I. BASE MASTER PLAN

A. Master Plan Components

1. Crew Support Habitat
   Facilities for the support of crew members and their activities will form the main focus of the base. This area consists of living quarters, work spaces, communications, laboratories, etc.

2. CELSS/Horticultural Research Lab
   The Closed Ecological Life Support System will be a study of an almost entirely closed cycle of food and waste management. It will serve as a prototype for a mature lunar base as well as space stations and a Mars outpost. An efficient environmental support system will reduce reliance on outside sources of materials and thereby lower the cost of running a manned off-world facility. Beyond its purely technical considerations it may also serve as a place for crew members to relax.

3. Launch and Landing Facilities
   Launch and landing facilities will consist of several remote landing areas that have lander servicing equipment and crew/payload transfer systems.

4. Base Garage and Maintenance Facilities
   This area is used to store and maintain vehicles when they are not in use as well as repairing damaged equipment. It may consist of a large non-pressurized hangar but may also have a pressurized area for more delicate repairs. It should be expandable and flexible.

5. Transportation Systems
   Surface transportation is needed to travel between some the more distant base elements as well as transferring payloads or crew from one area of the base to another. The transportation should be compatible with all possible payloads and it should be adaptable to many tasks.

6. Mining Surface and Production Analysis Operations
   The use of lunar resources will help provide economic incentive and leveraging, for the lunar base. The mining and refinement of metals, isotopes (Helium-3) and other materials (oxygen) are some of the processes that will take place and experimental systems to test methods of collecting and processing lunar raw materials will be an important component of the lunar base. This area will have special power needs and will have other location requirements in relation to the remainder of the base.

7. Construction Technology Test-bed/Tele-robotic Research Laboratories
   Some initial phases of base construction will involve high-technology tele/autonomous robotic techniques. Later phases of base construction will involve the use of exotic materials and high technology construction methods as well as in-situ materials for economical lunar development. Construction research will study these new materials and construction methods as well as advances in tele-robotic systems, lunar transport vehicles and EVA systems.

8. Power Plant
   There must be a dependable source of adequate power on hand at all times and it is likely that several redundant systems will serve the early lunar base. Some the possible power sources include nuclear power (SP-100), solar power, and fuel cells. Alternatives sources will be studied for effective use in future developments.
9. Lunar Farside Observatory/Science Base
Astronomical research will have an important role in the lunar base. An observatory on the farside of the moon will be free of radio interference and greatly increase the abilities of the present earth-locked research programs. Operation and monitoring of the equipment will be controlled from the base while servicing or repair will necessitate a visit by an astronaut.

10. Human Factors and Environment-Behavior Systems Monitoring Center
The study of the psychological and sociological effects of living in a remote closed environment will help refine base systems and components for a second generation lunar base as well as other off-earth outposts. The evaluation of the needs of the crew will take place primarily through daily interaction with equipment and a post occupancy evaluation (POE) of base elements.

11. Safe Havens
An area designated as a safehaven serves the base in case of an emergency or failure of the main habitat. It should be either easily isolated or physically separated from the rest of the base and it should contain everything the crew might need until a rescue attempt can be made. This would include food, water, communications, limited hygiene, EVA, ECLSS, shielding, etc.

12. Logistics or Materials Storage
Many elements of the lunar base need some form of storage to organize and protect materials and equipment. Both incoming supplies and outgoing materials as well as spare components and waste materials need to have an area designated to house them. This area should be easily expandable and adaptable and it should be easily accessed by members of the crew. At least one of these structures should be near the arrival and departure area.

13. Communications Equipment
Provisions will need to be made for omni-directional antenia, radar dishes, etc.

B. Base Layout

1. Module Configuration
The early stages of lunar development will be very dependent on earth launched supplies including most of the habitable structures. These modules (or inflatables, etc.) and their corresponding connecting nodes will limit the configuration to one which is economical and transportable. The primary issues for the configuration are separate, isolatable volumes, dual egress, phased growth, and modularity. Another factor to consider is keeping the early stage simple to allow for the limited construction capabilities of an early lunar outpost.

A. Dual Egress:
Separate, isolatable volumes and dual egress allow a crew member to exit a module in an emergency and it also allows complete circulation throughout the habitat in case one area is damaged or unusable.

B. Phased Growth:
The base elements will arrive from the earth at different times so they should not require additional units for complete usage. They should also function as an entire base when all of the elements are in place. Phasing the growth of the lunar base will require a configuration that provides for these needs as well as possible future expansion.
C. Modularity:
A limited number of module types lowers the cost of the base through standardization and length of on-site construction time. Unique elements require special systems and increase time and money spent on development.

D. Simplicity:
Lunar construction at this early stage may restrict structures to the two dimensional lunar surface. "Second floors" and "basements" require additional machinery which may not be justifiable until a later period of development. Generally, simple designs are more cost effective and easier to employ. Alternatively, there is a possibility of limited use of lunar lava tubes, sub-surface construction, etc.

Some possible geometric configurations that involve the use of a single module design are triangular, "raft," linear, and grid. The different configurations all have positive and negative aspects to them:

(References for all Figures are given in the table of Figures at the front of this document.)

*The triangular configuration allows for dual egress and uniform growth but the nodes become complex and exits are far from some points of the base.
*The raft allows dual egress but requires many nodes.
*The linear configuration has low numbers of nodes but limited circulation.

*The grid or orthogonal configuration appears to offer a good combination of dual egress, uniform growth, easy implementation and standardization, but requires four to complete the configuration.
A composite configuration would combine some of the positive aspects of several different geometries (SICS A, 1989).

![Diagram]

Different construction methods are likely suggest different configurations. Tunneling, for example, would not be dependent on modularity but the pathway and efficient use of tunneling machinery.

The use of craters, lava tubes or other physical features of the moon would result in a configuration dictated by lunar geography. This would give a natural ordering system to follow in the same manner in which towns on earth form around lakes, rivers, etc.

The psychological health of the crew should also be considered in the overall arrangement of the habitat. Modules will quickly tire the mind("visual landscape"). A larger length and width habitat is required for long-term psychological health. There should be public and private areas outside of those areas designated for meetings and private quarters. One centralized area would provide a physical focal point for the base which could correspond to some key activities of the base. A large public area with semi-public and private spaces nearby would lower the feeling of living in a collection of identical modules. It might also be helpful to have a rest area that would have reminders of earth. Such an area could simply be the biosphere with special additions such as benches or a trellis to remove the feeling of confinement in a human made environment.

2. Efficiency/Organization of Exterior Elements

The overall layout of the lunar base should reflect an organizational idea or geometry that allows the base to be understood functionally as well as used efficiently. Several ordering principles are inherent in the functions that make up the base. The functions of the base include living, science and utility, transportation, industrial, and power production(nuclear). The relationships of these functions to each other will help determine the shape of the base.

Science and Utility:

A science and utility area consisting of a solar power array and an observational science facility will need to be separated from dust producing activities: 10 km plus or minus 2 km should be sufficient with no atmosphere to move dust (SICS A, 1989).
Launch and Landing:
A launch and landing facility should be located in proximity to the areas of the base that it would most frequently serve such as the habitat area and industrial area. This proximity should be subservient to any safety requirements. The distance to the nearest critical element is still questionable. Probably 2-5 km for blast effects. Distances must also keep "walk-back" requirements in mind. Crew must be capable of EVA transfer to excursion vehicles without working rovers.

Industrial:
An industrial grouping which includes mining, power plants (radiators of nuclear plants must also be protected from dust), and manufacturing/processing should be located with regard to the safety and proper functioning of the other base elements. Eventual needs for transportation of lunar materials or products off-planet should be considered. One possible long term scenario might include the construction of a second launch and landing facility or a linear accelerator.

Base Garage/Maintenance:
Individual zones may each require hangers, servicing areas, and materials storage areas, but that may prove impractical at early stages of development. The base garage and maintenance facility will serve as a focus for repairs and storage of transportation equipment and it should be located so it is accessible to all zones of the base until each zone has its own limited facility.

Roadways:
Organized roadways between all segments of the base would allow for efficient transportation of materials and crew while also giving the base some structure.

3. Safety

Launch and Landing:  
The basic orientation of the base on the surface of the moon is determined by the link between the lunar surface and the earth. The lunar landers must descend from lunar orbit and have a clear path to the landing pad. By orienting the major base axis north-south (perpendicular to the standard lander orbit) and placing the landing area at one end of this axis, no component of the base would be endangered by an approaching lander or by a lander which overshoots its objective. The distance from the launch and landing facility to other parts of the base should be about 3-5 km to eliminate the amount of blast damage done to the rest of the base. This distance may be as little as 2 km with "blast shields" (Eagle Engineering, 1988).

Power System:  
The power supply for the base is of extreme importance for base survival and it should be located far from the launch and landing facility. The power system should also be placed far from the habitation areas so accidents will not endanger crew members. A linear relationship of these two components and the habitat area would satisfy the distance requirements.

Safe Haven:  
A safe haven should be accessible from all points of the base but its closest proximity should be to that of the crew habitat. It should be remote enough from the remainder of the base so that no accident at the base affects it adversely. Care should be taken to maintain the safehaven and equip it with appropriate supplies. It is envision that the base will be designed with separately isolateable areas for redundant safe havens. A micrometeorite penetration of a module would allow only
seconds to minutes to find safe haven. Power supply, EVA chamber, and ECLSS should all be separate from the main base facilities. Since the very early stages of the lunar base require such a self-contained module for use as a construction shack, it may be possible to outfit it for such a role.

4. Wayfinding
A regular pattern to the lunar base will be important psychologically. A grid or axis that is easily understood even at the large distances required for a lunar base will allow for easy orientation in relation to the base and the moon.

5. Future Growth
The future expansion of the lunar base will depend upon the success of the many different elements that make it up. Long range planning would allow for the expansion of each of the different zones without the loss of efficiency or safety. There should be areas around the main section of the base that can absorb a growing number of habitation sections and other facilities that might be required. A linear arrangement of the lunar base components would allow expansion of the transportation and industrial areas along the major base axis and expansion of the living area along a minor axis perpendicular to that major axis.

As the base expands it may also be required to alter the use of various sections of the base. A flexible system that could be rearranged or renovated would be useful. This would be "zoning" in its highest form.
C. Transportation/Exterior Circulation and Translation

1. Phasing
As the lunar base develops, the needs for launching and landing facilities will change. The very early stages of the lunar base will require landing sites near the base. This stage will end with the first manned occupation of the base. It would be very efficient if the landers involved in the early stages could be reused or recycled.

![Diagram of lunar base layout with different zones and types of materials]

After the first manned occupation, the landing facilities will need to be moved to a more remote location so that the base is neither endangered nor does it suffer blast damage. These temporary sites should be more than 3-5 km from the base and should allow for permanent launching and landing facilities closer to the base but still at least 3-5 km away (Eagle Engineering, Inc., 1988).

2. Safety
Launch and Landing Facilities:
The lander's orbit should not pass over any portion of the base and the landing facilities should be separated from the other facilities by at least 3-5 km (Eagle Engineering, 1988).

Landing Pads:
The individual landing pads should be separated from other equipment by 250-400m to prevent blast damage and the surface of the pad should be free of objects for about 100-200m around the target area. The actual target area should be about 50m in diameter and the surface should be level (slope no greater than six degrees, ideally less than two degrees). Surface stabilization may be considered to minimize dust. Markings and navigational aids will increase the accuracy of manned landings and allow for the possibility of unmanned landings. Until highly accurate unmanned landings are possible it may be necessary to have two separate facilities in the event of an accident. Unmanned facilities could be located farther out along the base axis near the early temporary landing sites (Eagle Engineering, 1988).
3. Proximity in Emergency
   Surface Transportation:
   Surface transportation should be capable of removing the crew to either the safehaven or to the launch and landing facility in an emergency. Rapid evacuation would require the use of a large pressurized transport to eliminate EVA preparation time. This could also serve as surface transport in non-emergency situations. Examination could be given to methods for pressurized crew transport from habitation areas to landers.

   Crew Emergency Rescue Vehicle (CERV):
   A CERV could be located at a point in close proximity to the habitation area. An alternative would be a spare lander at the launch and landing facilities. This equipment would need to function reliably in an emergency (NASA, 1989).

4. Protection/Maintenance of Equipment
   Surface equipment should have some form of blast protection and, if something remains on the surface of the moon for extended periods of time, it should have some sort of protection from the lunar environment and micro-meteors. This protection could be in the form of an actual shelter or a blanket placed over the equipment. The solution for this problem should be relatively simple to allow for easy crew access and to insure its regular use. In the case of actual repairs, the base garage and maintenance facilities should be adequately equipped to repair all of the necessary systems.

5. Low Manpower Requirements
   The movement of crew, payloads and equipment should tie-up as few man-hours as possible. Easily used transportation systems eliminate the need for large groups of people working on a single task and would help lower mistakes under stress. A pressurized transportation system would eliminate the time it would take to prepare for EVA.

6. Flexibility
   The transportation systems used for the lunar base should be highly adaptable to many needs. Modularity or the ability to add specialized equipment to a standard platform would lower the amount of space needed to bring the system from the earth.

D. Image

1. Public Face
   a. Acceptable appearance from Earth's surface
      Considerations should be made as to the visual effect a lunar base will have on the moon. Actual physical features will not be a problem of the early moon base, but it is possible that base lighting will be visible from earth during the lunar night. It is also possible that orbiting debris or dust will alter the familiar view of the moon. This visible evidence of lunar occupancy would not be viewed by all equally and a proper approach at the outset of exploration will lesson conflicts in the future.

   b. Acceptable appearance from transmitted images
      The lunar base is symbolic of a number of things to people not directly involved with the space program. It will hold a special place in the solar system as the first outpost on another world and should therefore reflect positive qualities of the nations involved. A configuration that is well organized and pleasing will suggest intelligence and forethought as well as goodwill and a sense of unity.

Project Genesis: A Lunar Outpost
2. Recognition/Icon
Part of the acceptability of the lunar base’s image will be the ability of people to recognize it as a human place. Visual cues can help identify the lunar base as a village, outpost, or home and not simply a collection of space hardware. A simple gateway on the path between the landing area and the rest of the base or a symbolic entry way in front of the EVA/base entrance are some examples of small details that would have a large affect on the image of the lunar base. These visual cues relating the base to other known structures may be especially important for the crew by giving them a feeling of security.

Since the entire habitation area of the base will be covered in some form of radiation shielding some, another cue will be necessary to mark the dignified presence of the lunar base. A series of lights on the buildings and along pathways would be a simple method of defining the base and creating a sense of unity among the base elements.

3. Care for Lunar Environment—Lunar “Erosion”:
A roadway system on the moon, even if not necessary for vehicular use, would help restrict or at least contain the amount of footprints and tracks left behind by crew members. A “paved” roadway or stabilized surface would lower the amount of lunar dust kicked up by movement throughout the base.

Litter:
A litter clean-up program would eliminate unsightly waste in the base surroundings and perhaps help encourage finding new uses for “useless” items. A careful treatment of the lunar environment will make the lunar base a more pleasant place to work and live in. It will also demonstrate to the earthbound that the nations involved in the lunar base are being thoughtful about future generations of visitors. Selection of materials (food containers, etc.) which could be re-formed for alternate uses will be important. Disposal of spent nuclear fuels will be an issue: burrying in place, collecting in one central burial place, or launch into the sun may be options.

Lunar Wilderness Preserves:
Surveys of some areas of the lunar environment should include their designation as wilderness preserves. Untouched regions of the moon will therefore be available for future generations of lunar explorers to view the moon in its untainted state.

4. Unified Image and Character
The lunar base should be consistent in its imagery on the interior and exterior. The overall base ordering should suggest a single organized structure that functions efficiently as a work place and is comfortable as a temporary home. Careful and creative use of space can increase the pleasure of working in the lunar environment and thereby increasing the efficiency of the crew members.