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Design Criteria for Buildings on the Moon

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During this revolution it turns exactly once on its own axis so that it always presents the same side to Earth (but the Sun illuminates all points on the Moon at some time during this revolution.) The Moon wobbles a bit so that actually we see about 59 percent of its surface.

Its diameter is 2160 miles, approximately \( \frac{1}{4} \) that of Earth, but its mass is only \( \frac{1}{81} \) that of Earth; thus its density (pounds per cubic foot) is only 0.61 times that of Earth or about 280 pounds per cubic foot. From this we derive, from Newton's universal law of gravitation, a most significant and important result, namely, that the gravitational attraction at the Moon's surface is only 0.165 (approximately \( \frac{1}{6} \)) that on the surface of Earth. Thus on the surface of the Moon every object will weigh only \( \frac{1}{6} \) as much as on the surface of Earth. The mass of each object is, however, independent of its location. In design one must continually keep the distinction between mass and weight clearly in mind.

The environment of a building on the Moon differs markedly from its environment on Earth. The Moon has no observable atmosphere. There is no haze, no clouds, no winds, no rain or snowstorms. The building is either bathed in intense sunshine or looks upon stark, black, cold Space. It will be continuously plagued by a great gnat-like rain of interplanetary dust.

The Moon has lost its atmosphere, if it ever had any, because of its small size and, hence, low gravitational pull. The velocity of escape from the Moon is quite low, 1.5 miles per second, as contrasted with 6.9 miles per second for that of Earth. The gravitational attraction of Earth is strong enough to grip and hold to it the nitrogen and oxygen molecules
that form our atmosphere. This is not the case on the Moon. The thermal velocities of the gas molecules are sufficiently high that if gas molecules were ever present, they would long since have wandered off into Space. A few molecules of heavy gases such as carbon dioxide, krypton, and xenon may have remained behind or may be seeping out from the Moon's interior but these are not significant. Thus the atmospheric pressure is zero, and any building constructed there must be internally pressurized with an atmosphere in which human beings can survive.

The Moon's surface, unshielded by an absorbing atmosphere, can feel the full force of the Sun's rays and become extremely hot on one side while the other side will quickly have radiated its heat into Space and become exceedingly cold. Day and night on the Moon are each about two weeks long.

The temperatures on the surface of the Moon have been carefully measured, using a telescope equipped with a vacuum thermocouple. On one occasion this was done during an eclipse and it was found that the surface of the Moon cools very quickly, reaching a low temperature in 20 or 30 minutes after the Sun stops shining. The temperature at lunar midday is 214° F; at sunset —32° F; and at midnight —243° F. It is possible to guess the sort of temperature environment, maximum and minimum temperatures and rates of changes in temperature, any structure placed on the Moon will be subjected to. Any structure placed there must be able to withstand these extreme temperatures and especially the tremendous temperature gradients.

The ultraviolet radiation, normally absorbed by Earth's atmosphere, will be sufficiently intense to render panes of glass or plastic useless as windows. Thus, shutters for such windows must be provided.

The Moon is continually bombarded by particulate matter: cosmic rays, charged particles, and meteoric particles. Not much is known about the rate of influx of cosmic rays although recent records from Explorer III indicate that they are considerably more abundant in space than we have thought. They probably do not present a health hazard but they may be sufficiently abundant to discolor glass or plastic after long exposure.

It is also not possible to define accurately enough the nature and distribution of meteoric matter to estimate it as a potential hazard to lunar structures. Extraterrestrial material exists in three forms: the most abundant by far is interplanetary dust, the dust which forms the zodiacal light, a faint band of light seen extending from the Sun at the end of twilight; the next is debris from comets, which, when they streak through our atmosphere produce intensely luminous trails, called meteors, and, lastly, the meteorites, probably great masses of stone and iron and fragments of planets which once resided between Mars and Jupiter in our solar system. The interplanetary dust ranges in size from 1 to 300 microns in diameter; meteors are fragile, porous bodies of low-gross density; and meteorites are solid chunks of iron and stone. The velocity with which any of these might strike the Moon ranges from 1.5 miles per second to about 44 miles per second. There will be no atmosphere to check its velocity as is the case with Earth, where the interplanetary dust and the meteors are rendered impotent.

The fall of a meteorite is a relatively rare event; about five per day reach Earth. Interplanetary dust is by far more abundant in Space with the abundance of this dust in the vicinity of the Moon being about 5 x 10^-21 grams per cubic centimeter. The Moon sweeps up this material at the rate of 110 tons in a 24-hour period.

Thus the chance of a large building being struck by a meteorite or a meteor is negligible, one hit in perhaps several thousand years. Interplanetary dust is the real hazard, and we do not know how great it is. The particles are small; and even though of great velocity, they could be easily warded off with an umbrella-like shield. The best estimate is that about three or four particles, with diameters ranging from 0.0002 to 0.0004 inches, would strike each square yard of exposed surface per day. A meteoric shield must be a part of any structure built on the Moon.
Scale model of a Moon building designed and built by the Wonder Building Corporation of America, as a permanent structure for our Moon explorers. The plastic bubble-type observatory in the foreground is protected from ultraviolet radiation by sliding metal doors. The overhead structure is a meteorite shield to protect the building proper. The dome in the center of the barrier is a traffic control tower. The proposed building would be 340 feet long, 160 feet wide, and 65 feet high.

From a practical viewpoint, the exact nature of the surface of the Moon is our greatest unknown. On a grand scale we know that the Moon's surface is covered with large and deep craters, huge mountain ranges, and vast flat areas. But we can not look at the Moon in the intimate detail needed to provide us with realistic design data for construction. Resolution with our best telescopes is about one mile.

Opinion is now divided as to the nature of the Moon's landscape. At an Air Force symposium on this subject in April 1958, three eminent astronomers summarized their variant ideas:

1. The maria (large dark flat areas) are almost certainly covered with lava and will make firm landing spots for Earth's spaceships.

2. The rock has turned slowly to dust by bombardment of rays and particles from the Sun and Space. The dust, kept stirred up by the same agents that formed it, has flowed like a slow liquid into the Moon's low places so the maria are not filled with lava, but with dust perhaps several miles deep. Dust near the surface may be as fluffy as baby powder. Unwary ships might disappear in dry quicksand.

3. Although the Moon may have plenty of dust, its surface has been solidified. There may be a thin layer like dust on a grand piano, but the underlying material, cemented together (not stirred up) by bombardment from Space, is probably "crunchy" and strong enough to support air alighting spaceships.

With this lack of knowledge and great divergence of opinion, we can only design for the worst condition: a sea of dust upon which we must float our structures.

Without defining the specific function of the building we know that it must provide for the following:

1. Living quarters, including rooms for sleeping, cooking, eating and recreation.

2. Physics, chemistry, and biological laboratories.
3. A control tower for communication, meteorological studies, earth observations, astronomical observations, traffic control, etc.

4. Air conditioning, heating, power and refrigeration plants, oxygen production units, extreme-temperature regulating devices, water supply and sewage disposal plants.

5. A machine shop and equipment maintenance area. Further, we know that the structure must be built as an integral floatable unit.

We assume the following: (1) that the location of the building on the Moon will be fixed; (2) that the building will be constructed from materials brought from Earth; (3) that the building will provide the functions listed above; and (4) that it will be a permanent-type building in the sense that it will be occupied on a continuing basis for several years.

A Moon building presents its own peculiar problems, and first is the matter of gravity. The force of gravity on the Moon is approximately 1/6 that of Earth. This means that the deflection of a cantilever beam or any other load-supporting beam or column will be only 1/6 as great as it would be on Earth. Changes in gravity will not affect the strength properties of the materials. For design purposes we can, in static situations only, replace the gravity of 32 feet per second which repeatedly appears in our strength of materials formulas by 1/6 its value, say five feet per second. A whole new field of design is opened up.

We must, however, be wary of any dynamic situation. We do not change the mass of our material by transporting it to the Moon. It would be just as difficult to accelerate a car on the Moon as it is on Earth. Thus, designs involving vibratory or rotary motion must conform to the normal Earth pattern. An electric generator designed for Moon use would not appear substantially different from an earthly one.

Reduction in gravity will influence the convective flow of air and the rate of flow of liquids downhill. These changes are likely to become important in design of the heating, power, water, sewage, and ventilating system.

Ramps and stairs can be much steeper because man will be able to lift himself with 1/6 the effort required on Earth. A crane designed for a one ton load on Earth can be lift at least six tons on the Moon. We must, on the other hand, be careful with our elevators for here we are accelerating and decelerating masses.

No consideration need be given wind or snow loads since they will not exist. Our major stresses now come from the artificial atmosphere contained within the hermetically sealed building. Normal atmospheric pressure, 14.7 pounds per square inch, is a realistic figure to use for design purposes; 10 pounds per square inch would be sufficient. The problem is not unlike that encountered by the designers of high-flying aircraft except perhaps in one respect which could be significant. On the Moon we can play the gravitational forces against the air pressure forces, achieving some kind of equilibrium which may gain us an advantage. This is a matter that needs looking into. Broad expanses of curved structures can be used, but we must tie the whole together with rods or similar means so that it does not explode.

Rapid, intense heating and sudden, severe cooling present difficult but certainly solvable design problems. The parts of the structure becoming shaded will immediately become very cold, while those in the Sun will remain heated to a high temperature. During the lunar day, when the Sun is upon the structure, devices must be provided to regulate the influx and efflux of heat. These should be tied together to the heating and ventilating systems. But we must also be prepared to be without our principal energy source, the Sun, for two weeks at a time. This means providing energy storage facilities of no mean proportion.

The potential hazard from cosmic rays, while still one of the big unknowns, is probably not great enough to warrant modifying building practices. Eventually the living quarters may be lined with thin sheets of lead.

The bombardment by meteoric matter is serious but can be dealt with. The best approach is to use the scheme long in use by tent dwellers to protect themselves from the
fury of rainstorms; a canvas canopy covering, placed above and separated some distance from the roof of the tent, which dulls the force of the impact of the raindrops and diverts the material away from the roof of the tent. On the Moon, the canopy must be of a metal, with a thickness sufficient to stop meteoritic dust. A 1/32-inch thick aluminum shield should be sufficient. We cannot hope to protect against chance encounters with large meteoric bodies anymore than a canvas shield protects against large hailstones. Provision should be made for replacing sections of the shield as they become damaged.

Finally, we are concerned with foundations for the building and here is the greatest difficulty. There seems to be but little else to do but to design the building as a structure which floats in a stationary ocean of dust, anchored in place by large, heavy blocks suspended by long cables from the body of the structure. In many ways its construction will resemble that of a ship at anchor, a freely-floating, self-contained unit. The building need not be streamlined. Fortunately, also, it need not be built to withstand the tumultuous forces exerted by a watery ocean. The dust on the Moon is as calm as a mild pond.

According to Archimedes' principle a body immersed in a fluid is water buoyed up by a force equal to the weight of the fluid it displaces. A 10,000-ton ship, for example, has 320,000 cubic feet immersed when it is floating. Now, how will the dust ocean act in this respect? We are safe in concluding that it will act as a fluid of low density: for design purposes, about 0.5 times the density of water or 30 pound per cubic foot. Thus the lower part of our building will be covered with dust, the volume, V, so covered being given by

$$V (ft^3) = \frac{\text{Total weight of building (pounds)}}{30}$$

The dust will tend to support the lower floor or hull. At a 6.6-foot depth, the pressure acting on the floor will be just equal to atmospheric pressure. If the hull is embedded to depths greater than this it must be designed so as not to be crushed by the weight of the dust.
Since the building is floating, weight must be fairly uniformly distributed if it is not to topple over or settle unevenly.

If the Moon's surface proves to be sufficiently solid, it will provide normal support for the building and may be used as foundation blocks.

There is no one building uniquely qualified for placement on the Moon. Design requirements allow as well as demand a diversity of structural types, proportions, materials and forms. The Buck Rogers portable and inflatable plastic balloon house is a perfectly practical type of temporary housing.

Permanent housing must be fabricated from more durable materials. Aluminum suggests itself immediately because of its high strength, low weight, and ease of fabrication. Aluminum also provides a good reflecting surface which aids in cooling problems.

The basic elements of the Wonder Building Corporation of America's "Truss-Skin" roof system are well suited for construction of Moon buildings because of its great flexibility and versatility. Some details have necessarily been modified, including the development of means for hermetically sealing the structures.

The basic scientific information needed to complete first designs of functional and attractive buildings for use on the Moon are at hand. Our task has been the very specific one of taking these scientific guide lines and producing a practical model.

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