The Space Congress® Proceedings 1964 (1st) - Where Are We Going In Space?

Apr 1st, 8:00 AM

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Scholarly Commons Citation

Hayes, T. J., "Ground Support for Man in Space" (1964). *The Space Congress® Proceedings*. 1.
https://commons.erau.edu/space-congress-proceedings/proceedings-1964-1st/session-1b/1

GROUND SUPPORT FOR MAN IN SPACE

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Since man first conceived the idea of rockets, he has been concerned with facilities to launch them, and engineers have had to design and build them. Initially, they were relatively simple. However, the rapid intensification of manned space flight efforts in recent years has led to even larger and more sophisticated launch vehicles, and corresponding developments in launch concepts. The result has been a vast ground support effort for man in space -- itself a major challenge of the national space effort.

As those of us engaged in aerospace activities know better than most, this Nation has made giant strides in the aerospace field since the end of World War II, when the Army started testing variations of captured German rockets at the White Sands Missile Range in New Mexico. During the years that followed, the simple rocket has been developed into a complex family of ballistic missiles.

The most advanced are the great ICBM's which can carry nuclear warheads to targets a continent away. The Army Engineers have built hundreds of launchers for these, of several different types, as the weapons and their ground support evolved.

It was highly specialized work -- an engineer's dream which often became a nightmare -- a tremendous team effort without parallel in the Nation's history of construction which received fitting recognition in 1962 as the outstanding Civil Engineering achievement of the year.

Today, with hundreds of ICBM's on the alert, we are over the hump in the urgent, nationwide program which so greatly strengthened the defenses of this country. The same technology that achieved this vital military success also ushered in the Space Age and made it possible for man to set new goals far beyond our earth.

A space age revolution is sweeping our country, propelled by the impetus of The National Aeronautics and Space Administration's Manned Space Flight Program as it builds up to its great climax.

A few years from now NASA will launch three astronauts in lunar orbit 100 miles above the moon. Once in this "Parking Orbit" two of the spacemen will leave their Apollo mother ship and head for the lunar surface in a 12 ton, bug-shaped shuttle.

They will land, perform their exploring mission, rejoin their Apollo vehicle and return to earth. When this has been accomplished, they will have fulfilled one of mankind's most ambitious dreams. Yet, the logical sequels are even more far-reaching:

A manned base on the moon,
Manned flights to other planets,
Unmanned probes of other parts of our universe,
Astronomical observatories orbiting in space.

A vital element of this Space Program is the development of a vast array of rocket and spacecraft fabrication and assembly plants, as well as ground-testing and launching facilities, in a year-round warm climate.

Here, along a 1500 mile crescent starting on a lake front in Eastern Texas down below Houston and sweeping through the South to a swampland on Florida's Banana River, are the major NASA Centers which are engaged in the Manned Space Flight effort. Their work has been called the beginning of a new and basic industry, sired by the missile age for the 21st Century. But it's also an industry based on solid construction, for without adequate construction support this program could never be undertaken.

The Army Engineers are playing a major role in this effort. Our part includes a number of different activities. However, at this stage of this rapidly moving space program our most important contribution is a massive construction buildup. (Figure 1)

Today our space projects include complex facilities at a number of locations for the National Aeronautics and Space Administration and the Air Force's Space Systems Division. Examples are:

1. Rocket engine test stands in California, and
2. Test facilities for the Lunar Excursion Vehicle at WSMR, New Mexico.

However, the bulk of our space work is at the four Centers on the Gulf Crescent --

1. The Manned Spacecraft Center at Houston which develops the spacecraft.
2. The Marshall Space Flight Center at Huntsville, Alabama which develops the rocket engines.
3. The quarter billion dollar facility in Mississippi for testing the space boosters.
4. The billion dollar spaceport at Cape Kennedy.

In part, the assignment of this critical work to the Corps derives from our vast experience in large and critical construction. But it also reflects the dependence of this Space Program on the navigable waterway system, which the Corps has developed over the years. (Figure 1). These four key Centers all adjoin our waterways, since the giant boosters of the space program are too large to travel except by water.

The Air Force's Atlas and Titan were developed as ICBM's, but are also the mainstays of the Space Program until the Saturn boosters become available.

1. Atlas, among other things, launched the earth-orbiting capsules of the four astronauts in Project Mercury.
2. Titan will be used for our second step in space, Project Gemini, which will put two men into earth orbit for periods of a week or more. There they will bring two spacecraft together and join in space -- essential experience for Project Apollo.

3. The two-stage Saturn I-B will be used for earth orbital development flights of the Apollo spacecraft and for training the lunar crews.

4. Perhaps the most urgent engineering challenge of Apollo is the development of the three-stage Saturn V -- a launch vehicle powerful enough to send the equivalent weight of two freight cars hurtling across 230,000 miles of space to a lunar landing.

The J-2 and F-1 engines for the various stages of the Saturn V vehicle will provide power for the Apollo launch vehicles. These engines are huge; they dwarf a man.

Each of these engines must undergo a successful test firing before it becomes part of a space vehicle. This requires construction of a carefully instrumented and controlled test stand, where the engine can be anchored down, and then turned on full force for a static test. (Figure 2) One indication of the forces at work is that this F-1 engine consumes one ton of kerosene (RP-1) and two tons of liquid oxygen (LOX) per second.

Development of these engines and launch vehicles is the responsibility of Dr. von Braun who heads MSFC at Huntsville. There a number of stands have been built for static test of the various engines. Such a stand combines the problems of high stress and vibration, tremendous thrust, torrents of incandescent gases, and elaborate plumbing for various exotic rocket propellants, all in a single massive structure.

Some stands are for individual engines, but the stand in Figure 3 is now under construction at MSFC to test the cluster of five F-1 engines which will make up the booster stage of the Saturn V launch vehicle. Each of the concrete pylons is 48 ft square at the base.

The growing power of engines and stages which must be test fired called for a new test center at an isolated location, but still with access by water to the Gulf. This led to the decision to build the MTF in Southern Mississippi, about 40 miles northeast of New Orleans.

Construction began on this unusual facility a year ago. Initial work includes four stands for test firings of the Saturn V boosters. (Figure 4) The test area will be serviced by 15 miles of canals so that the large rocket stages can come in by barge and be unloaded directly on the static test stands.

Figure 5 shows the concept of one of the 400 ft dual position stands to be built, showing the Saturn booster being transferred from its barge. The five F-1 engines of this booster generate the combined power of one-half million automobiles. Imagine the problems of anchoring down something so powerful it can lift 4,000 tons off the earth or put 120 tons into orbit! This work at Huntsville and Mississippi is being carried out by our District Engineer at Mobile.

Meanwhile, in Eastern Texas near Houston, our Fort Worth District is building the ultra-modern Manned Spacecraft Center.

Work on the Center is moving along on schedule, with many of its buildings completed, and several of the more technical facilities under construction. Still others are under design. This Center is a combination operation, research, testing, and training facility which will manage the development of the space ships, train the astronauts, and control their flights. A number of these Space Age buildings are quite unusual.

They include an enormous centrifuge which will subject several astronauts at a time to the high gravity stresses of launch and re-entry under vacuum conditions. (Figure 6)

Another is the largest environmental test facility in the U. S. This will simulate on earth the conditions of space and the lunar surface; such as intense light or total darkness, and temperature extremes from 260°F above zero to 315° below, all in a near vacuum. In fact, the air pressure in these chambers would have to be increased 76 million times to bring it up to the atmospheric pressure at sea level. Obviously the spacecraft, the astronauts and their protective space suits will be well tested under such conditions. (Figure 7)

Another special facility is the Integrated Mission Control Center which will direct future Gemini and Apollo space flight missions and maintain contact with our astronauts far out in space.

Basic facilities have been completed at the Manned Spacecraft Center and about 3,000 NASA personnel have moved into their facilities. However, construction of laboratory and other research type buildings will continue over the next two years.

When the astronauts have been trained and their space ships perfected at Houston, and the mighty boosters have been successfully tested in Mississippi, all will move over here to Cape Kennedy to be assembled into the space vehicles for launch on their long journey.

A harbor was built here on the southern end of the Cape to support the test programs. We plan to double the size of this harbor in the near future to accommodate the increased traffic expected.

Since 1950, over a billion dollars has been spent at Cape Kennedy to convert an abandoned World War II Naval Air Station into the Free World's largest rocket test center. This is a portion of the Cape as it looks today. (Figure 9.)

In the foreground is Complex 37, for launching the Saturn I. So far it is the largest launch complex in the Free World -- and the first built for peaceful use of space. From this complex in late January, a Saturn I launched the largest payload -- about 19 tons -- ever put into orbit. Behind it is Complex 34, which has launched the first four Saturn flights to date. Beyond are the Titan I and Atlas stands, later modified for Mercury, Gemini, and other space programs.

Before we send a man to the moon, a tremendous program is still necessary at Cape Kennedy. Here, over the coming years, more than a billion dollars will be spent to prepare this historic site for its even more historic role. All of this construction work is now being carried out by our newly organized Canaveral District.

The map in Figure 10 shows the present Cape Kennedy - Merritt Island area. To the North, is the new area on Merritt Island which has been acquired for NASA. This $55 million real estate program has expanded the test center to six times its present size. Here, an area largely made up of rattlesnake and alligator infested swamps, with scattered orange groves and a few small palm-fringed housing developments, is being converted into the "Gateway to the Moon."

Here we are building the science-fiction type structures of the Space Age, starting with two giant complexes.

The first is for the Titan III, the Air Force's largest entry in the current space program. This will launch the MOL, Manned Orbiting Laboratory, into an earth orbit to enable astronauts to conduct observations and military experiments in near space just beyond the earth's atmosphere. Titan III will consist of a modified Titan II ICBM with two solid fuel motors, of a million pounds of thrust each, strapped on each side, to carry over 12 tons into earth orbit. Construction of this project is well underway. This is the launch pad, as it will look when completed. (Figure 11.)

Large as this facility is, it will be dwarfed by the new NASA Complex 39 that will launch the Saturn V and its three-man Apollo spacecraft to the moon.

The various stages and components will come by barge to the unloading basin, in the lower center, then move into this Vertical Assembly Building. Here in a controlled environment, the Saturn V will be assembled and erected on its launch rack.

Figure 12 gives a close-up of the $100 million assembly area, showing the Barge Unloading Facility, the Launch Control Center, and towering over them, the huge Vertical Assembly Building.

At the left a launch vehicle is seen all checked out, with its spacecraft in place, ready to move on to its pad several miles away. In the distance a launching is underway. Inside this VAB the unobstructed headroom space is high enough to clear a 45-story skyscraper, yet it must be hurricane proof, water tight, and able to ride out the worst storms ever recorded in this area.

Figure 13 gives another view of the VAB. Nothing like it has ever been built. Its doors are 456 feet high. Here the Apollo vehicle is shown moving out in flight attitude on its 2,000 ton launch platform, its 400' umbilical tower in place, all mounted on a giant crawler-transporter -- the world's largest land vehicle. This vehicle and its load weigh about 17 million pounds. The launch platform is half the size of a football field. It is difficult to see the men, they're so small in comparison.

The VAB will be connected to three launch pads like this by eight miles of crawlerways raised above the swampy terrain.

Figure 14 shows the launcher-umbilical tower, the Saturn and the arming tower in place on the supporting piers at launch site, and the crawler-transporter withdrawn. Here the fueling begins -- 3,750 tons of kerosene & LOX. The arming tower will be moved back to its parking area prior to launching man on his greatest adventure.

However, our discussion of ground support for man in space must not be limited just to terrestrial facilities. We must also consider the requirements for extra-terrestrial support facilities.

Studies are now underway involving systems to support initial surface reconnaissance operations in the immediate post-Apollo period. Today the lunar base is not an approved program, but such a base appears to be an essential part of our national space program in the next decade. Facilities of some type will be required to support the manned surface activities needed for exploration of the moon. If exploitation of lunar resources becomes feasible, more extensive facilities will be required. We in the Corps of Engineers are interested in this effort as an extension of our present efforts in support of Apollo.

First, let's look at the location for these facilities. Figure 15 shows the moon as it would appear to an observer looking through a telescope. However, the engineers and scientists concerned with selecting lunar landing sites, base locations exploration routes, etc., need more information than is shown in this photograph. One of the more recent efforts to provide this information is shown in Figure 16, which is a lunar topographic map at a scale of 1:2,500,000 produced by the Army Map Service, an agency of the Corps of Engineers. This map shows the central portion of the visible side of the moon. The initial manned landings will probably take place in an equatorial band between ± 10° latitude.

The contour interval on this map is 1000 m. with supplementary contours at 500 m. Unfortunately, this is about the best product that can be made at this time with photographs taken from earth-based telescopes. Future photographic information obtained from Ranger, Surveyor and Lunar Orbiter flights should yield much more reliable lunar topographical data. Information which may be obtained from the Surveyor spacecraft lunar landing should also enable us to improve the photogeologic maps of the moon which were first prepared in 1960.

Available information concerning the lunar surface, lunar materials, and the lunar environment is incomplete, subject to interpretation, and controversial. Therefore, until direct evidence is obtained, lunar conditions can be described only in general terms. Large-scale surface features can be divided into two categories: highlands and lowlands. The highlands, or continents, are extremely rough, containing mountain ranges, ridges, rills, faults, and a large density of steep-wall, circular craters ranging up to 180 miles in diameter. Slopes vary generally between 0° and 15° with some of the smaller craters exhibiting interior slopes up to 35°. The lowlands, "lunar seas" or maria as they are more commonly called, are generally featureless having the appearance of large, flat plains. Slopes reach a maximum of 2° or 3°. Craters up to about 50 miles in diameter occur at random in the maria, but at a much lower density than in the continents. The entire surface is covered probably by a low density, highly porous dust and rock froth. This surface layer should be no more than 1 to 6 inches thick in most places, but locally may accumulate to several feet.

The main characteristics of the lunar environment which are of interest from an engineering viewpoint are:

a. Atmosphere -- Essentially non-existent with a density of less than 10^{-12} relative to the earth's atmosphere at sea level.

b. Temperature -- Varies from a maximum surface temperature of 390 K (117 C) at the subsolar point to a nocturnal value of 105 K (-153 C). Changes in surface temperature occur very rapidly with the transition from day to night or night to day.

c. Radiation - Two principal types of penetrating radiation are of interest: solar and galactic cosmic. Flux rates and solar flare events levels have been established within a factor of about two.

d. Meteoroid Impacts - Size and flux of these high-velocity particles have been estimated, but there is no empirical information on which to assess the reliability of these estimates.

e. Gravitational Attraction - Value at the lunar surface is one-sixth of that at the earth's surface, or 5.31 ft/sec^2.

The establishment of any type of facility in such a hostile environment will be a very difficult task. Due to the current state-of-the-art in many fields, it is impossible to determine just how difficult such a task may be. For example, consider the design of a personnel shelter. Since there is no atmosphere on the moon, personnel shelters must be sealed and pressurized to an earth-like atmosphere. Before such shelters can be designed, we must know how materials will behave under high vacuum and extreme temperature ranges. We must insure that meteoroid particles will not puncture the pressure vessel; therefore, we must have information about the effects of hypervelocity impacts on materials. The shelter must also provide protection from ionizing radiation.

As in all lunar systems, the shelter must be designed for extremely high reliability. Since NASA estimates a cost of about $5,000 to transport a pound of material to the moon, our guide for selection of materials and systems stresses lightness and reliability rather than the cost.

The Army Corps of Engineers has been considering seriously the problems of lunar construction for several years. As the primary governmental construction agency, the Corps of Engineers must be prepared to undertake whatever construction mission may be assigned, regardless of its nature or location. One recent effort was a lunar construction research study completed last year.

The purpose of this study, conducted at the request of NASA, was to define the research and development effort required to provide the United States with a lunar construction capability beginning in 1968. Comprehensive studies were made of several engineering areas considered to be of major importance in developing a lunar construction capability. These studies identified many of the problem areas in the design and construction of lunar base facilities and outlined appropriate research and development tasks. These tasks were then integrated into a time-phased plan of action for achieving a lunar construction capability on a schedule compatible with NASA thinking for manned lunar exploration.

Results of studies in some of the problem areas are summarized briefly below:

a. Construction Materials - It appears that current materials technology will meet the needs of most lunar construction design problems. Improvements in present design concepts should result, and answers to yet unsolved materials problems can be anticipated. However, existing data on materials for space applications have been, for the most part, produced and assembled in isolated and uncoordinated activities. This information needs to be assembled, correlated and placed in a form for application to lunar construction problems. Research needs to be initiated for some materials applications such as studies in thermal balance and investigations of lubricants, lubricating techniques, and heavy duty bearings. Testing standards need to be developed for evaluating materials behavior under environmental conditions.

b. Structural Systems - Structural systems will include shelters, maintenance structures, chemical storage containers, communication antennas, towers, and smaller structures such as power and life support modules. Whereas extreme reliability is essential in every aspect of lunar construction design, the high delivery costs demand the optimum in exact analysis and design. Reduced gravity and the absence of certain external loads common in terrestrial design will help in obtaining high performance, lightweight design. Reliable astrophysical data and procedures are needed for appropriate analysis by computers for design optimization.

c. Construction Tools, Equipment and Techniques - The construction tasks to be performed on the moon may be similar to terrestrial construction in many respects. However, many of the tools, equipment and techniques to be employed in these lunar tasks will probably not resemble their terrestrial counterparts. Restraints imposed by the lunar suit, the phenomena of constant mass and reduced gravity, and other environmental conditions will introduce unprecedented design parameters in the development of equipment and procedures. Manual procedures and equipment will be required for unloading spacecraft and subsequent transportation and handling of payloads. Some surface modification may be required. Excavation for placement and protection of base facilities may be the most difficult and critical of all construction operations. Research and development are needed for surveying and mapping instruments, special anchoring devices, and a family of hand tools and other multi-purpose devices for construction, operation and maintenance of the base.

d. Electric Power. Considerable work has been done in developing electric power and equipment for use in spacecraft and satellites, but no great amount of research has been directed to the problem of developing the sizes and types of electrical equipment required in a lunar base. Fuel cells, batteries and solar cells are promising sources for initial power demands of lunar exploration systems. However, the power system supporting any lunar base should include a prime power source with decentralized and mobile power units which may be integrated into an expandable base complex. Considering the probable power requirements for a permanent-type lunar base, nuclear power is the optimum choice as prime power source; however, solar systems may well be used for certain tasks. Early definition of power requirements is essential because of the long time and major effort required to develop a suitable plant.

The Corps' study concluded that a lunar construction capability does not exist today, but it must be developed if landings on the moon are to be exploited. A three-part program was recommended for achieving this capability. First, a comprehensive lunar base study to define detailed concepts and planning for lunar bases. This master plan will establish base requirements and will then identify, define and schedule all significant construction and engineering capabilities required. It will also define performance requirements of related man-systems and space transport vehicles.

Second, the initiation of a technical engineering development program. This integrated program was based on the series of studies discussed previously in each of the major engineering areas involved in lunar construction.

The third part of the recommended program concerned terrestrial facilities needed in the development program. Two of the facilities are of special interest.

The Operations and Test Facility shown in Figure 17 is a large "field house" type of facility which provides a lower-order simulation of certain lunar phenomena under ambient earth atmospheric pressure. The interior of the light-tight building will be finished in black to simulate deep space, and lighting conditions on the moon will be simulated. A portion of the floor will be covered with a lunar soil simulant. In this facility, real-time studies, tests, and evaluations can be conducted on facilities, equipment, and systems concepts. It will also be used for testing and training of personnel. This facility will provide an essential bridge between the capabilities provided by natural terrestrial field sites and the costlier capabilities of a high-order simulation facility.

In the final analysis, however, sufficient reliability cannot be achieved until the combined performance of integrated man-machine-materials systems is demonstrated in the highest level of environmental simulation that is economically possible. For a lunar construction research program it is essential that the simulated lunar environment include the lunar surface for testing of equipment, base components and personnel performance on or within the simulated surface material. A review of existing and planned facilities indicated that none would achieve this capability. Therefore, performance specifications and preliminary plans were developed for such a Lunar Environmental Simulator, which is shown in Figure 18.

The chamber would be 65 feet in diameter and approximately 91 feet high. Lunar surface material simulant can be placed in a container 55 feet in diameter and the depth can be varied from 3.5 to 17 feet. An off-axis xenon-lamp system would simulate solar radiation over an area 20 feet in diameter. Intensity of illumination could be varied to simulate lunar-day and lunar-night operations. The vacuum system would include mechanical roughing pumps, diffusion pumps, and cryopumping panels of gaseous helium. The system is designed to maintain test pressures at or below 10^{-5} torr.

Last July, NASA began a study program to outline a tentative lunar base concept. The concept being studied envisions a flexible, building-block approach for the lunar base. The simplest base will consist of a single module. Other modules will be added for larger bases or for extended missions. These modules are described below.

a. Personnel Shelter. The basic module of the lunar base system will be a shelter designed to house several men. It will have integral life support, power and communication equipment, and could function virtually alone as the principal element of a small temporary outpost. In larger installations, separate subsystems will provide additional capabilities for life support, power and communications, and the equipment installed in the shelters may be retained primarily as standby for emergency use. In emergencies the shelter should be able to house twice its normal complement of personnel.

b. Life Support. All but the most temporary outposts will be served by a central life support subsystem. The subsystem will consist of several modules, the number being dependent on the population of the base and the desired degree of logistic independence. Installations in an early phase of development or small installations for short missions will be served by modules which perform only the most essential functions. In larger, more permanent installations the basic life support modules will be supplemented by regenerative equipment to reduce the need for resupply. The ultimate base complex may include additional modules to generate life support materials from lunar resources.

c. Power. For other than the smallest installations, nuclear power plants will serve as the basic source of energy. A single plant may be used for short missions and during the early phases of base development, but multiple plants of standard design will be the usual source of power.

d. Vehicular Fuel. The vehicles and equipment required for construction and operation of the base will require substantial amounts of energy. This energy will probably be in the form of chemical fuels. In the smallest installation the fuel subsystems will consist of modules which only store and dispense this fuel. To reduce the logistic burden to a minimum, larger installations will be equipped with additional modules which regenerate fuel using energy drawn from the nuclear power plants. In the ultimate base, additional modules may make up fuel system losses by generating fuel materials from lunar resources.

e. Communications and Control. The basic module of this subsystem will provide local and Moon-Earth communications. In addition, it will serve as a navigation aid to spacecraft. Other equipment may be required to provide long range lunar communications and to permit personnel on earth to assume some of the burden of operating the power, life support and fuel systems.

f. Maintenance. Maintenance modules will provide installations of various sizes the capability to maintain vehicles and installed equipment.

g. Vehicles and Mobile Equipment. Construction and operation of a lunar base will require vehicles for materials handling, surface modification, transportation and reconnaissance. Multiple-purpose vehicles may be practicable.

h. Mission Support Equipment. Specialized equipment to support specific scientific missions will be needed.

The study program, now referred to as a study of Lunar Exploration Systems for Apollo (LESA), is divided into three phases. Phase I is an initial concept study to define a reference system which serves to guide the other studies toward a common objective. Phase II is a number of studies of the various subsystems which examine in detail the engineering and operational implications of the base concept. Phase III is an integrated conceptual design study which will re-examine the initial reference concept and incorporate changes indicated by the subsequent subsystems investigations.

The initial concept study was completed by the Boeing Company last December. Four phases were selected in this study to represent activity levels as the lunar base evolves from a small temporary base to a more permanent base which will accommodate more persons for longer durations and increased mission activity. The four base models provide logistic support for 3 men for 3 months; 6 men for 6 months; 12 men for 12 months; and 18 men for 24 months or longer.

The shelter module shown in Figure 19 is designed to be a basic, self-sufficient, support nucleus. All support subsystem modules required in the first base are an integral part of the shelter module. The 25,000 pound payload capacity of the Saturn V transport system also permits a roving vehicle to be carried in the lower part of the basic module.

The interior volume of the aluminum shelter provides sufficient space for six men. Thus, when the base expands to the six-man crew level of Base Model 2, all personnel can still be accommodated in one shelter module. However, additional radiation and meteroroid shielding is required for the longer duration of Base Model 2. The shelter concept provides a caisson as an expandable outer shell of the module. This caisson is expanded about two feet and filled with lunar soil to provide the necessary shielding. Lunar soil is also placed on top of the shelter. Additional life support supplies, power units, fuel modules, and other supplies and equipment required in Base Model 2 will be delivered to the lunar surface as a single Saturn V logistic payload.

Base Model 3 is established by delivering a second shelter module to the lunar surface; positioning it next to the first module; and connecting the two modules. Additional equipment and supplies are delivered as separate payloads. Finally, another shelter module is delivered, positioned and connected to form Base Model 4 shown in Figure 20. Also shown in this figure are the logistic support payloads used to deliver additional supplies.

Most of the comprehensive subsystem studies in Phase II of the LESA program are just being initiated now. However, at the beginning of the program it was believed that two subsystems -- the nuclear power plant and an engine and regenerative fuel system -- would probably most strongly influence the overall base design and might present the most serious development problems. Thus, these studies being done by the Westinghouse Electric Corporation under supervision of the Corps of Engineers, were started last September.

The objective of the multi-purpose engine-fuel system study is to define a concept for a complete system which will provide the power required for the initial shelter module, portable applications, and lunar surface vehicles.

During the early phases of manned lunar operations, the system will be a simple lunar refueling system which will be completely dependent upon resupply from Earth. As the lunar base grows in complexity and power demands increase, base requirements will be furnished from a nuclear power plant. When this occurs, the engine-fuel system can be supplied with fuel regenerated from the engine reaction products by a processing plant operated from this prime nuclear plant. Thus, dependence on earth resupply will be reduced. Ultimately, it may be possible to achieve further independence from earth by using natural lunar materials if their use as fuels proves feasible.

In the engine-fuel system study, possible power systems were evaluated in terms of engineering, techno-economical, and qualitative considerations. When these factors were combined, a comparison of the possible systems could be made for each application. Five basic sources of energy were investigated: solar, thermochemical, electrochemical, cryogenic, and radioactivity. Both static and dynamic engines were evaluated. The recommended systems resulting from this study which has just been completed, can be described in terms of the principal applications of the multipurpose engine-fuel system.

A solar cell and fuel cell combination is used for the shelter power system to meet the moderate requirements of Base Models 1 and 2. Since there is no atmosphere to absorb solar energy, the sun provides 130 watts of energy per square foot on the lunar surface. Maximum use is made of this free energy for the relatively constant demands in the shelter module. A solar photovoltaic engine composed of silicon cells produces direct current power from direct conversion of sunlight to electricity. The solar engine consists of a flat array of inter-connected cells supported by a framework which is oriented with respect to the solar flux by means of a simple drive mechanism.

For the lunar-night power supply, a hydrogen-oxygen fuel cell is used. This type of fuel cell has several attractive advantages. One is the modular design inherent in the fuel cell itself. This means that power can be provided in as small a block as necessary or can be extrapolated to meet requirements while retaining good fuel characteristics. Another advantage in using hydrogen and oxygen is that the product of their combustion is water. This water can be used to meet life support requirements or it may be regenerated into the original fuels with an efficiency that makes regeneration in the later bases an attractive part of the energy plan.

In moving applications, it was considered impractical to use a solar engine to reduce logistic weight because of the difficulties of orienting the solar cell array. Thus, only a fuel cell is recommended for vehicle engine systems. Optimization of engines for vehicular applications is very difficult until specific mission requirements are established. For long operating periods without refueling, it may be necessary to use an isotope-power system which would require biological shielding.

A silver-cadmium battery is the preferred system for portable power requirements of 1 kw or less. For this application, the primary requirements are simplicity, convenience, light engine weight while in use and minimum bulk. The silver-cadmium battery is hermetically sealed and produces a given amount of energy for a given weight. Thus, the power level is flexible, i.e., a large power can be drawn for a short period or vice versa. For the larger portable power supply, the preferred engine is the fuel cell.

The nuclear power plant study, still underway, is investigating nuclear reactor power system which could meet the major power demands of the larger lunar bases. The initial base concept study indicated that startup of the first nuclear power plant becomes economically appropriate when Base Model 3 is established. The high costs of unscheduled power outage resulting from large costs for transportation of back-up power systems and fuels, and from high costs due to loss of base functions both in terms of dollars and possible complete disaster, place heavy premiums on high plant capacity, long plant life and very high reliability.

Figure 21 shows the nuclear power plant module as it would be delivered by a Saturn V logistic vehicle. Possible over-all plant arrangements and associated modes of packaging range from a relatively low capacity plant with integral shielding (i.e.,brought from earth) and a fixed radiator to a potentially much larger plant with all or much of the shielding accomplished by lunar material (e.g., by burial of the reactor) and a deployable radiator. An integral shield would take up a large portion of the available payload weight. However, such a concept has advantages for the early plants because of their small demand on the limited available construction effort and their insensitivity to lunar surface characteristics.

The concept being developed envisions locating the plant about two miles from the personnel shelters. This separation distance provides sufficient radiation attenuation so that the plant shielding can be reduced to an acceptable payload weight. Studies of electric power transmission from the plant to the base proper have indicated that it is feasible to transmit over this two-mile distance with a transmission system of modest weight. A typical lunar base transmission line would consist of bare conductors, operating at elevated temperature, losing heat essentially only by radiation to space. The conductor would probably consist of several parallel conductors with multiple interconnections so that the transmission system could withstand meteroroid hits and still function.

The nuclear power plant concept currently being investigated in the study is shown in Figure 22. There are reasonably well developed technologies on which to base a design which has a good probability of meeting the program objectives. There is, however, no existing plant which will fit the anticipated requirements of the lunar base. Thus, an aggressive development program is required. The present concept is for an initial plant rating of at least 100 kwe and a growth potential to 300 kwe. The reactor will operate at a high temperature and use an enriched uranium fuel. The power conversion system will be a liquid metal Rankine cycle.

One of the important constraints on engineering a power plant for lunar use rather than terrestrial operation is that heat must be rejected by radiation. Thus, a radiator is required for space electric power generating systems. However, the meteoroids present in the space environment make it necessary to provide sufficient armor for the radiator to prevent meteoroid penetration which would release the coolant. If all the coolant is lost,the plant becomes inoperable. To improve the survivability of the radiator, as well as somewhat reducing the armor requirements, multiple radiator loops are used.

The radiator of the proposed lunar nuclear power plant, as can be seen in Figure 22, is composed of about one hundred closed end tubes. At the base of each tube is a bellows joint with a mechanical hinge that permits deployment of the radiator as shown in Figure 23. In this position the total radiator area is approximately twice that available on the surface of the capsule if the radiator were not deployed.

This two phase, natural circulating, refluxing radiator also takes advantage of the lunar gravitational force. The turbine exhaust vapor goes into a large manifold which contains small boilers attached to the end of each of the radiator tubes. These boilers contain liquid potassium. The vapor from the turbine condenses on the boilers; the liquid metal boils; the metal vapor rises into the tube where it condenses on the surface by radiation; and the liquid then drips back into the boiler.

Concepts for other subsystems will be defined in detail in the other Phase II studies of the LESA program. When the integrated concept study is completed in Phase III, NASA expects to have a sound and comprehensive plan for a lunar base system.

CONCLUSION

This paper has covered briefly some of the broad engineering and construction support which the Army Corps of Engineers is putting behind this nation's manned space program. The first phase of the journey to the moon will be right here on the ground.

Our future successes in space are dependent on the nation-wide effort which NASA directs and spearheads, but certainly an important element of this is the accelerating program to provide the complex ground support facilities required throughout the effort. This program involves design of highly sophisticated structures, much of it to criteria which transcend the state of the art; development and procurement of special and unusual components which tax the capabilities of the industry; and construction to tight schedules and exacting standards which are foreign to the industry.

The next phase of our manned lunar landing program will be the support facilities required on the moon. Providing these facilities will require solving unprecedented engineering problems imposed by delivery systems limitations and the harsh environment about which there is little information. A significant development program is needed to develop the equipment, techniques and reliability necessary for this difficult task. Such a program must be started now if we are to have an orderly program rather than a wasteful, crash program later -- wasteful in terms of personnel, materials and funds.

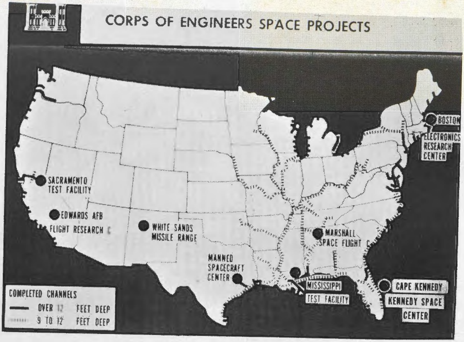


Figure 1.

Figure 2. F-1 Engine Undergoing Static-Test on Stand Constructed by Corps of Engineers

Figure 3.

Figure 4.

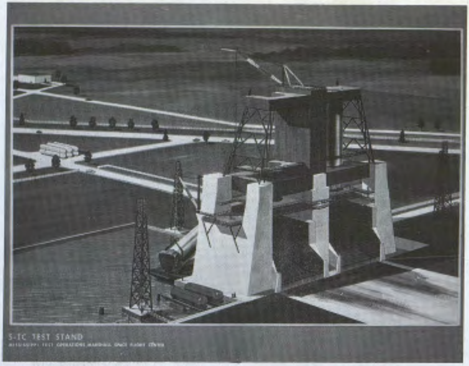


Figure 5. Dual position stand at Mississippi Test Facility under construction.

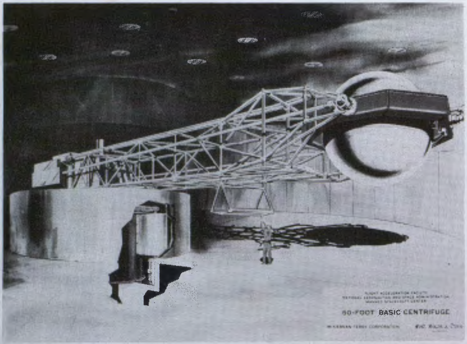


Figure 6. Huge Centrifuge being constructed at the Manned Spacecraft Center near Houston, Texas.

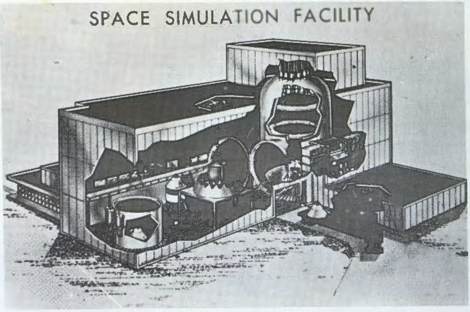


Figure 7. Space chambers going up at the Manned Spacecraft Center.

Figure 8. Artist's concept of completed Manned Spacecraft Center.

Figure 9. Cape Kennedy as it looks today.

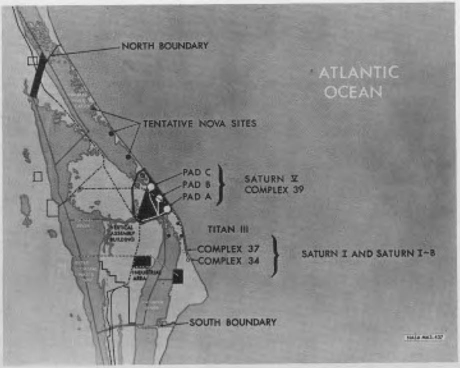


Figure 10. Map of Cape Kennedy and adjacent Merritt Island launch area now under development by Corps of Engineers.

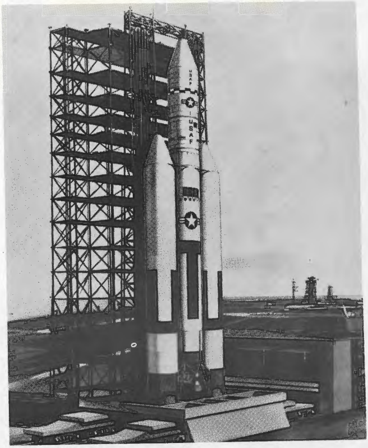


Figure 11. Titan III launch pad being constructed for the Air Force.

Figure 12. Complex 39, under construction for NASA, will become the Nation's Moonport.

Figure 13. Close-up view of the Vertical Assembly Building and Saturn V on crawler-transporter.

Figure 14. Saturn V shown lifting off on flight to Moon.

Figure 15. The Moon as seen through a telescope.

Figure 16. Topographic map of moon shows area where initial manned lunar landing will be made.

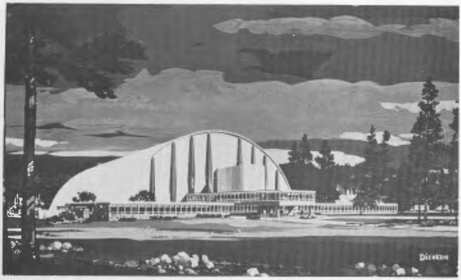


Figure 17. Proposed Operations and Test Facility for simulating certain lunar phenomena.

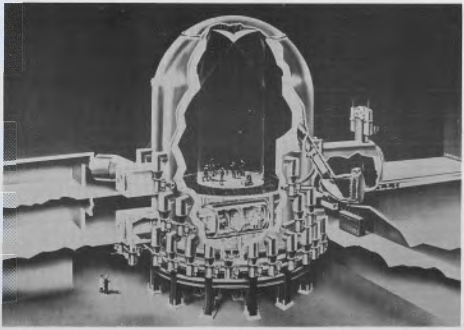


Figure 18. Environmental simulator needed in a lunar construction research program.

Figure 19

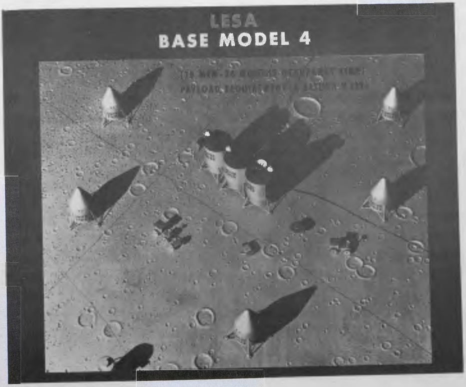
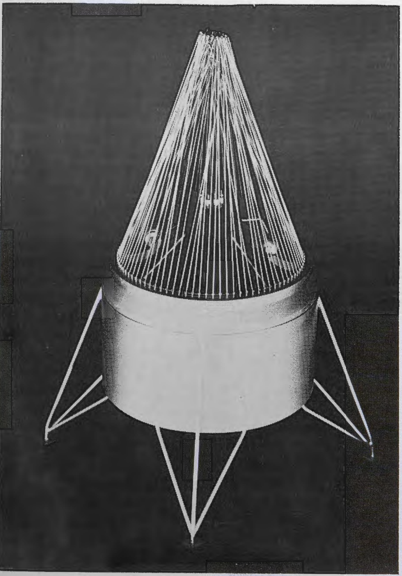


Figure 20

Figure 22.



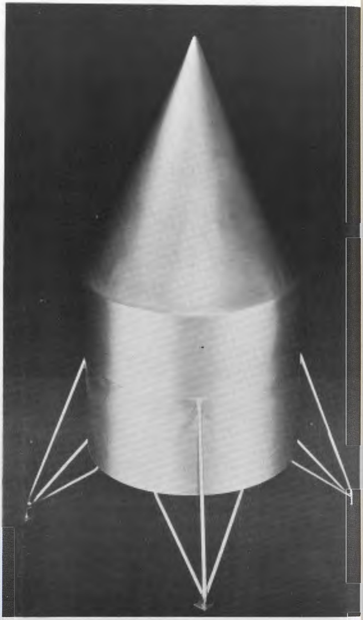


Figure 21.

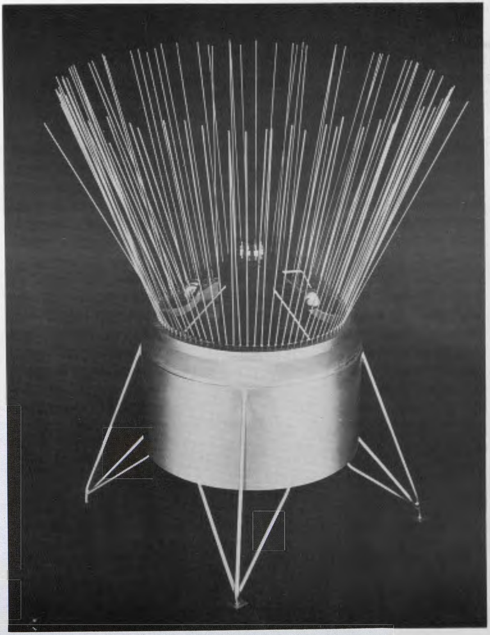


Figure 23.