Lunar Base Designs

"We can be sure that those who come after us will think of much better ways of doing these things - and will wonder at our conservatism and our quaint, old-fashioned ideas. And they in their turn will be laughed at by those who come after them, when the Moon is only a suburb of the Earth, and the real frontier is far away among the planets. . ."

-Arthur C. Clarke

What will the first lunar base actually look like? No one knows yet, but many have been designed. In the 1950's and 1960's, many designs were put forth by scientists and engineers who hoped that by the next century a lunar base would be fully operational. In 1992, the FLO design, the First Lunar Outpost reference, mission was developed (and rejected) by NASA. Igloos, railroads, buses, ecospheres, and domes, have all been proposed. Inflatable structures, underground structures, structures at the South Pole, and space ports at lunar libration points have all been designed. Hotels, laboratories, observatories, sports arenas, as well as mining and manufacturing plants are all very real possibilities. What would a lunar base that you designed look like? What types of power will be used on the moon? Solar? Nuclear? Fission reactors? Fusion reactors? Laser beamed electricity? What kinds of fuel will be developed for rockets making the journey? Aluminum? Oxygen? Hydrogen? Solar sails?

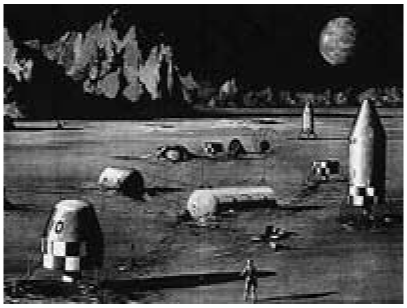
NASA design for a solar powered lunar base

What kinds of life support systems will need to be developed for life on other worlds? Water, air and waste recycling are all major concerns. Read more about regenerative life support systems. Visit some of the NASA sites on regenerative life support systems. For more on regenerative life support systems visit Discovery Channel's SpaceRef.com. An alternative power source for the lunar night is to illuminate the solar arrays with laser power beamed from Earth.

Historic Lunar Base Designs

Early designs for bases included a design by Arthur C. Clarke, the science fiction writer, published in 1954. Igloo-shaped habitats were covered with dust for insulation and an inflatable radio mast was used for maintaining contact with crews in the field. Power was supplied by a nuclear reactor. The colonists farmed using hydroponic techniques and electric monorails connected their habitats, mining facilities, and telescopes. (Clarke's 1955 spy novel "Earthlight" is based on his plans.)

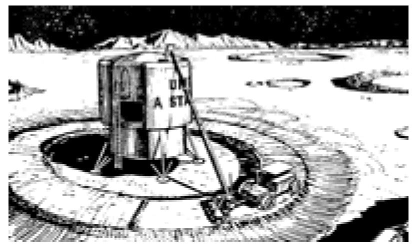
In 1953, the German rocket scientist Herman Oberth designed a caterpillar-like 'moon car' that would be able to cross chasms by jumping 125 meters!



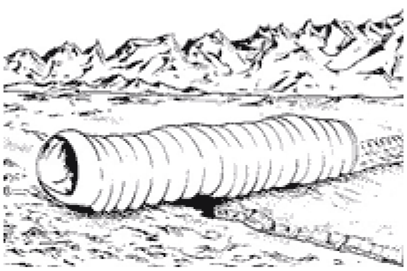
A 1962 design for a lunar base

In 1962, a lunar base study by John DeNike and Stanley Zahn was published in Aerospace Engineering. Their chosen location was a flat region on the moon that included the Sea of Tranquility (the Apollo 11 landing site).
Their base housed 21 crew members and was located in tunnels dug into the ground or buried under lunar soil for radiation protection. The base had 30 habitat modules and was 1300 square meters in size. There were seven living areas, eight operations areas, and 15 logistics areas. It was built in one year and was powered by nuclear reactors. Some solar power systems were designed but were considered unreliable.

In 1963, William Sims proposed an "Architecture of the Lunar Base," in the *Proceedings of the (13th) Lunar and Planetary Exploration Colloquium.* His design was also buried beneath the lunar regolith. The site he chose was located between Agrippa crater and Sinus Medii and it included nuclear reactors for power, a landing field for spacecraft and the habitat located inside the wall of an impact crater. The habitat was three stories high and had offices, workshops, labs, living areas and a farm. Windows in the ceilings of the top floor were insulated with water tanks for radiation protection. Sunlight was reflected into the habitat and throughout the facility and farm areas.



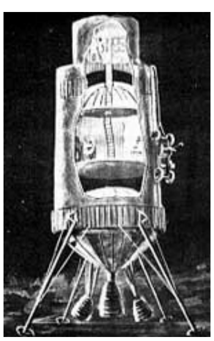
A 1964 design for an above ground lunar base by the Boeing Corporation



An 1966 artist's concept shows a "lunar supply vehicle" with a window at one end. The supply vehicle, which is about 35 feet long, crawls like a caterpillar.

In 1966, Philip Culbertson wrote an article in *Astronautica Acta* titled, "Lunar Base Concepts and Operational Modes." This journal issue included many lunar base designs. Culbertson was then the director of the Advanced Manned Lunar Mission Studies Office at NASA Headquarters.

His plan was to launch a Saturn V rocket each year over four years. Rotating three-person crews set up basic habitat modules, nuclear power facilities, and fuel modules. Eventually the crew was increased to 12 at the end of the build up period.



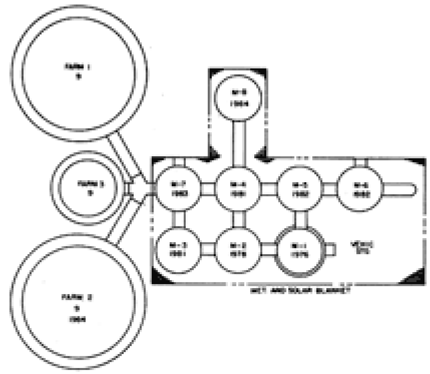
1966 design for a lunar lander and habitat

Culbertson used the Apollo Command Module and Lunar Module to send crews to the moon. After the crew of 12 was reached, a new lunar lander would be designed. An electric rover was used to travel across the moon's surface, which 1-2 person flying units allowed crews to reach difficult areas.

Build a model of the Apollo Command Module or Lunar Lander.

In the same issue of Astronautica Acta, Paul D. Lowman contributed the article "Lunar Resources: Their Value in Lunar and Planetary Exploration." He considered lunar resources extremely important in the development of moon bases. He discusses the uses of solar energy, water, sulfur, oxygen, and basalt. He recommends subsurface mining and the manufacturing of rocket fuel on the moon to reduce the cost of the missions.

In 1968 MOONLAB, "A Study of the Stanford-Ames Summer Faculty Workshop in Engineering Systems Design," was proposed by Jack LaPatra and Robert Wilson. This study proposed a moon base for the purposes of a lunar observatory. The base was located in the deep crater Grimaldi close to the lunar equator. Grimaldi has a flat floor and is 222 kilometers across thus providing a clear view of the horizon. The MOONLAB program began with the first Apollo moon landing. By 1976 a rotating three-person crew would live in the first habitat for three months at a time. The habitat had three stories, the top floor would be used for storage and provide radiation protection for the crew as it was buried under several feet of lunar regolith.



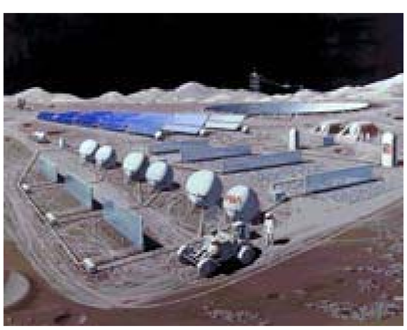
Moonlab base

The main focus of this lunar base was the science program including astronomical research. Eventually, the crew would increase to six with the addition of more habitats. By 1981, crews would live on the moon for a year at a time. By 1982, farms would be built. The farms would house plants grown in lunar soil and be designed to produce 75 percent of the food needed by the crew. A 40-inch telescope was brought to the moon in 1984. The final population of the base was 24, eight of whom worked in the astronomical observatory. 37 launches completed MOONLAB and no lunar resources were used except for the soil for shielding.

Design Baselines

The objective of many early lunar bases was to get material into orbit so that products and services could be sold to support outer space development. Some studies had the lunar base making components on the surface of the Moon and blasting them up into space.

Surface manufacturing capabilities for the purpose of building up a lunar base using in-situ materials is a more efficient technique and could be used to make steel and glass-ceramic structural items. A mobile solar reflector oven could make the landing/launch pad, road surfaces, dome roofs, etc. Most of a lunar base, in terms of weight, will probably be produced on-site from local materials, not blasted up from Earth, achieving the same goals for far less cost.



A lunar base will need a landing/launch pad, a power plant (perhaps a solar cell array for daytime "peak" energy and a small nuclear power plant for night time), base construction equipment, a spare parts and maintenance garage, a central control and communications center, housing for the people on-site, and life support systems.
To be constructed, it will also need mining and manufacturing equipment such as flailers or front end loaders and haulers, and a solar oven to be used in materials processing.

Lunar bases can be characterized by the following five design terms.

Location

Base site, environmental condition adaptations: 1/6 gravity, vacuum, lunar dust/regolith, solar winds, cosmic radiation, temperature extremes, fortnightly day/night cycle, etc.

Architecture
Buildings, machines, roads, industries, laboratories, observatories, equipment, rovers, etc.

Personnel
Quantity; rotation; mix; ages; medical concerns; psychological needs; etc.

Activities
Life support, astronomy, lunar science/geology, manufacturing, power systems, communications, transportation, etc.

Governance
Government, management, capitalization, funding, policies, etc.

Inflatable Habitats

In 1992, "A Horizontal Inflatable Habitat" design was proposed by Kriss Kennedy at the SPACE '92 conference.
An inflatable habitat made of composite fabric landed on the moon and was deployed there. A metal floor was used to ground the 45 x 8 meter module. The habitat had two levels and was designed with high ceilings and stair steps.

The habitat was either covered with lunar regolith or 'radiation shielding'. Kennedy included a solar storm shelter for the crew to retreat to when a solar flare occurred. An airlock allowed crew to clean up before entry into the base. Supply and service modules for storage and life support equipment were attached to the habitat. Office space, a space suit area, computer areas, medical facilities, a gymnasium, laboratories for astronomy, geochemistry, petrology and life sciences were included in this base design.

NASA Inflatable Habitat design

An experimental agriculture area for growing plants using hydroponics was proposed. The crew had an entertainment area, dining room, galley, and storage facility. Each crew member had a personal space with a bed, clothing area and communications and recreation system. Showers and toilet facilities, laundry rooms completed the crew area.

Artemis/FLO Lunar Base

In 1992, a joint study was done by engineers at McDonnell Douglas in the U.S. and Shimizu Corporation of Japan. This design evolved from NASA's proposed Artemis automated lander and the First Lunar Outpost (FLO).

The mission design began in 1997 with automated landers that collected data, performed in-situ resource utilization tests, and brought samples back to Earth. Beginning in 1999, rotating four person crews would begin six-week stays on the surface. The FLO habitat would be moved by an automated crane from the lander spacecraft to the lunar surface and covered with regolith for radiation, micrometeoroid, and thermal protection. By the year 2003, the crew would increase to five, and the lunar base would evolve to include astronomical research and oxygen, hydrogen, and helium-3 production. The base would recycle all of its water and convert carbon dioxide into oxygen. By 2009, the crew would be increased to eight. Two laboratories modules would be staffed along with oxygen, hydrogen, and helium-3 production plants.

In the year 2012, the crew would increase to ten, and three new modules would arrive. A Mars test facility would help scientists and researchers practice and test systems that would be used at a future Mars base. A second habitat and a third laboratory would complete the lunar base. Solar power would be used for energy, and by this time, 100 kilograms of helium-3 would have been produced. This is enough to test the helium-3 fusion system. By 2022, the base is now considered a colony with a staff of 15. The entire base is considered a closed system now, with all waste recycled and food produced in a greenhouse.

Mobile Lunar Base Project

In 1995, two Russians I. A. Kozlov and V. V. Shevchenko proposed a "Mobile Lunar Base Project" in the Journal of the British Interplanetary Society.

Kozlov and Shevchenko proposed multiple base sites for different functions. For example, one location for an observatory and a different location for mining. Conservation of lunar resources encouraged them to maintain that mining should occur over several small areas.

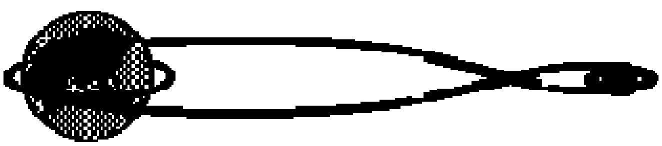

NASA design for a mobile base

They proposed a 'mobile base' which delivered automated equipment and facilities (some also mobile!). The equipment is operated from the base via a lunar-orbiting satellite.
The Russian design for a mobile base focused on lunar geology, geophysics, astronomy, lunar resource manufacturing and future lunar base infrastructure. The spacecraft would be built at a space station orbiting the Earth. Cosmonauts would use a robotic arm to manipulate pieces of the spacecraft and habitat together. The mobile base detaches itself automatically from the lunar lander after arriving on the moon.

A three-person crew lands nearby in a separate lander. The crew brings an airlock and two additional modules which they attach to the mobile base. A second lander brings three more crew members to the moon and an unpressurized rover. A regolith scooper is used to cover the area between the modules for shielding from radiation, temperature fluxes, and micrometeoroids. A cargo rocket brings scientific equipment and a drill. The mobile base is then functional.

Solar power is used as a back-up for a nuclear reactor that beams energy (in the form of microwaves) to a receiving antenna at the base. Crew quarters include six private cabins, a mess hall, an agricultural facility and a suit room.

The Artemis Project Lunar Base

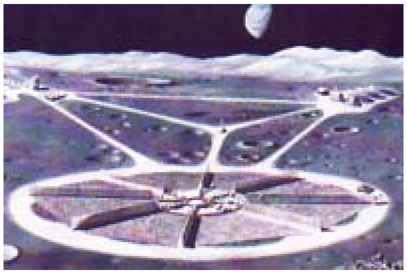


The Artemis Project has a plan for the first lunar base. In their design, the lunar transfer vehicle is a small habitat with propulsion systems and support for the crew during flight to the moon. The flight follows a similar trajectory to the Apollo flights. Upon arrival in lunar orbit, the habitat separates from the lunar transfer vehicle and lands on the surface of the moon. The lunar transfer vehicle remains in lunar orbit while the crew descends to the surface. On the moon, the crew configures the lunar base habitat for permanent operation. On their first trip outside they set up power systems, radiators, and antennas.

The crew explores the landing site and gathers samples during a one-week visit. They film their activities for use in movies and documentaries. When they have completed their stay on the moon, the crew boards the ascent stage and makes the two-hour flight to rendezvous with the orbiting lunar transfer vehicle. Interestingly the ascent stage is an open vehicle so the crew must remain in their space suits for life support. After docking to the lunar transfer vehicle the crew returns to Earth. The spacecraft remains in orbit for use on later flights. For more information visit the Artemis Project.

Transportations Systems: A Lunar Railroad

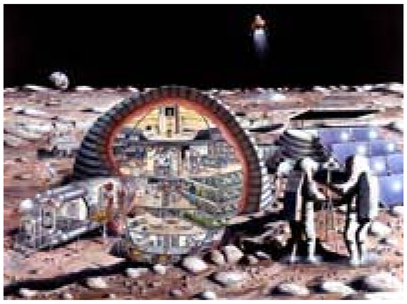
In 1998, a lunar railroad system was proposed in the article "Physical Transportation on the Moon: The Lunar Railroad," by David Schrunk, Madhu Thangavelu, Bonnie Cooper, and Burton Sharpe.



A lunar base with both nuclear and solar power plants

The authors proposed building a railroad around the lunar South Pole. Teleoperated robots would do the job. A circular railroad would begin at a proposed lunar base (called 'Newton Base') and be used to construct and maintain a series of solar arrays used for power. They hypothesize that one kilometer of solar array could produce one megawatt of electricity. The materials for the railroad and the solar panels would all be constructed from lunar aluminum and lunar silicon.
The railroad would be 950 kilometers long. The average speed of the train would be 30 kilometers per hour. An additional rail line would be built to link the lunar base to the dark cratered regions of the South Pole.

Science Activities at the Lunar Base



NASA lunar base

Basic science is one of the primary functions of the first lunar bases, and will offer scientists an opportunity to demonstrate science techniques and data analysis in the field. Once a base is operational, various scientific studies and experiments can commence.
The following science projects were conducted in simulations by the Young Astronauts organization in their Lava Tube Lunar Base simulation:

"Environmental Science: Environmental monitoring instruments both inside and outside the lava tube base were set up. Data sheets were kept near each station and as participants passed the station they recorded the time, read the instruments, and recorded the environmental data. Back in the lab data was displayed as graphs showing changes and relationships between the parameters.

Astronomy: During the winter months in which the simulations were conducted, the skies were dark by the time the base became operational. An 8-inch reflecting telescope was set up near the cave entrance to examine star clusters, planets, and nebulae. Young Astronauts identified planets, stars, and constellations.

Cartography: Maps are important for planning many activities. Compasses, tapes, and inclinometer measurements were used to map the interior of the cave and surface in order to find the surface projection of the underground lunar base.

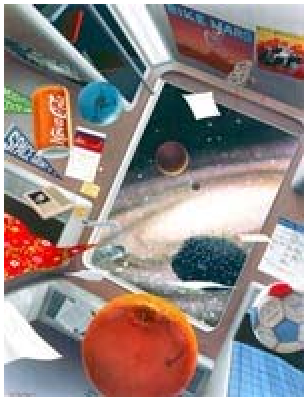
Sand/Dust Analysis: Samples of the cave sands were collected from the vicinity of the base. In the lab they were examined by microscope and other analytical techniques (flotation; magnets; spectral analysis). To counter the dust contamination, it was decided a dry, anti-static lubricant was needed. One of the researchers (Walden) suggested an aerospace lubricant developed by Ball Corporation and marketed as a vinyl phonograph record preserver called "Sound Guard." This lubricant appeared to alleviate some of the problems caused by the dust.

Geology: Simple geological analysis tools were used at the base site. Young Astronauts collected samples of rocks, sand, and cave-wall mineralization which were then subjected to oxidizing and reducing thermal reactions. Some elements could be analyzed by examining the spectral characteristics of the samples.

Sample Collection: Geological and biological samples were collected, collection sites and contexts were described, and the samples were identified by reference to books or experts. Collections could be organized according to criteria selected by the collectors.

Time-Motion-Design Studies: In the process of constructing the lunar base and using the components for housekeeping, science studies, etc., design and procedural changes would be suggested by experience. This was a version of time-and-motion efficiency studies and human-engineered design work. Thanks to the modular construction system of the facility, designs could be changed easily. Lightweight system components could be physically rearranged even after construction in order to improve efficiency or answer to other needs. Other problems were best addressed by modifying the work procedures or reassigning personnel."

Lunar Libration Point Space Port



Future Space Port

In 1992, Norbert Lemke of the Technical University of Berlin presented "The L1 Transportation Node," at the 43rd Congress of the International Astronautical Federation. Lemke proposed a space station at L1, the libration point located close to the moon. He recommended an L1 space station as a port for flights between the Earth and a future lunar base, as well as spacecraft going to Mars and other planets.

The Lagrange-1 (L1) point is the neutral gravity point between the Sun and the Earth. Lagrange points are points between two orbiting masses in which the gravitational pulls from both bodies are balanced exactly with the centripetal force required to rotate with them. Objects at these points then orbit at a constant distance from both masses. The L1 point is one percent of the way to the sun, or four times the distance from Earth to the moon, or about one million miles away from Earth.

Lemke points out that this location could provide a space port for passenger pick up and drop off, and for maintenance and refueling of space vehicles. He also considers an L1 port as a node for communications and data transmissions and even a future laser power station!