

# DESIGN OF A MICRO-GRAVITY SPHERICAL SPACE HABITAT

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## Abstract

The paper examines the problem of converting a large spherical metallic shell in space, rotating once each 24 hours, into a desirable human habitat. A design equation for sizing window and cooling surface, as a function of solar distance, is developed. Shell coating, agricultural land creation and irrigation drainage problems are considered along with the advantages of a larger sphere size in coping with the catastrophe of shell damage or cooling system failure while also providing the possibility of cooling air flow and water flow without pumps. The Location and angle of the axis of rotation are discussed as are the pleasure and problems of micro-gravity living Rate of Rotation.

## Introduction

Diameter, location, internal temperature, lighting, window size, rotation rate and cooling area location and size all must be selected to design a habitable sphere in space. After a rate of rotation and window location are chosen, equations defining window size and cooling area size, as a function of the other parameters, can then be developed from a heat balance. The design analysis then seeks to determine the design features that will allow the habitat to maintain a safe human environment in spite of catastrophes and system failure.

## Rate of Rotation

Suppose we can produce a hollow metallic sphere, 1/8 inch in thickness and several miles in diameter, in an orbit around Venus. What are the design decisions required to transform this barren metallic hulk into an inviting world, that people would chose to call home?

Design decision number one, the sphere's rate of rotation: There is no possibility of spinning a sphere, this large, at a speed that would simulate Earth's gravity. It would be torn apart. Why not assume that medical science will find a solution to the human body's difficulty in coping with low gravity.

If our bones no longer fix the sphere's rate of spin, one obvious choice is the rate of rotation that several million years of evolution have accustomed all living things on Earth to consider normal. A sphere, rotating once each 24 hours, with a window at the equator filled with sunshine during the day and stars at night, is an option, and one well worth exploring.

## Interior Coatings

The construction of a window many square miles in size, to light the sphere, may not be that difficult. There are no vapor pressure limitations on the size of a glass bubble, that may be blown, inside of a metal sphere in space. The high vapor pressure instability, of surface tension shaped liquid spheres in a vacuum, can be prevented with only a fraction of one psi pressure inside a sphere.

No matter how large the metal sphere, a glass bubble can be expanded to coat the metal shell's interior. A window, plus a glass film to protect the shell's interior from corrosion, could be achieved this way. To retain shell strength the window area of the shell might admit light by cutting small holes in the shell, forming a screen, to be covered by the expanded glass bubble.

Almost any solid material can be expanded inside the pressurized sphere to increase the wall thickness. The slag waste products, produced while refining metal for the shell might be used. This rock layer will act as a barrier the to radiation and the temperatures extremes of space. The rock will also add strength to the sphere. Stress at the equator, caused by a once a day rotation, is less than 2 psi, not the tens of thousands of psi stress, in a shell rotating in minutes to produce Earth type gravity. The interior coating must produce the equivalent of about 8 feet of steel strength to contain one atmosphere of pressure in a ten mile radius sphere.

The rock layer must not coat the entire sphere. The window, of course, would remain rock free, as would a heat exchange surface at one or both poles of the sphere. A successful design requires a solution to the sphere's heat balance problem.

## Heat Balance

The sunlight entering through the window to light this world, brings in heat, that must be radiated back into space. At the Earth's distance from the Sun, solar energy arrives at a rate of 438 BTU/sq ft/hr. At Venus it is 1.9 times this rate. A 70°F air

mass inside the sphere radiates at about 111 BTU/sq ft/hr. This radiation flows out the window 24 hours a day, while the Sun shines in only 12 hours a day. Still, the radiation out the window removes only half the solar energy, entering in an Earth orbit, and a quarter the energy entering in a Venus orbit.

If the excess heat is not removed, the interior air temperature will rise, until it radiates energy at the same rate that the energy arrives from the Sun. This is 170°F in Earth's orbit and 354°F in Venus's orbit. These temperatures are independent of the size of the windows. Most of the sphere's outer surface will be designed to reflect solar heat. But an area, near the pole, must be sheltered from the Sun to radiate heat.

#### Cooling Load

Near Venus, the window need be only 1/1.9 the size of the window near Earth for the same brightness, inside the sphere. A reasonable load of cooling, for these spheres to handle, would be about 1/4 Earth's sunshine. This is not a dim world. The difference between a bright sunny day and a over-cast day is a factor of 12 in Sun brightness. To produce this much light in a Venus orbit the window's size would be  $1/(4*2*1.9) = 6.57\%$  of the sphere's surface. With an average heat input of  $438*1.9/2 = 416$  BTU/sq ft/hr, (416-111) excess BTU/sq. ft./hr. remain to be disposed of by surface radiation.

If a radiation area near a pole is held at a temperature of 32°F, it can radiate into space at about 96 BTU/sq ft/hr. This is only 30% of the rate excess heat enters each square foot of window. To remove the excess heat, the Venus sphere's surface radiation area must be 3.28 times its 6.57% window size or 21.58% of the sphere's surface area. Near Earth a window 1.9 times this size, 12.5%, produces the same Earth brightness.

Here, only 14% of the surface is required to remove the excess heat. In a Mars orbit 41% of the sphere's surface would be required for a window, nearly the entire hemisphere, to obtain the same amount of light, that 6.5% produces near Venus and a 14% window produces near Earth. Still, this large window in Mars orbit will not keep the sphere warm. More heat will escape each night, than enters during the day.

#### Heat Balance Design Equation

The equation used to determine the fraction of the sphere required, for waste heat radiation at the poles, shows the effect of solar distance on a sphere's heat balance. All heat rates (Hx) are in BTU/sq ft/hr, all fractions (Fx) are less than one:

D Distance from Sun AU

He Solar energy rate at Earth	438
Hs Waste heat radiation rate from surface	95
Ha Radiation rate of air out window	111
Fe Fraction of Earth's brightness inside sphere	.25
Fr Fraction of surface for waste heat radiation	
Fw Fraction of surface for window	

$$\text{Solar Input} = \text{He}/2D^2$$

$$\text{Fw} = D^2\text{Fe}/2$$

$$\text{Excess Heat} = \text{He}/2D^2 - \text{Ha}$$

The surface area required for waste heat radiation is the ratio of excess heat rate entering the window, to waste heat radiation rate, times window size:

$$\text{Fr} = [(\text{He}/2D^2 - \text{Ha})/\text{Hs}] * D^2\text{Fe}/2$$

$$\text{Fr} = [(\text{He}/2 - \text{Ha}D^2)/\text{Hs}] * \text{Fe}/2$$

#### Solar Distance for Zero Cooling

The waste heat radiation area required goes to zero when:

$$\text{He}/2 = \text{Ha}D^2$$

$$D = \sqrt{\text{He}/2 * \text{Ha}} = \sqrt{1438/2 * 111}$$

$$D = 1.4\text{AU}$$

Mars is located at 1.524 AU. Not enough heat comes through a Mars window to maintain warmth. No excess heat is available to power an atmospheric water pump.

#### Cooling Near the Sun

The heat rates in the above table are essentially constants and would exist at any distance from the Sun. If we plug them in to the waste heat area equation, we get an unexpected result:

$$\text{Fr} = [(438/2 - 111D^2)/95] * .25/2$$

$$\text{Fr} = .288 - .146D^2$$

As D goes to zero, near the Sun, a maximum surface area for waste heat radiation is reached, at less than 29% of the sphere's surface. The window size shrinks to a crack, but still maintains brightness. Heat radiated out the window is negligible. Of course, there are practical problems in living very close to the Sun, such as the efficiency of the sphere's heat reflection surface (not included in the equation), but it is likely that these sphere habitats would prosper inside the orbit of Mercury.

## An Orbit Near Mercury

At Mercury, window size shrinks to  $(.387)^2 * .25/2 = 1.7\%$  of surface area and radiation surface is 26.6% of surface area. Window plus radiation area at Mercury are 28.3%, only a little more than the 28.2% area required near Venus, or the 26.5% required near Earth. Low gravity Mercury is a likely source for construction material for sphere habitats. Its high metal content may mean that some of the rocks, that formed Mercury, have been through the solar distillation process, recommended for extracting metal from space rocks for sphere construction.

## Air Cooling

To remove excess heat by polar radiation, the sphere's air must be moved past the polar surface, to give up its heat. If humid air is cooled from 80°F to 50°F, the volume of air to be moved is an easily remembered value of about 1 cubic mile hour of air for each 100 square miles of sphere surface, radiating into space at 32°F.

## Irrigation Water

In addition to maintaining air temperature, this method of cooling produces a marvelous bonus. Up to 1.38 lbs. of water/day is extracted by each square foot of cooling surface. When distributed over the remaining surface area, not used for the window or cooling, this much condensation provided 36.9 inches/year of irrigation water for Earth orbit, and 58.2 inches/year in Venus's orbit. This is the correct order of magnitude to satisfy the needs of the farms and forest covering the remaining surface.

## A Salt Sea

Until abundant plant life develops, a boiling salt sea may be required to maintain air humidity and prime the atmosphere's water pump. A body of water is necessary as a sink for irrigation water. Although water is likely to move more quickly by capillary action, than by gravity, in these low gravity worlds, ultimately it should find its way down hill to the equatorial river. The rotation of the sphere, around an axis parallel to its geometric axis, but displaced toward the equatorial window, should create a salt sea opposite the window at the equator.

## Agricultural Land

The agricultural surface of the sphere would be covered with several feet of space gravel over the lava rock. This load will cause no structural problem in the shell. For a sphere radius of 10 miles, gravity produced by once a day rotation is 1/100,000 the gravity on Earth. One pound for each 50 tons on Earth. The gravel will provide soil for plants, added radiation shielding and a self sealing barrier to small

holes in the shell from meteors. Hopefully, heavy metals will have been removed from the gravel in the refining process, to obtain metals for the shell, but soluble salts, such as sodium, are likely to be present. These salts need to be leached from the soil to improve fertility.

A black spot, in the shiny reflective outer surface of the sphere, located under the salt sea, will heat the salt sea each night as the Sun passes over the spot. The ratio of heat retained, to heat returned to space, will be about the same as through the window. The sea could be brought to a boil each night if more water is required for irrigation. Heat input to the sea must be paid for, with more cooling area or a reduction in light input, to maintain heat balance.

## Effects of Sphere Size

The design parameters, discussed so far, have been independent of sphere size. As we examine the effect of sphere radius, it will be seen that bigger is better. Better, means not only the reduction in cabin fever produced by a 1,000 square miles of field, forest, gardens and communities present in a 10 mile radius sphere, instead of only 10 square miles of similar landscape in a one mile radius sphere. It also means safety and simpler functioning utilities.

Both of these spheres are large enough to be safe if a small hole in the air tight shell is punctured. It takes about 273 days for a cubic mile of air to escape from a 100 foot diameter hole. But if a major catastrophe occurred knocking a 1,650 foot hole, through which a cubic mile each day of air can escape, the one mile radius sphere would be in serious trouble, in a day, with only 4.2 cubic miles of air. The 10 mile radius sphere, with a thousand times as much air, would take a 1,000 times as long to match the one mile sphere pressure loss. A cubic mile/day loss would cause a pressure drop of less than 1% a month in the larger sphere.

With a cooling system failure, it takes 10 times as long for the 10 mile radius sphere to reach the same dangerous temperature, reached earlier in the 1 mile sphere. The greater rate of cooling at night, causes a daily temperature swing, in both the one mile and ten mile spheres. In both, the night time heat loss is equal to about 14.4 hours of the cooling systems capacity in Venus orbit. This causes a 5.8°F temperature swing, in the one mile sphere, and a .58°F swing in the ten mile sphere. The smaller sphere has 1/1,000th heat capacity of the larger, but also only 1/100th the window size.

A six degree temperature swing each day, in the small sphere, might be pleasant, but if its cooling system fails, instead of a 5.8°F change from night to day there is a 4.6°F temperature rise each day until

the cooling system is restored. The air temperature of the one mile radius sphere would rise 32.2°F a week, until cooling is restored, 354°F is reached or steam pressure splits the sphere. By 300°F steam would add another 100 psi to the 14.7 psi atmosphere pressure inside the sphere.

#### Cooling Pole Shifting

In the ten mile radius sphere the temperature rise would be .46°F each day. With this much heat capacity, it may be possible to obtain polar cooling, as the Earth does, by tilting the axis toward the Sun. In the Venus orbit, the ten mile radius sphere could tolerate the 20°F to 30°F temperature increase, that would occur twice a year as cooling shifts from one pole to the opposite pole. This 56 day transition period would occur twice during the 224.7 day cycle around the Sun.

In Earth orbit there is only 47% as much excess heat to remove as in Venus orbit, but a longer 90 day transition between poles. The .3°F per day temperature rise during a 90 day transition produces a 27°F change. This is greater than the 25.7°F change during the 56 day transition in Venus orbit. Cooling pole shifting is easier the closer the sphere is to the Sun. A similar pole shift near Mercury raises temperature only 12.7°F.

For the one mile radius sphere a reflecting skirt, of some sort would have to be built, to protect the heat radiating pole from the Sun, since its low heat capacity makes shifting cooling poles impossible.

#### Cooling Without Motors

The circulation of air, to remove excess heat can, of course, be done with electric motors and solar panels. The life and death necessity for this system to function, makes one wish for something more reliable, as well as more environmentally and aesthetically satisfying. On Earth the hot air, rising at the equator, is drawn at high altitude to the poles to replace the heavy cold air that flows toward the equator, driven by its own weight. In the ten mile radius sphere, there is a possibility of a similar cooling flow of air without fans.

The once a day rotation, of the sphere, produces a speed of 2.62 miles per hour at the equator. If air is pumped away from the rotation axis of the sphere, to a pole, the hot air, rising from the hot sea or the solar window at the equator, will have this 2.6 mile per hour of kinetic energy, plus the velocity it gained as it rises, lifted by the cooler air flowing from a pole. Air scoops at the rotational axis to direct this breeze into a large pipe, guiding the air to a pole, may make cooling possible without fans. To supply the 2.71 cubic miles of air per hour, required

to cool the ten mile Venus sphere, requires a 1.3 mile diameter pipe, with a two mile/hour flow of air inside. There should be no structural problem hanging this pipe with its scoop at the zero gravity axis of rotation.

#### Water Flow Without Pumps

The movement of water without pumps and motors is also possible in the ten mile sphere. The production of water at the rotation axis should allow water to flow down hill, from its source, toward the equator. However, at the near zero gravity region, surrounding the axis, this flow may need help. The water produced at the pole is likely to behave like the drop at the end of a spigot fighting to break the grip of surface tension without success.

A ten mile high column of water, reaching from the sphere's center to the surface, is 52,800 feet high. When reduced by a factor of 100,000, the ratio of equatorial gravity to Earth gravity, we get about a six inch head of water. Unfortunately, we must halve it again, because this motion produced gravity increases linearly, from a zero value at the center, to reach its value at the equator. A three inch head of water produces about 16.5 lbs./sq.ft. of pressure. Not much, but enough to empty your bathtub on Earth and enough for a 30 foot pipe to drain a square mile of condensing surface at the pole.

The one mile radius sphere, with less than a third of an inch of water head, might make some use of the head for irrigation, but pumps would be required for most water movement. With a three inch head of water and a spigot the size of your bathtub drain, you could fill the tub in the time it takes water on Earth to leave the tub. Draining the tub would be a more difficult problem. Lifting the tub and tossing the water out the window might be the easiest way.

Persuading water to flow downhill will be a continuing problem. A dripping faucet will form a hemisphere shaped puddle, three feet tall and six feet across before surface tension releases its grasp. The same surface tension, however, through capillary action, will provide a useful uphill flow of water. The water that rises an inch or so up a glass tube, until stopped by gravity on Earth, will reach astounding heights in this world. Water carried to the equatorial valley in pipes will quickly climb back up the slopes through the soil, to wet the thirsty roots of growing plants. Some smart plumber will probably find a way to use this force to empty a bathtub.

#### Micro-gravity Considerations

Micro-gravity has its good and bad sides. It is easy to avoid falling pianos. One hour is required for a falling object to reach its maximum rate of fall of one foot/second. The 1/100,000 Earth gravity on

the ten mile radius sphere is strong enough to clear the air of debris, but weak enough to allow you to leap tall buildings, at a single bound and fly like a fish. Flying trash is likely to be a problem in the one mile radius sphere, with 1/10th the ten mile sphere's gravity. Falling objects, with a maximum rate of fall of only one foot each ten seconds, may be carried upward by a cooling system, that must pump the total air in this sphere once each 6.5 days to maintain heat balance.

In spite of the bizarre behavior of some of its inanimate objects, a world, without the danger of accidents from falls, where a man has physical powers, possessed only by gods and comic strip characters on Earth, has its appeal.

Someday, in the not too distant future, the owner's of the large and growing fleets of self repairing, self duplicating mining robots in space will decide that the market for their products on Earth and Mars is saturated. A new product is needed. Orders will go out to the ammonium tanker fleet, diverting a tanker from the Mars run to rendezvous with a 20 mile diameter hollow metallic sphere recently placed in orbit around Venus. If they build it, we will go.

### Conclusion

For a spherical habitat rotating once each day, a ten-mile radius sphere has the possibility of providing cooling and water supply without electrical power. These critical systems require only the continuing rotation of the sphere as a power source. The large volume of air inside the sphere makes cooling system failure or shell breach air losses of a cubic mile per day possible for a month or more without life threatening results.

The possibility of shifting cooling between the two cooling poles as the sphere rotates around the Sun provides a backup system in case of failure of one of the two cooling systems. The design provides a simple, but fail-safe, method of maintaining stable environmental utilities.

### View From a Pole

