managing long-term effects of low gravity on human health would therefore be a significant issue for long-term occupation of Titan, more so than on Mars. These effects are still an active field of study. They can include symptoms such as loss of bone density, loss of muscle density, and a weakened immune system. Astronauts in Earth orbit have remained in microgravity for up to a year and more at a time. Effective countermeasures for the negative effects of low gravity are well-established, particularly an aggressive regime of daily physical exercise. The variation in the negative effects of low gravity as a function of different levels of low gravity are not known, since all research in this area is restricted to humans in zero gravity. The same goes for the potential effects of low gravity on fetal and pediatric development. It has been hypothesized that children born and raised in low gravity such as on Titan would not be well adapted for life under the higher gravity of Earth.

Temperature

The temperature on Titan is about 94 K (−179 °C, or −290.2 °F), so insulation and heat generation and management would be significant concerns. Although the air pressure at the surface is about 1.5 times that of Earth sea level, because of the colder temperature, the density of the air is about 4.5 times that of Earth sea level. This substantial density should moderate shifts in temperature over time and from one locale to another, to a fraction of the types of temperature changes familiar from the day/night cycle, the seasons, and weather on Earth. The corresponding narrow range of temperature variation further reduces the difficulties in structural engineering.

Relative thickness of the atmosphere combined with extreme cold makes additional troubles for human habitation. Unlike vacuum, the high atmospheric density makes thermoinsulation a significant engineering problem.

Flight on Titan

The very high ratio of atmospheric density to surface gravity also greatly reduces the wingspan needed for an aircraft to maintain lift, so much so that a human would be able to strap on wings and easily fly through the atmosphere.