~~PROPOSED~~

~~SPACE MEDICINE PROGRAM~~

LUNAR HOUSING SIMULATOR

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WORKING PAPERS

INTRODUCTION

The following preliminary design scope for the Laboratory of Lunar Ecology is presented to show the feasibility of construction of such a facility with present technical methods.

Preliminary studies have been conducted in the following fields:

1. Structural Analysis of the Geodesic Dome to demonstrate it's suitability for both a Lunar Base and Simulator construction.

2. Preliminary investigation of the fields of Hydroponics to show the possibilities of this area in a closed Ecological environment.

3. Investigation of methods of communication between the earth and the Lunar station.

4. Investigation of conversion of Solar Energy to useable power source for the Lunar station.

In addition, the factors of Human Engineering, Architecture and necessary fields of Engineering have been studied to incorporate their requirements into a preliminary design for the Laboratory of Lunar Ecology.

The requirements for the Photosynthetic Gas Exchanger have been included in this design.

The following descriptions and schematic design drawings demonstrate the feasibility and use of this facility. Testing of materials and equipment, familiarization of personnel with problems encountered in space and on extra-terrestial environments, and system testing of components all may be accomplished in the Simulator.

THEORETICAL SELECTION OF STRUCTURAL FORMS FOR THE LUNAR SIMULATOR

Due to the extreme pressures encountered in the Lunar Facility and the Simulator,it will be mandatory that a structural form that eliminates all bending stress be chosen.Explosive decompression due to meteorite puncture on the Moon,or panel failure in the Simulator would destroy any structure that was designed in bending.

For each condition of loading in a structure there exists a corresponding frame shape in which bending can be eliminated.

Variations in loadings can be properly anticipated by choosing the shape which corresponds best to loadings expected.This chosen frame will also require the least material to erect and usually not cause tensile stresses.Weights of materials will be of prime consideration due to the problem of transportation to a Lunar site.

The frame shape can be established by examination of the pressure line curve.This curve is a string polygon for any given loading,and is illustrated on Sheet 4.

Since rectangular frames depart most from the pressure line,they will not be considered as suitable for this structure,although they are shown on Sheet 4.

The optimum structural framing system for the Lunar Facility and the Simulator is one in which no bending exists,as previously mentioned,and one which will best resist the effects of explosive decompression and other anticipated stresses.

Three basically stable structural frames are considered in this study; they are the Triangular Panel, the Shell Dome, and the Geodesic Dome. A comparative analysis of the theoretical applications of these forms is discussed.

Triangular Panel:

Transverse bending moments in the triangular panels are greater than those in shell forms, and material thicknesses to withstand these stresses must be corresponding greater. The panels in a triangular form are considered supported at the intersection lines, and will act as beams.

The panels act in pure bending in beam theory, and dead loads due to structure weight are greater. Perforations are easily accomplished but additional framing will be required for the openings.

Shell Dome

Shells derive their strength from their ability to transfer loads by membrane stress. These are then the direct stresses of compression, tension and shear acting over the entire shell at any point.

The shell must be a homogeneous material to take advantage of this stress transfer. There is no bending element of the shell, and no need for continuous longitudinal support, if the membrane is homogeneous. However, the homogeneity will allow little flexibility in perforations, and make for difficult construction, since concrete as we know it cannot be used in the absence of atmosphere. The solidity of the membrane will require the Photosynthetic Gas Exchangers to be located outside the shell structure.

Geodesic Dome

The geodesics on the curved surfaces (of this dome) play the part of straight lines in plane geometry. Basically, the structural form of the geodesic dome is a prismatic shell, in which flat prism forms are used to approximate shells of double curvature.

Each prism panel is supported at the intersection lines and becomes one span in a series of continuous beams.

There is a transition from the pure shell effect, and prisms may be considered as beams, and stresses computed from the moment of inertia of the entire cross section. Material required to resist those stresses is minimal. Present technology (1958) indicates a requirement of 1.5 lb. of material to enclose each cubic foot within the geodesic domes. Panels could be prefabricated and shipped to the moon for final assembly.

The advantage of the prismatic (Geodesic) dome is that the failure of one of the prismatic panels will not cause a failure in the structure. While this is also true of the Shell Domes, the requirement of a homogeneous material obviates the flexibility of perforations in this form.

The Gas Exchanger panels may be located in the exterior of the shell, and alternate panels of opaque and transparent materials may be used.

HYDROPONICUM FOR USE IN THE LUNAR SIMULATOR

Hydroponics, or the growth of plants in water, has been selected for the lunar based facility for a number of reasons. As yet we do not know the composition of moon soil, and growth in this soil is not predictable. The completely controlled environment of hydroponic culture will result in larger yields per area of planted space. Finally, the hydroponic tanks may be used as a reservoir of water for human consumption. By filtering the chemicals out of the hydroponic solution, potable water can be produced.

In an ecological environment of the nature that we are attempting to establish, the presence of water and plant life are essential to the completion of the cycle. Animal and plant residue after dessication and oxidization will be returned to the hydroponic solution to complete this cycle of growth.

The basic requirements for successful hydroponic culture are:

1. Composition of the nutrient solution.
2. Plant requirements in relation to:
   a. Difference in temperatures.
   b. Atmospheric conditions.
3. Light available for photosynthesis, which will present no problem on a lunar facility.

Since all these elements are under complete control, we can expect much larger yield per planted area, and a reduction of time cycles for maturity of the plants. In other words, producibility of food stuffs will be increased four to ten times over that normal cycle on the earth.

The following forms of plant life have been selected for growth in the Hydroponicum, because of their place in human dietary requirements, and the ease with which they may be grown.

Cereals	Vegetables	Fruits
Wheat	Potatoes	Pear
Rice	Tomatoes	Apple — in the form of minature trees.
Corn	Onions	Peach or Apricot
Soy Beans	Lima Beans	
	Others	

These plants, in addition to the Chlorella produced by the Photosynthetic Gas Exchangers, will be adequate to support both human and animal life in a lunar based facility. The inclusion of the Hydroponicum is necessary in the Simulation Laboratory to define final details and familiarize personnel with the operation of the hydroponic system.

Basic Hydropomic Formula for Nutrient Solutions:

Chemical		Molecular Wt.& Grams/ Liter	CC of Mol. Solution per Liter	Milligrams of Salts/Liter of Solution
Potassium Nitrate	KNO_3	101	10	1,010
Calcium Nitrate	$Ca(NO_3)_2$. .	164	1	164
Monocalcium Phosphate	$Ca(H_2PO_4)_2$.	234	1	234
Magnesium Sulfate	$MgSO_4$ . . .	120	1	120
			13	1,528

This is the basic "three salt" nutrient solution required for the hydroponic growth of cereals, vegetables and fruits.

The other chemicals required are known as trace elements, and are Iron, Zinc, Copper, Boron and Manganese, in the form of Iron Sulphate, Zinc Sulphate, Copper Sulphate, Borax and Manganese Sulphate and Molybdenum. Their composition will vary with the conditions encountered in the water and other environmental factors not definable at this time.

The best pH reading for the nutrient solution is between 5 and 6.5. This ratio between hydrogen and hydroxyl ions must be held, or damage to the root tips or failure of the plants to absorb the required chemicals will result.

The temperature of the solution should be held at 68°F., since the Oxygen content of the water in solutions will be highest at this temperature.

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Air temperatures will be dictated by the environment of the facility itself, although the cereals will grow best at 28 to 31°C. (80° to 85°F.). This temperature may, if required, be controlled by isolation of the Hydroponicum from the rest of the facility.

Light requirements for the photosynthetic process will vary with the type of plant. Allowance must be made for a certain amount of Tropism (leaf turning) in the arrangement of the tanks. Since incident solar light on the moon will be unilateral, this will not be so serious a factor as in the Simulation Laboratory.

The plants selected for growth are of high to medium light requirement plants. The thin leafed, rapid growth plants, such as corn, potatoes and tomatoes have a high light level. Thick leafed, large root system and moderate growth rate plants such as legumes have a requirement for medium light levels.

The depth of the Hydroponicum Tanks will be approximately six inches. This depth will allow for the development of all the roots systems of the plants chosen for the facility.

In general, four to ten times the average soil planting yield can be expected by the use of the hydroponic system. Control of atmospheric conditions, nutrients and water, and by the use of multiple cropping will produce the larger yields expected.

BASIC DATA FOR HYDROPONICUM, ANIMAL FARM AND DIETARY REQUIREMENTS

Dietary Requirements

Meat:

Per capita consumption USA 801 lbs./yr. (Based on U.S. Department of Agriculture Data)

Calorie Value = 1,000 calories/lb.

Cereals:

Per capita consumption 981 lbs./yr.

Caloric value = 1,000 calories/lb.

This figure will vary with the grain selected. It ranges from a low of 330/lb. for wheat to a high of 1,500/lb. for corn. For the purposes of this study, a figure of 1,000 calories/lb. will be used.

Vegetables:

Caloric value for fresh vegetables = 500 calories/lb.

Caloric value for dried vegetables = 1680 to 1700 calories/lb.

Fruits:

Caloric value = 300 calories/lb.

Basic caloric requirements for active man (see Chart No. 1) 3000 calories/day:

1 lb. meat =	1000 calories
1 lb. cereal =	1000 calories
2 lbs. vegatable =	1000 calories
	3000 calories total daily requirement

Requirements per person per year:

365 lbs. meat

365 lbs. cereals

730 lbs. vegetables

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Average grain yield per bushel = 60 lbs. grain (this figure is approximate for wheat, rye, corn and rice).

<u>Cereals:</u>

Yield of 1000 bushels per acre per crop is possible using hydroponics and a completely controlled environment. This figure is not feasible with ordinary field growth, but can be achieved as mentioned.

1 acre equals 43,560 sq. ft. or 4840 sq. yds.

At 1000 bu./acre, one bushel will require $\frac{43560}{1000}$ or 43.5 sq. ft.

Using hydroponics and the controlled environment, the yield can be upped to three (3) crops/yr. Therefore, area requirements will be one third of 43.5 sq. ft., or 14.5 sq. ft. (the study will use 15.0 sq. ft. for convenience) per 3 bushels of grain produced per year.

? 91.5 ft^2

$\frac{365 \text{ lbs.}}{60 \text{ lbs.}}$ = 6.1 bu./yr./person

6.1 bu. require 1.0 sq. ft. cropped three times/yr.

1 bu. requires 5 sq. ft., but cropped 3 times a year = 3 bu.

<u>Vegetables:</u>

1 yr. yield from 130 sq. ft. of tomatoes = $\frac{1224 \text{ lbs.}}{130 \text{ sq.ft.}}$ = 9.5 lbs./sq.ft./yr. Approximate at 10.0 lbs.

500 calories/lb. used for average vegetable. 730 lbs. of vegetable required per person/yr. With a production rate of 10 lbs./sq. ft./yr., this will require 73 sq. ft./person. However, this does not take into affect the production of Chlorella, which will average 5 lbs./day during its most productive oxygen growth cycle, and which will have to be harvested. A conservative estimate ~~is that~~ the Chlorella could produce at

least one half of the human's vegetable requirements. The area for human production of vegetable growth in the Hydroponicum can then be halved, or established at 36.5 sq. ft. (For the study we will use 37.0 sq. ft.)

Fruits:

It is almost impossible to predict the area requirements for the growth of fruits in a Hydroponicum, although every past experience indicates that the fruits do very well in hydroponic culture. An allowance of 100 sq. ft. total has been made for the growth of fruits to add variety to the diet, in the form of miniature pear and apple trees, or some vine fruits (strawberries, etc.).

Animals and Fowls:

Animals:

The rabbit was chosen as the chief meat supplier for the simulator for the following reasons:

High rate of productivity. Rabbits litter six times a year with approximately 6 to 10 offspring per litter. An average figure of eight was chosen for the study. This would allow the rabbit population to increase at least by 48 per pair/yr.

High edibility. Average weight of commercially raised rabbit is 4.86 lbs., with approximately 3.0 lbs. edible, leaving a residue of only 1.86 lbs. The meat has a high caloric value (1000 calories/lb.).

Rabbits may be eaten at 6 months after littering. This means two crops/yr.

The skin (fur) will be useful for clothing, etc., once the lunar base is established. The animal is hardy, and not susceptible to many diseases and may be fed with the excess Algae.

Caloric meat requirement = 1 lb./day/person or 1000 calories per day. 365 lbs./person/yr. of meat will be required. With an edible weight of 3 lbs., this will average out to a consumption of 120 rabbits/person/year. Raising two litters reduces the required rabbits to 60 rabbits/person. Due to the high rate of productivity, however, it seems logical to furnish only one fourth of this number as a start, or the lunar station may be faced with the same problems as the Australians.

Allowing for 15 rabbits/person, and each pair requiring 6 sq. ft. of hutch, the space requirement will be 90 sq. ft., including runs.

Fowl:

Chickens were added to the animal farm chiefly as a supplemental dietary intake. The feathers may be useful, and eggs can well be used to supplement the diet. Fowl also may be fed on excess Algae.

Each hen will lay eggs starting at 5 or 6 months after hatching. The average hen will lay 15 eggs/month for 10 to 12 months. After this the chickens will be eaten. Full egg production and edibility will be reached after 6 months, so we allowed for 2 batches of 10 fowls. This will mean at the end of the year, there will be 20 fowl, with an egg production of 300 eggs a month. Reduction in the fowls by slaughtering should still leave a basic group of fowl of 10 with which to start a new crop.

COMMUNICATION IN LUNAR CONDITIONS

Approximate distance from the earth to the moon is 238,000 miles. Radio waves, even travelling at the speed of light will require 2.6 seconds between statements and rejoiners (round trip). Partially because of this time lag, and because of the technical nature of communication between the earth and the moon, a radio operated teletype system will be the most practical. There are several technical advantages to this system, which can be better treated elsewhere.

Radio frequencies of 50 megacycles and above pass through the earth's atmosphere and into space readily. For this reason, standard television broadcasts at 50 mc are limited to line of sight transmission, since they cannot take advantage of the reflectance of the earth's atmosphere. However, radio signals, like light, diminish proportionally to the inverse square of the distance. This explains the time lag and signal fade that will be major problems in lunar communications.

There will be noise in space to be overcome. Galactic noises (Jansky, 1933) come from dark stars radiating waves of varies frequencies. This is a spotty and variable transmission, and should not present much difficulty.

There is thermal noise due to the solar activity in the galaxy, which produces energy that will radiate along a continuous spectrum. Anomalous solar radiation is produced by our own sun, which rises and falls with sun spot activity.

Consequently, transmission must overcome this noise, and signal to noise ratio must always be greater than unity.

There is a strong probability of signal fading. The earth's atmosphere causes alternate reinforcement and cancellation of wave lengths, depending on conditions in the ionosphere. This will bear on the receipt of messages from the lunar station. A factor of safety for the signal noise ratio is approximated at 10, to compensate for these factors.

Taking into consideration these many factors, it is assumed that a micro wave transmitter/receiver of 1,000 to 30,000 megacycles will be adequate for radio teletype communications between the earth and the moon.

Micro wave systems are excellent for space communications because they can be confined into tight beam patterns using antenna arrays.

The spread of the micro wave beam is a function of the wave length of radiation and area of the antenna array:

$$\text{Dispersion angle} = \frac{6.7 \times \text{wave length}}{\text{antenna width}}$$

A 6'-0" parabolic reflector using a 3 cm. (10,000 megacycles) micro wave has a beam width of 1°. Since the moon subtends an arc of $\frac{1}{2}^{\circ}$ the beam will cover the face of the moon.

Using a radio teletype transmitter/receiver system on a pulsed modulation from a 3 cm. magnetron, we can avoid the problems of noise interference consistent with voice transmission. This system will overcome the time lag problem and furnish a permanent, written record of all communications.

SOLAR ENERGY DEVICES FOR LUNAR APPLICATION

Serious consideration should be given to the problem of utilization of solar energy for the Moon Based Facility. There will be large energy requirements generated by the facility by communications equipment, measurement, test and recordings instruments, computers, kitchen equipment, laboratory equipment and other items too numerous to list here.

The ability to use incident solar energy on the moon will greatly simplify the problem of supplying energy to the facility. Utilizing an existant source of energy will obviate the need to transport generating equipment and fuel supplies from the earth. The saving in costs alone would offset any additional research and development programs necessary to perfect these devices.

The surfaces of the moon exposed to direct solar radiation receive 21 Kilocalories/minute/sq. meter, but the earth, inspite of being closer to the sun, only receives (at the Equator) 22 Kilocalories/minute/sq. meter due to the attenuation of the atmosphere. Testing of a solar device could be carried out on the earth with approximately the same results that a lunar device would achieve.

Temperatures on the moon vary considerably. In the time the sun's light first strikes the moon, before any heat is reflected, the temperature is at 70°C. (158°F.). At the height of solar incidence, temperatures reach 400°C. (284°F.) and at "night" the temperature drops to -100°C. (-148°F.). Both incident solar energy and temperature differentials could be utilized to produce energy.

The "day" length on the moon is 354 hours. Further solar light can be directed by the use of mirrors, or a normal diurnal cycle can be established through the use of mirrors which would alternately reflect and focus the light of the sun on the lunar station.

Three solar energy devices are discussed here. They are the Thermopile, the Hot Gas Generator and the Solar Boiler. Also taken into consideration is the Silicon Cell which develops electrical energy by conversion of light. However, little is known about the capabilities of this cell at this time. Further research may develop a practical application of the Silicon Cell for the lunar facility.

The Thermopile consists of a series of thermocouples linked together. The thermopiles generate electrical energy when exposed to light and heat differential. Basically, the thermocouple is fabricated from two dissimilar metals, welded at one end. Current is generated when light strikes these elements. The thermocouple will also generate electrical energy when impinged by cosmic radiation. This effect will have to be investigated in relation to total power output, since cosmic radiation will be greater on the moon than at the earth.

Variation in temperature will also increase the output of the thermocouple. As previously mentioned, this will be between 400°C. and -100°C.

The Hot Gas Generator consists of a series of tubes containing a compressed gas in front of amirror device which will focus solar light on the tubes. The gas in turn expands and is used to drive a turbine-generator device. The gas should be Ammonia or Carbon Dioxide (or others with a low adiabatic value so that exhaust pressures for returns are low). Mercury vapor can be used but its efficiency is low.

For the best efficiency the exhaust temperatures should be about 175°C. (347°F.) and an initial temperature of approximately 730°C. (1170°F.)

at a pressure of approximately 20 to 30 atmospheres.

The electrical energy requirements for the facility will dictate the type of generator that can be used in conjunction with the Hot Gas Generator.

The Solar Boiler consists of a standard boiler arrangement in front of a concave mirror which is used to focus solar light on the boiler shell. The side towards the sun should have a reflectant inward surface, and the side towards the mirror (reflected sun light) should have a highly heat absorbent surface.

The heated liquid will then drive a liquid turbine-generator device. The return will be to the boiler to be reheated and reused. Hydrogen Peroxide might be used in the Solar Boiler.

Hydrogen Peroxide Turbines can be utilized. They will operate on the steam produced by the decomposition of H_2O_2.This decomposition process can also be used to produce Oxygen for an internal combustion engine,possibly in the manner of the Walter Closed Cycle Diesel developed by the German Navy for use in submarines during World War II.

The disadvantages of the Hydrogen Peroxide system are obvious.The H_2O_2 must be shipped in from the earth,and the Oxygen content cannot be reprocessed once used in an internal combustion engine.The disposition of exhaust gases would ahve to be carefully studied in relation to the Moon's lack of atmosphere.

Some form of Solar Energy device should be incorporated in the Lunar Simulator to test it's capabilities and to familiarize personnel with it's operation.

Storage Batteries will be required to store the electrical energy during periods when the Sun will not be available.These also should be included in the Simulator.

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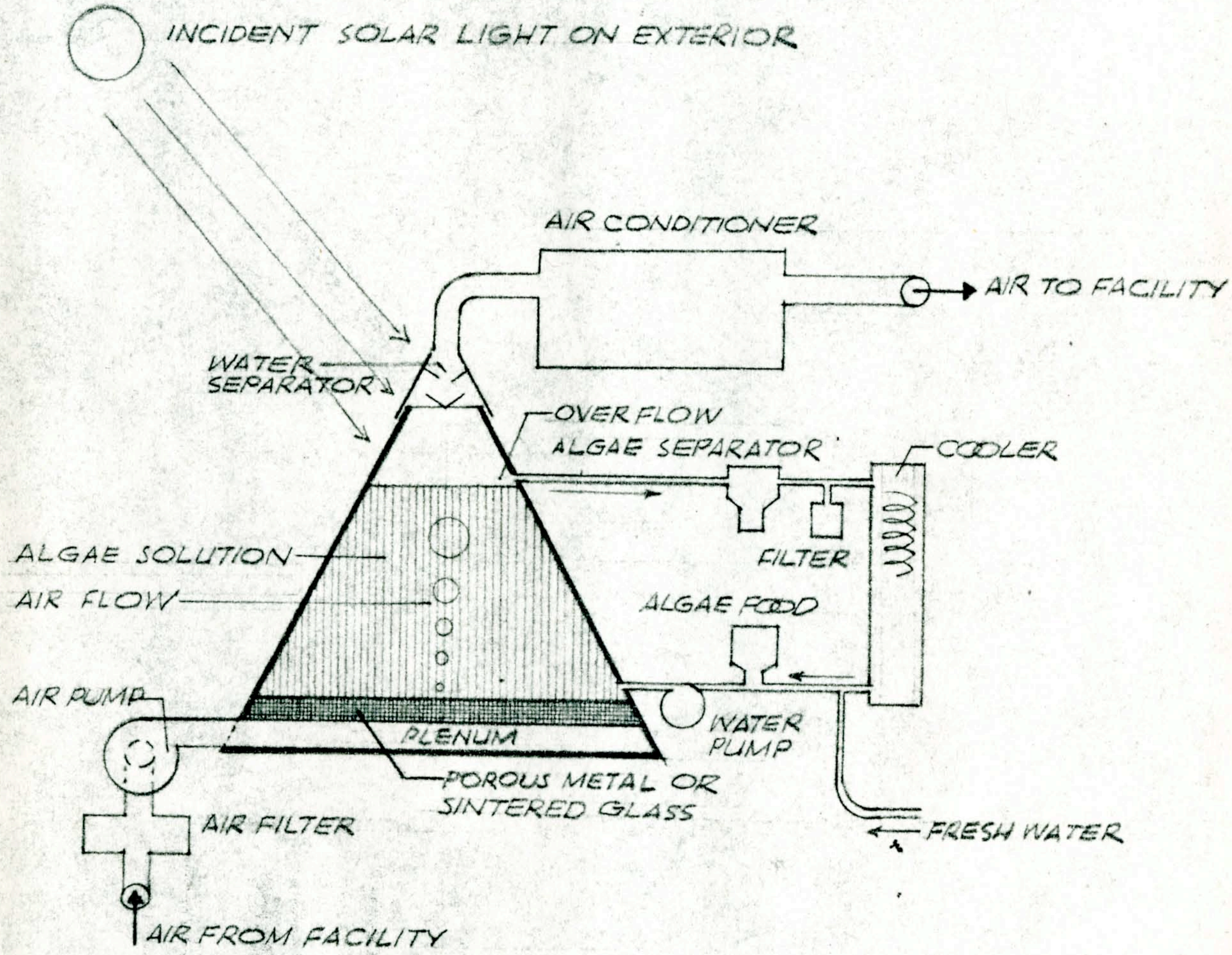
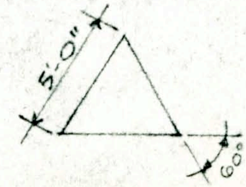


SCHEMATIC DIAGRAM
PHOTOSYNTHETIC GAS EXCHANGER

NO SCALE (INTERIOR VIEW)

GAS EXCHANGER PANELS TO BE PLACED WITHIN FRAMING OF GEODESIC DOMES



AREA OF PANEL: 20 ⌀
REQ'D. AREA 1,200 ⌀
TOTAL PANELS 60

WORKING PAPERS I

MARTIN
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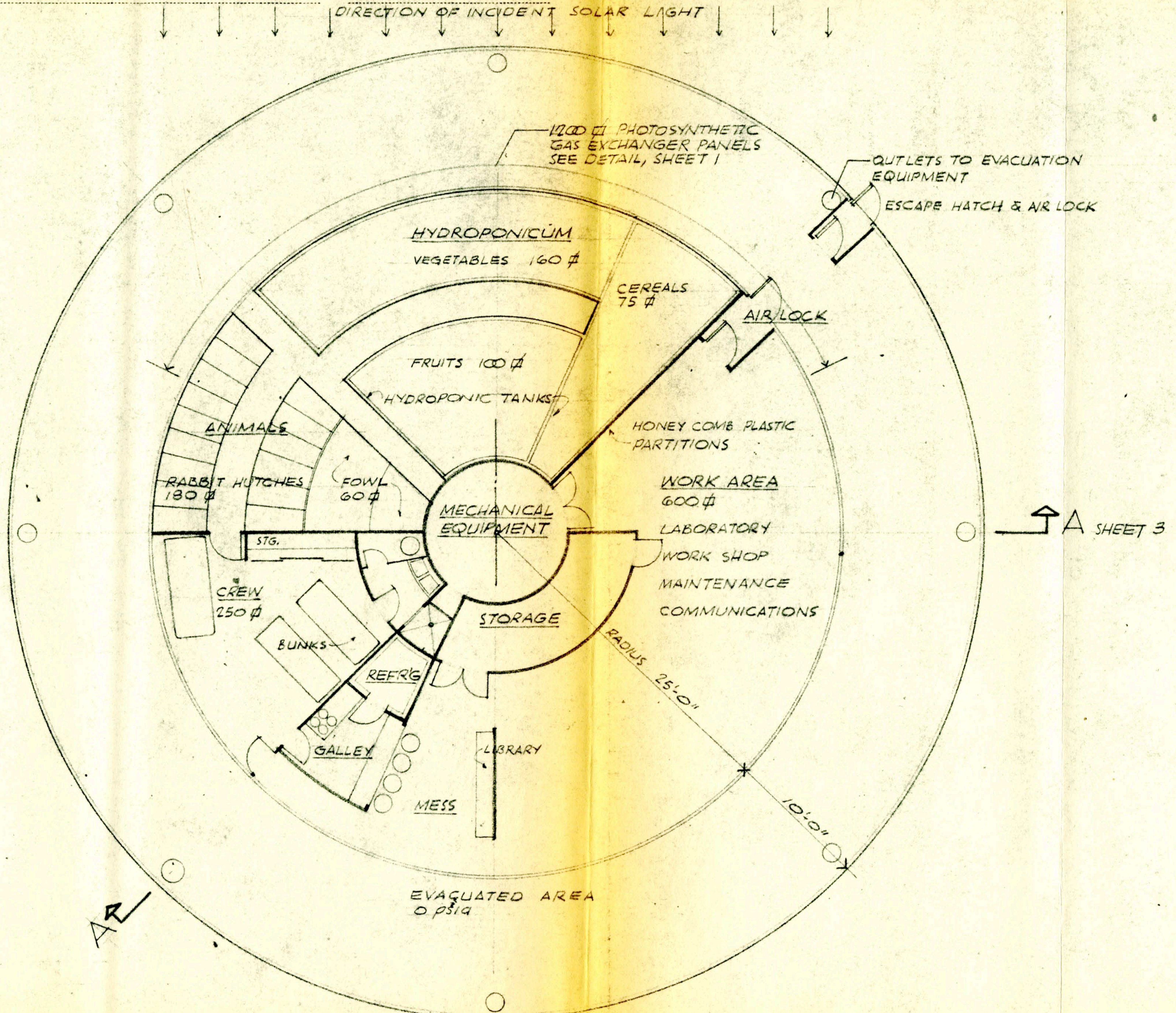
BY ENGLISH DATE 16 APR. 58 SUBJECT LABORATORY OF LUNAR ECOLOGY SHEET NO. 2 OF 4
CHKD. BY .... DATE .... JOB NO. ....



PLAN OF SIMULATOR
SCALE: 1/8" = 1'-0"

TOTAL AREA INNER DOME - 1,962 ⌀ @ 5 to 10 psia
TOTAL AREA OUTERDOME - 3,910 ⌀ @ 0 psia

WORKING PAPERS 2

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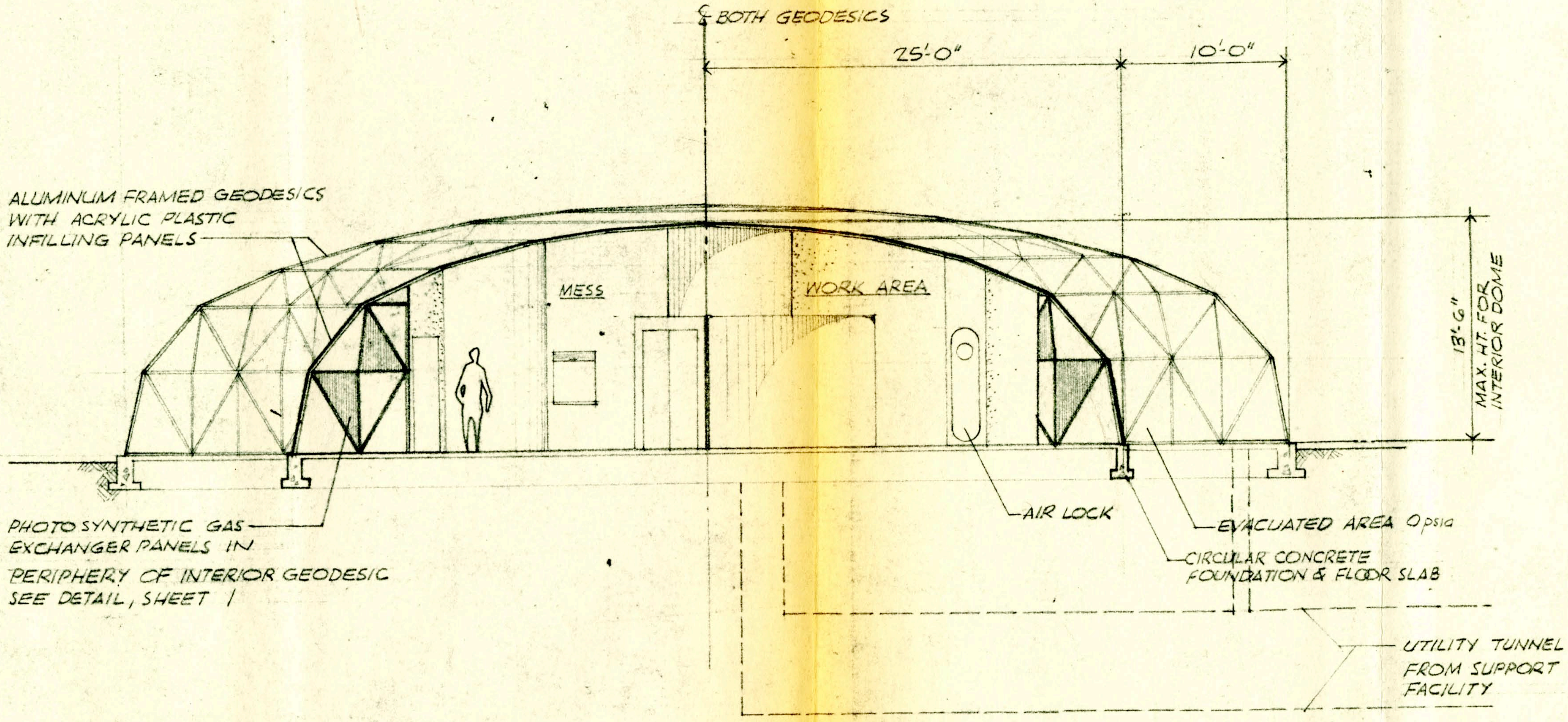
BY ENGLISH DATE 16 APR '58 SUBJECT LABORATORY OF LUNAR ECOLOGY SHEET NO. 3 OF 4
CHKD. BY DATE JOB NO.



SECTION A THRU SIMULATOR
SCALE: 1/8" = 1'-0"

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BY W. ENGLISH DATE 18 APR '58 SUBJECT LABORATORY OF LUNAR ECOLOGY SHEET NO. 4 OF 4
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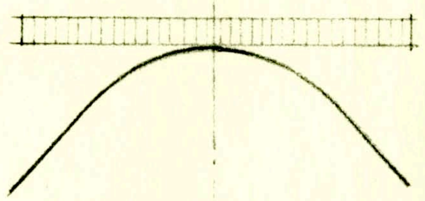
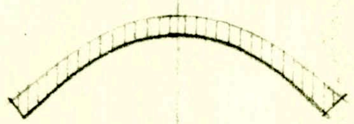
FRAME SHAPES TO ELIMINATE BENDING STRESS

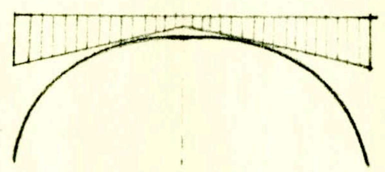
SHOWING TYPICAL STRING POLYGONS



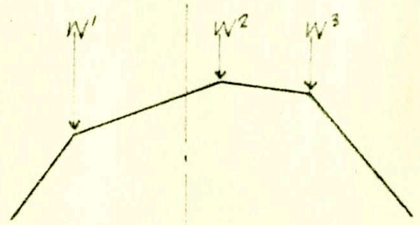
EQUAL HORIZONTAL LOAD
PARABOLA



DEAD LOAD OF CONSTANT SECTION
CATENARY

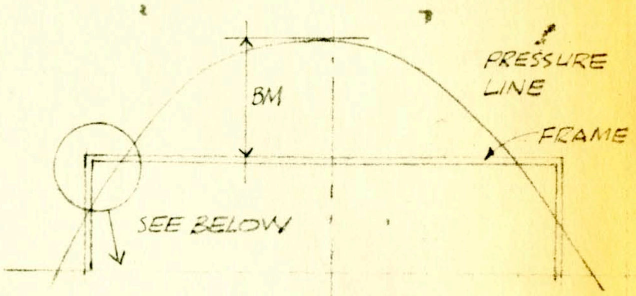


INCREASED LOAD ON ABUTMENTS
ELLIPSE



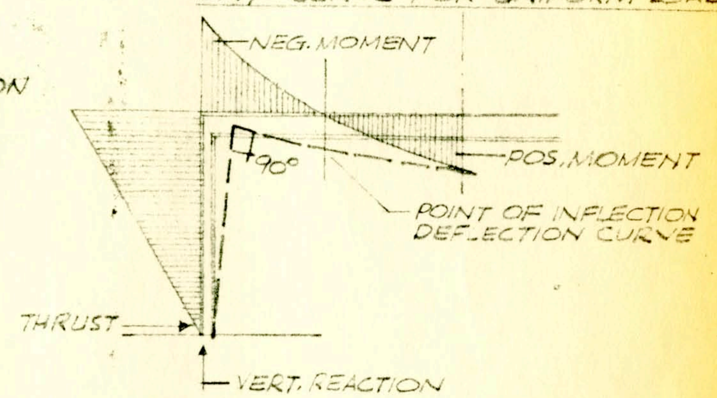
CONCENTRATED LOADS
POLYGON

RECTANGULAR FRAMES PRESSURE LINE

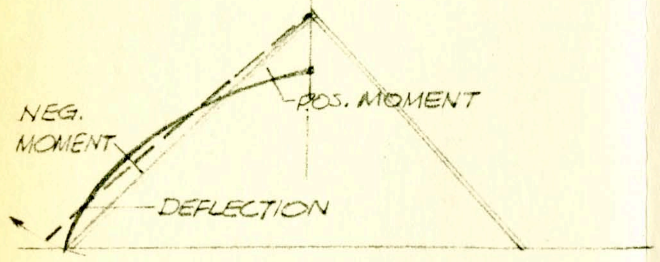


BENDING MOMENT (BM) VARIES IN PROPORTION TO THE DISTANCE FROM THE FRAME TO THE PRESSURE LINE

DEFLECTION & BENDING MOMENT CURVE FOR UNIFORM LOAD



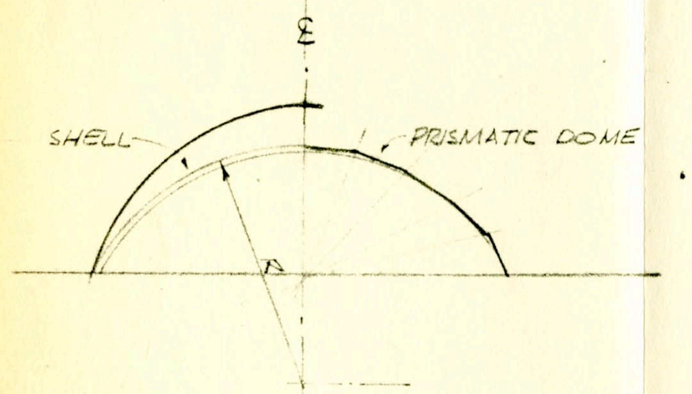
TRIANGULAR FRAMES PRESSURE LINE



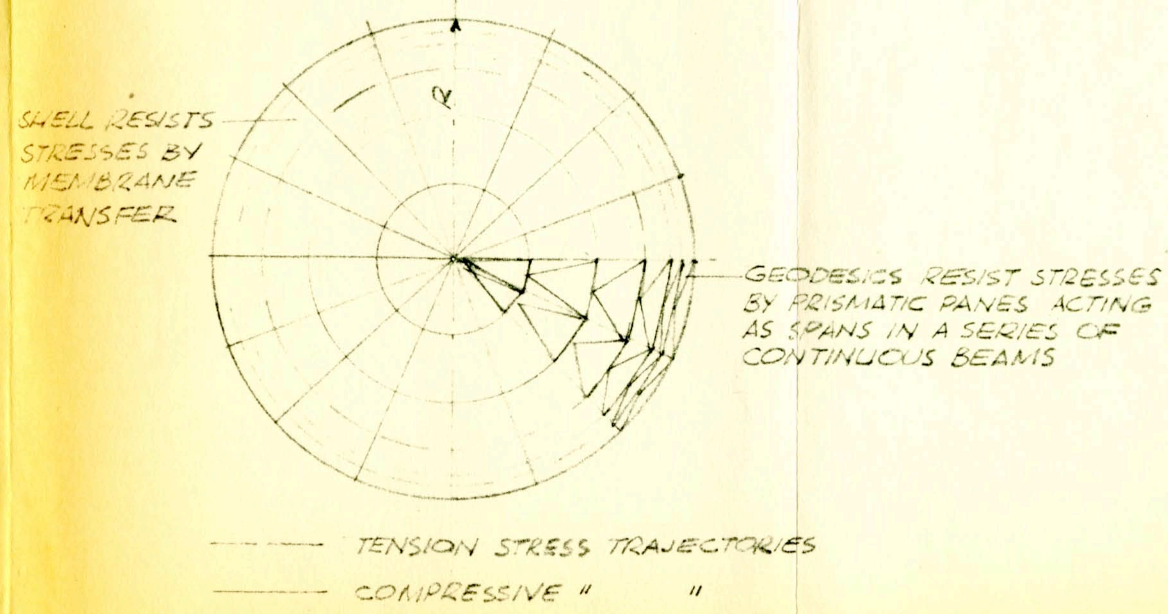
(3 HINGED ARCH TYPE)

SHELL DOMES PRESSURE LINE

(NO BENDING)



STRESSES TRANSFERED TO COMPRESSION & TENSION



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