APPLICATION OF PERMSELECTIVE COMPOSITE TECHNIQUES FOR ATMOSPHERE-THERMAL CONTROL OF EMERGENCY AND EXTRAVEHICULAR MANNED SPACE ASSEMBLIES

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FOREWORD

This study was initiated by the Biomedical Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The research was conducted by the Missile and Space Division, General Electric Company, Valley Forge Pennsylvania, under contract AF33(615)-2850. Mr. D. J. Withey was the principal investigator for the General Electric Company. Mr. D. A. Keating and Mr. George Filson were contract monitors for the Aerospace Medical Research Laboratories. The work was performed in support of project 6373 (Equipment for Life Support in Aerospace) and task 637302 (Respiratory Support Equipment). The research covered herein was performed between May 1965 and August 1966.

This technical report has been reviewed and is approved.

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ABSTRACT

This program encompasses the analysis, research, design, fabrication, and testing of an exploratory laboratory model of an emergency or extravehicular space assembly using permselective membrane techniques for atmosphere control. The purpose of this effort was to develop an advanced concept which would depart from the traditional approach utilized in spacecraft design by transferring most of the atmosphere-thermal control functions from the associated hardware subsystems to the enclosing structure. A silicone rubber permselective composite incorporated into the pressure retention wall of the enclosing structure permits selective permeation of carbon dioxide, water vapor, and contaminant gases to space with minimal oxygen permeation. In addition, the use of superinsulation on the exterior surface of the structure provides passive radiant thermal control. This, in conjunction with the permselective composite material, substantially reduces the weight, volume, and power requirements of environmental control subsystems required for a manned emergency and extravehicular assembly. While the permselectivity of the silicone rubber composite was determined, the final structure was subject to a large amount of leakage. This resulted in the cancellation of the full scale test program and in redirection of the project effort to include a failure analysis to determine the cause and solution to the leakage problem.

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INTRODUCTION

Current personal protection concepts intended for extravehicular space operation are characterized by a nonpermeable enclosing structure and an associated environmental control subsystem. The enclosing structure functions as an atmosphere-retaining envelope. The environmental control subsystem maintains a viable atmosphere composition and a comfortable atmosphere temperature. The extravehicular and emergency space enclosure (Emergency Cocoon) developed in this program departs from these traditional concepts because it transfers the function of atmosphere composition control from separate equipments to the enclosing structure itself by integrating a permselective material into the pressure retention layer of the cocoon wall. This permselective material allows H_2O, CO_2, and other noxious and toxic gases to permeate to space, while retaining the internal atmosphere pressure. Atmosphere composition control is thus passive and requires only the addition of makeup oxygen to provide complete atmosphere control. In keeping with the passive atmosphere composition control, atmosphere temperature control is also provided by passive techniques.

The objectives of this program were to demonstrate the feasibility of using a permselective material as the basis for a passive atmosphere control system to support a man in space, to fabricate a structure utilizing a permselective material in conjunction with a passive radiant thermal control assembly and to demonstrate the practicality of a completely passive atmosphere and thermal control assembly.

A 71-inch (180-cm) diameter spherical inflatable structure (Emergency Cocoon) was fabricated. The structure contained a hatch and observation port as well as a blanket of aluminized "Mylar" film to be used as a superinsulation thermal shield. The permselective characteristic of the silicone rubber membrane was designed to maintain the atmosphere within the Emergency Cocoon at a suitable level for human comfort when inhabited by one man provided with an adequate oxygen supply. The system was designed to operate at 5 psig. The thermal control for the cocoon was provided by the use of a multilayer blanket of aluminized Mylar superinsulation used in conjunction with a small internal electric heater and fan. This thermal control system was designed to maintain temperatures inside the cocoon between 65° and 85°F (26.875 ± 6.25°C) during any inclination orbit of 100 to 300 nautical miles (185.3 to 555.9 kilometer) altitude.

During the initial testing of the Emergency Cocoon a large number of leaks in the permselective composite prevented the planned full scale testing of the cocoon. A failure analysis was then undertaken to determine the cause of the leakage. The analysis identified the cause of the leakage and provided several possible solutions to the problem.

SECTION II

ANALYSIS AND DESIGN

GENERAL

The Emergency Cocoon was designed to demonstrate the feasibility of a compact, manned, inflatable structure incorporating, as nearly as possible, a passive atmosphere and thermal control system. Hardware for emergency or extravehicular space use, such as, attitude control, propulsion systems, etc. was not considered. That is, the primary design objective was limited to the evaluation of the permselective and passive thermal control concepts.

The cocoon was composed of five major components; an inner bag, the outer bag, a hatch, observation port, and a layer of aluminized Mylar superinsulation. A small heat source was designed to meet the thermal requirements of the cocoon while in the dark, i.e. cold portion of an orbit. A floor and a chair were provided to facilitate manned testing of the structure.

The unique design feature of the Emergency Cocoon System is its ability to maintain a habitable atmosphere passively by allowing the waste products of respiration (CO_2 and H_2O) to permeate selectively to space. This was accomplished by incorporating a permselective silicone rubber membrane into the wall of the cocoon. Under equal partial pressure differences across the silicone rubber membrane, water vapor will permeate through the wall at a rate of 60 times that of oxygen, while CO_2 will permeate 5.5 times as fast as oxygen.

The Emergency Cocoon was designed to control the atmospheric and thermal requirements for one man when the cocoon is in a space environment. The metabolic rate of the man was considered to vary from a low of 300 BTU/hr (21 gram-cal/sec) to a high of 500 BTU/hr (35 gram-cal/sec). The CO_2 and H_2O production rates considered were 0.05 to 0.1 lb/hr (0.0063 to 0.0126 gram/sec) each. The atmosphere control requirements were: (1) Control the partial pressure of CO_2 to near 3.8 mm Hg, with a maximum not to exceed 7.6 mm Hg, and (2) maintain the relative humidity at 50%. The oxygen supply and regulation required to maintain this pressure and to supply oxygen makeup for leakage, permeation, and metabolic losses was not a control requirement.

DESIGN ANALYSIS - ATMOSPHERE CONTROL

The size and shape of the cocoon was determined by considering the permselective characteristics of the membrane, the partial pressure of CO_2 to be maintained, and the practical size for human comfort over an extended period of time.

The permselective characteristics of the membrane were originally obtained from previously published information (Reference 1) which lists the values as follows:

Gas	Permeability Constant $\frac{\text{cc (STP)-cm}}{\text{sec-cm}^2\text{-cm Hg}}$
Nitrogen	28×10^{-9}
Oxygen	60×10^{-9}
Carbon Dioxide	320×10^{-9}
Water	$3,800 \times 10^{-9}$

The CO_2 production rate was calculated for the maximum and minimum metabolic rates specified using 1 liter/min of oxygen consumed equal to 1158 BTU/hr (81 gram-cal/sec). For example a man with a metabolic rate of 300 BTU/hr (21 gram-cal/sec) will consume oxygen at the rate of:

$$\frac{300 \text{ BTU/hr} \times 0.252 \text{ Kcal/BTU}}{4.82 \text{ Kcal/Liter of } O_2} = 15.65 \text{ liters of } O_2/\text{hr}.$$

Assuming a respiratory quotient (RQ) of 0.82, the CO_2 production rate will be 15.65 x 0.82 = 12.83 Liters/hr or 0.0557 lb/hr (25.3 gram/hr). CO_2 production for a metabolic rate of 500 BTU/hr (35 gram-cal/sec) will be 0.0927 lb/hr (42.1 gram/hr).

This range was found to be close to that specified in the work statement. Thus, CO_2 production rates as high as 0.1 lb/hr (45.4 gram/hr) were considered in the subsequent analysis. The CO_2 production rate <u>vs.</u> metabolic rate is also shown on Graph A of Figure 1.

The membrane area required to maintain a pCO_2 of 7.6 mm Hg, under the maximum design CO_2 production rate of 0.1 lb/hr, (45.4 gram/hr) was calculated as follows:

$$Q = \frac{P_R \quad A \Delta P}{t}$$

Where Q = CO_2 permeation rate, cc(STP)/sec.

P_R = Permeability Coefficient of silicone rubber for carbon dioxide, = 320×10^{-9} cc(STP) -cm/sec-cm^2-cm-Hg

A = Membrane area, cm^2

ΔP = CO_2 ΔP across membrane = 0.76 cm-Hg

t = Membrane thickness = .00254 cm (1 mil)

AREA OF MEMBRANE CONSIDERED = 98 ft.^{2} (91,000 cm^2)

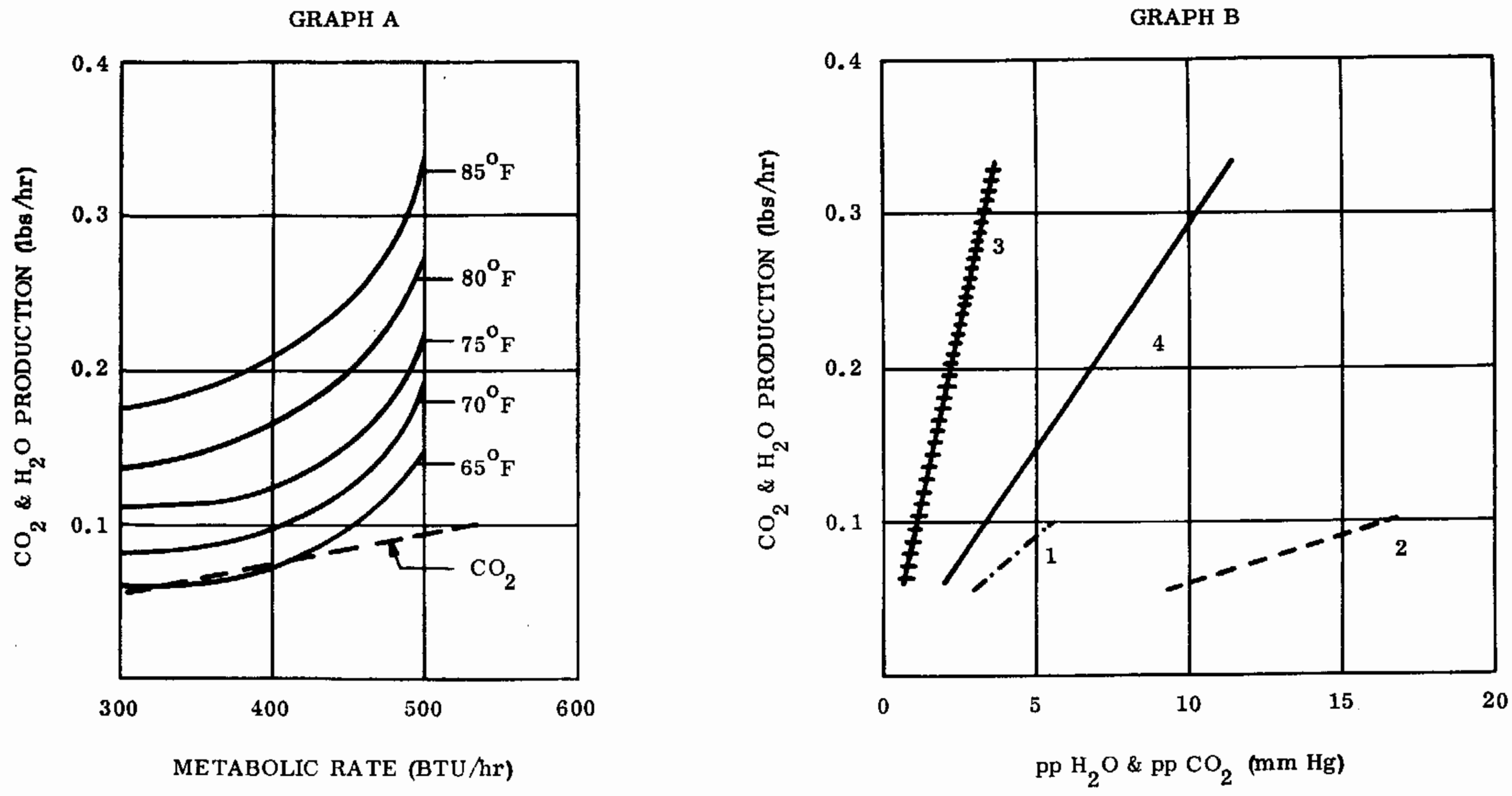

Figure 1. Emergency Cocoon, Internal Environment

Thus, for a Q equivalent to 0.1 lb/hr (45.4 gram/hr), the required membrane area was found to be 75.8 ft^2 (70,500 cm^2).

Assuming 15 ft^2 (13,920 cm^2) of the total area to be nonpermeable due to the need for a hatch, observation port and seams, the gross area required in the structure was then 90.8 ft^2 (84,300 cm^2). This is the area of a sphere with a diameter of 5.3 ft (162 cm) which was not considered adequate for the comfort of the individual. Therefore, a spherical structure with a diameter of 6 ft. (183 cm) was used. The gross area of a 6 ft. (183 cm) diameter sphere is 113 ft^2 (105,000 cm^2). Of this area 15 ft^2 (13,920 cm^2) were assumed to be nonpermeable due to the hatch, etc., thereby leaving a permeable area of 98 ft^2 (91,100 cm^2).

Using this area, the formula above, and the previously listed permeability constants, the equilibrium (steady state) values of pCO_2 were calculated for all production rates. These curves are shown on Graph B of Figure 1. As shown in Curve 1 of the graph, with a constant permeable membrane area of 98 ft^2 (91,100 cm^2), the pCO_2 within the cocoon will vary from 3.1 to 5.6 mm Hg. The nominal point, corresponding to a metabolic rate of 400 BTU/hr (28 gram-cal/sec), will be 4.1 mm Hg.

The production rate of water vapor within the cocoon was taken from the following sources:

Figure 3 of Reference 2 provides the following information on metabolic rates.

	Man at Rest			
Temperature, °F	70	75	80	85
Latent Heat, BTU/hr	95	130	170	225
Sensible Heat, BTU/hr	300	270	230	175
Total BTU/hr	395	400	400	400

	Man with Metabolic Rate of 500 BTU/hr			
Temperature, °F	70	75	80	85
Latent Heat, BTU/hr	175	230	295	375
Sensible Heat, BTU/hr	315	265	205	150
Total BTU/hr	490	495	500	525

In addition, table 9 of Reference 2 gives a metabolic rate of 330 BTU/hr (180 BTU/hr sensible and 150 BTU/hr latent) for a man seated at rest with a dry bulb temperature of 80°F.

Figure d of Reference 3 gives the following data for evaporative heat loss for metabolic rates of 500 and 400 BTU/hr.

	Latent Heat Production BTU/hr				
Temperature ^{o}F	65	70	75	80	85
Metabolic Rate BTU/hr					
500	150	225	255	275	325
400	75	100	125	175	215
300*	63	86	117	146	186

The latent heat production in BTU/hr was converted to water vapor production in lbs/hr by dividing the average of the values in the foregoing tables by 1050 BTU/lb (the heat of vaporization for water at 77^{o}F). The data was then plotted in Graph A of Figure 1. Graph A shows the water vapor production to be strongly dependent on the dry bulb temperature of the air. It varies from a low of 0.06 lbs/hr (27.2 gram/hr) to a high of 0.333 lb/hr (151 gram/hr). These water production rates were considered to represent the actual anticipated water vapor production loads in the cocoon atmosphere and thus were utilized in the subsequent analysis.

Using the above water vapor production rate, and a membrane area of 98 ft^2 the equilibrium water vapor pressure within the cocoon was calculated (using $Q = P_R\ AP/t$) and is plotted as Curve 3 Graph B of Figure 1. This curve shows that the equilibrium water vapor partial pressure will vary from 3.8 mm Hg (dry) to 0.7 mm Hg (very dry). The nominal point, at 400 BTU/hr (28 gram-cal/hr) and 75^{o}F, is 1.9 mm Hg, corresponding to a relative humidity of 8% which is considerably below the 50% value desired.

There are two possible ways to increase the humidity within the cocoon. The first is to decrease the permeable membrane area. This, however, would increase the pCO_2. If CO_2 pressures of 9.3 mm Hg (nominal) to 16.8 mm Hg (maximum) were acceptable however, the nominal pH_2O would be raised to 5.7 mm Hg (25% RH). This could be accomplished by only using one third of the available membrane area. (This solution is discussed later in the report). The second possibility is to add a humidifier to raise the cocoon atmosphere pH_2O. This method, however, is wasteful (requires an expendable) and detracts materially from the simplicity of the passive atmosphere control system, requiring controls, instrumentation, etc.

Analyses of these two possibilities disclosed that neither was sufficiently attractive to warrant its incorporation into the design. The nominal relative humidity of 8%, although quite low, should not cause harmful physiological effects. Some discomfort would arise from the drying effect on the mucous membranes over a long

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* Extrapolated from available information.

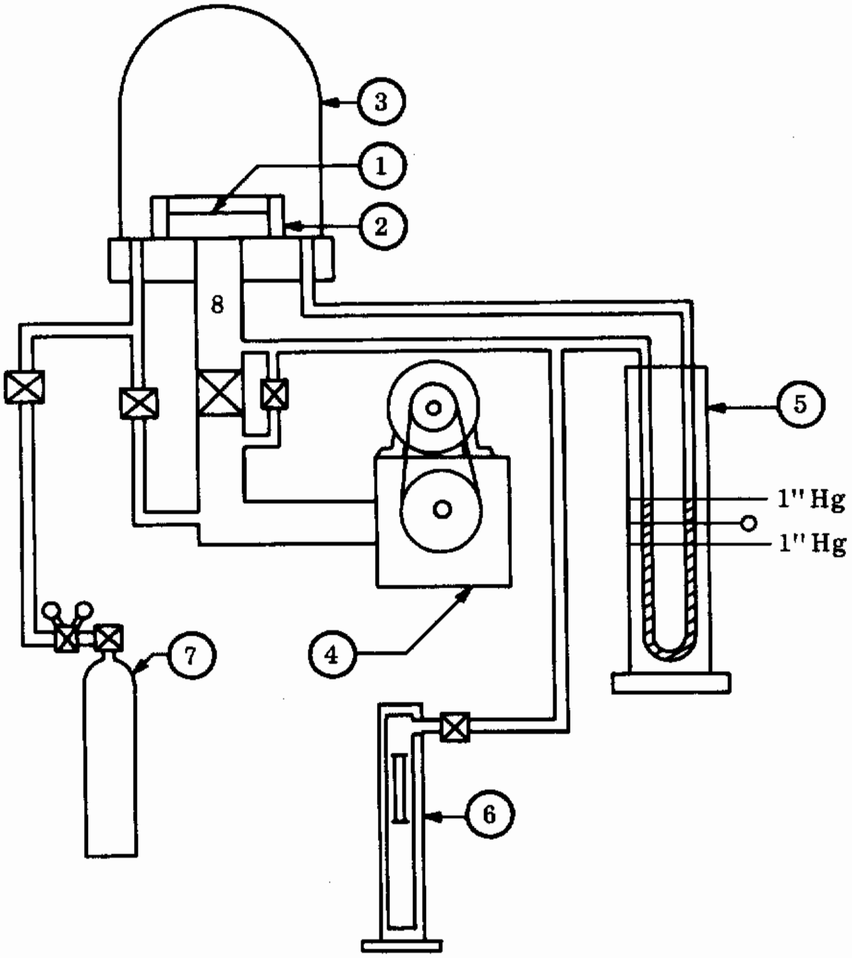
period. However, these humidity levels are approximated under normal living conditions in some heated dwellings in wintertime, and in desert areas. Thus, low humidity is not completely foreign to "normal" environmental conditions, and the period of time an individual would be inside the cocoon should not be long enough for the man to be affected by this low humidity. Although all design work and considerations to this time were based on previously published membrane permeation data, at this point in the program a series of tests was conducted to evaluate the validity of the published data. Early tests indicated that leakage would be a major problem in fabrication of the cocoon; therefore, the composition of the membrane was changed from two 0.5-mil-thick (0.00254 cm) layers of silicone rubber to three 0.5 mil-thick layers.

The change greatly improved the integrity of the membrane, and permeability data was then obtained for this thicker membrane. The tests were conducted using a system as shown on Figure 2. In this test, the entire system was evacuated until a system pressure of 0.05 mm Hg or less was reached, after which the permeation sink was isolated from the bell jar by manipulation of the valves. (NOTE: for satisfactory results, this test required accurate measurement of the permeation sink volume, including lines to pressure measuring devices, etc.) When the permeation was isolated, the sample gas was admitted to the bell jar until a pressure of 2 in. of Hg (5.08 cm of Hg) was reached within the bell jar. The gas supply was then shut off and the rate of rise in pressure in the permeation sink due to gas permeation through the permselective samples was recorded by observing the Dubrovin gage and measuring its rate of change with a stopwatch. The permeation rate of the membrane was then determined by calculating the amount of gas required to raise the pressure in the permeation sink and dividing this value by the elapsed time. The permeation constants of samples taken from the material to be used in fabrication of the cocoon were determined to be:

Gas	Permeation Constant $\frac{\text{cc(STP)-cm}}{\text{sec-cm}^2\text{-cm Hg.}}$
Nitrogen	16.6×10^{-9}
Oxygen	33.4×10^{-9}
Carbon Dioxide	161.0×10^{-9}

The values listed are the average values of the samples tested. Comparison of these values with those previously published for this type membrane discloses that the selectivity of the material is the same as previously published, but that the absolute permeability is approximately 50% of the published value.

Using this new permeation data the design of the cocoon was again considered and the results are as shown in Curves 2 and 4 of Graph B, Figure 1. These curves



LIST OF COMPONENTS	
ITEM NO.	ITEM
1	PERMSELECTIVE SAMPLE
2	SAMPLE FIXTURE
3	VACUUM BELL JAR
4	VACUUM PUMP
5	MERCURY MANOMETER
6	ABSOLUTE PRESSURE GAUGE (DUBROVIN-TYPE)
7	SAMPLE GAS SUPPLY
8	PERMEATION SINK

Figure 2. Permselective Membrane Permeability Test Schematic

show that the CO_2 partial pressure in the cocoon will vary between 9.3 and 16.8 mm Hg for the CO_2 production rates of 0.055 lbs/hr (25 gram/hr) and 0.1 lbs/hr (45.4 gram/hr) specified. Also, partial pressure of H_2O maintained within the cocoon will be increased to between 2 and 11.5 mm of Hg for the range of metabolic rates and temperatures considered.

DESIGN ANALYSIS - THERMAL CONTROL

Requirements

The requirements which were followed for the thermal design and analysis can be summarized as follows:

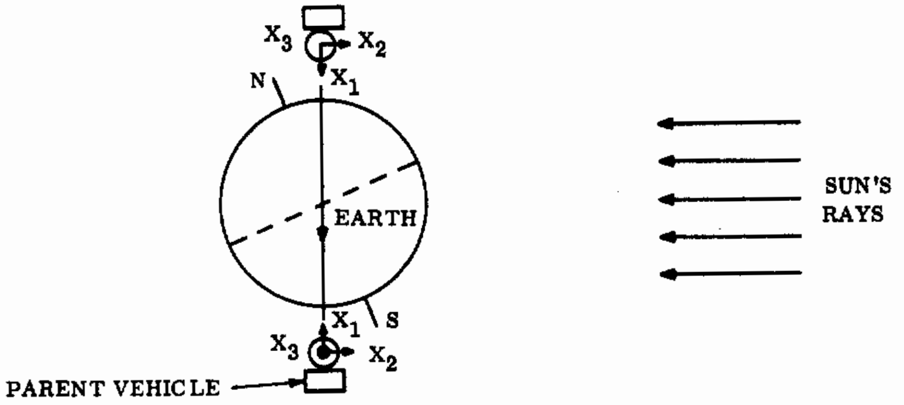
(1) 100 to 300 nautical mile earth orbits
(2) 6 foot diameter cocoon
(3) parent vehicle 10 feet in diameter by 10 feet in length
(4) random orientation of cocoon to the parent vehicle
(5) separation between cocoon and parent vehicle of 0 to 100 yards
(6) thermal control of cabin air temperature between 65° and 85°F to be accomplished by passive or semi-passive means
(7) man's metabolic heat generation rate between 300 and 500 BTU/hr.

Environment

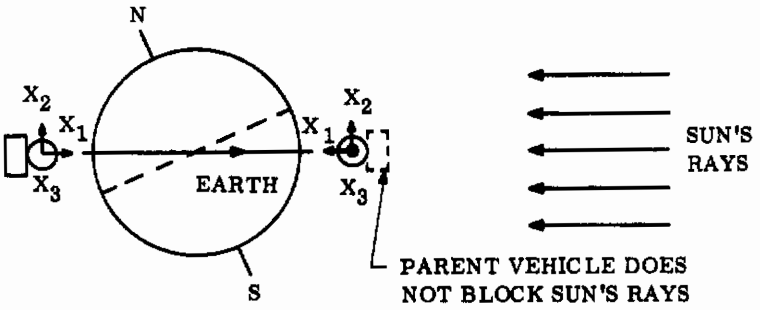
The environment of the Emergency Cocoon in earth orbit is characterized by solar (S), albedo (A), and earth-emitted (E) orbital heat fluxes as well as a heat flux emitted from the parent vehicle (Qp).

Figure 3 shows possible orbit geometries for extreme cases of heat flux incident upon the cocoon. Two hot cases (Figure 3(A) and (B)) and one cold case (Figure 3(C)) are considered.

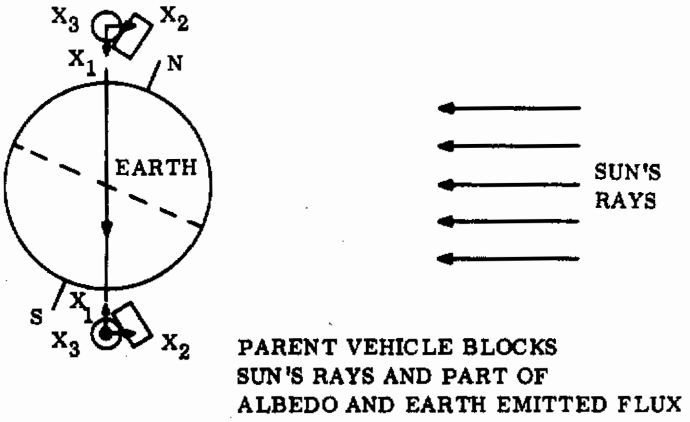
In Figure 3(A), the orbit and configuration chosen produces the maximum heat flux upon the Emergency Cocoon. The orbit is near polar, so that the cocoon is continuously in sunlight. Also, the earth's distance to the sun is at a minimum thus the solar heat flux is maximum. The configuration and altitude of the cocoon to the parent vehicle and earth is arranged to provide a maximum heat flux from each. In Figure 3(B), the same altitude and configuration is used, but the orbit allows the cocoon to enter the earth's shadow. In the cold case, Figure 3(C), the external heat flux is at a minimum. The orbital altitude and maximum distance from earth to sun provide minimum values for the heat flux originating from them. The parent vehicle also blocks all the solar flux and part of the earth albedo and radiation as well.



A. HOT CASE 1 - PERIHELION (DAY 2), 100 NM ORBIT



B. HOT CASE 2 - PERIHELION (DAY 2), 100 NM ORBIT



C. COLD CASE - APHELION (DAY 184.6), 300 NM ORBIT

Figure 3. Orbits and Configurations, Thermal Analysis

To determine the incident heat fluxes for these cases, the Orbital Heat Flux (OHF) Computer Program (Reference 4) was run. The nodal breakdown of the cocoon which was used in this program is shown in Figure 4. A total of 26 nodes were utilized.

Tables I, II, III, and IV show the resulting instantaneous and average incident heat fluxes for the extreme orbits considered. The heat flux was assumed to emit from the parent vehicle (Q_p) at a value of 25 BTU/hr-ft^2. This a representative value, and could vary considerably, depending on the surface radiating properties of the parent vehicle. However, the heat flux is small, and does not materially affect the cocoon temperature. Thus variations in the value of these heat flux would not alter the results of this analysis.

Heat Rejected

The net heat rejected from the cocoon (q_{NET}) is the sensible portion of man's metabolic heat generation rate. This sensible heat rate was obtained from data on latent heat rejection presented in Reference 3.

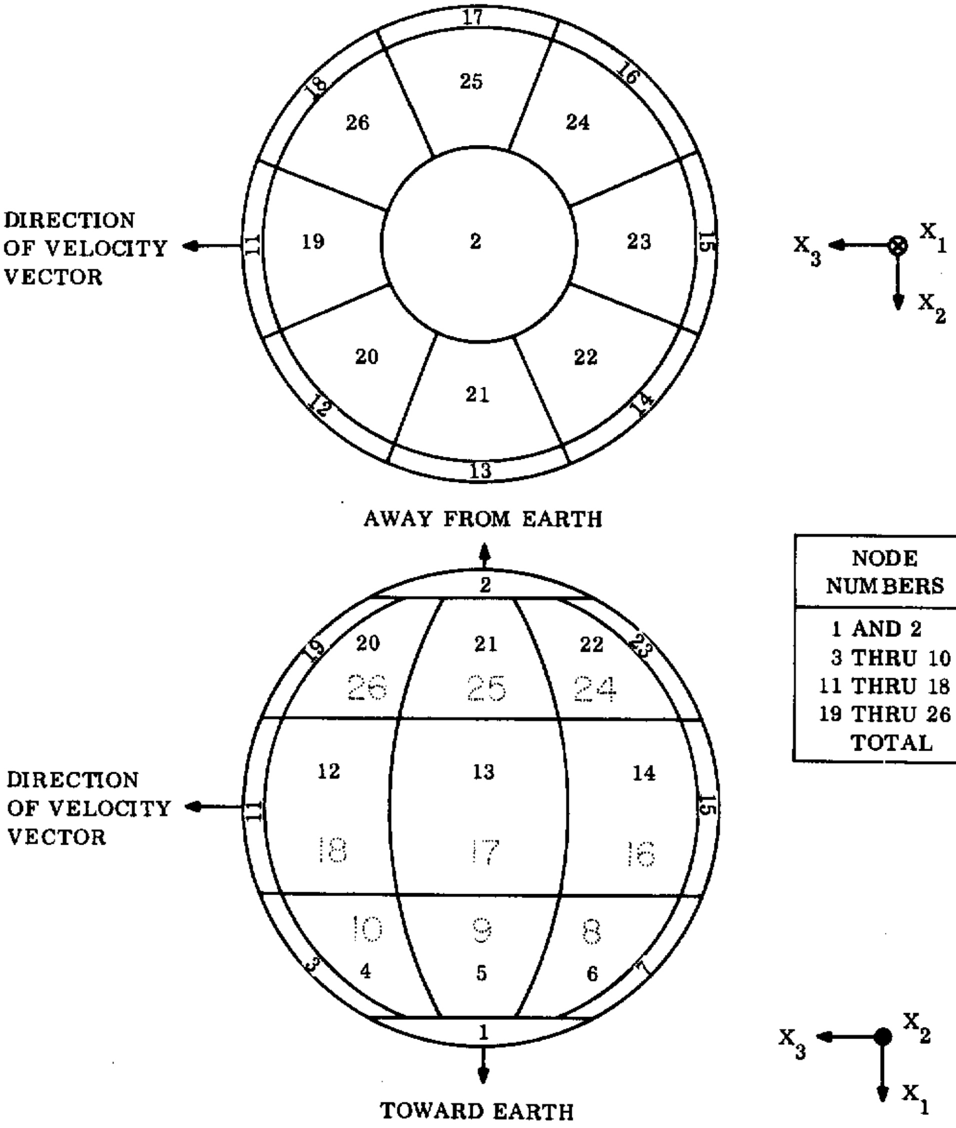
The following values were obtained from Reference 3 and are plotted in Figure 5.

qMetabolic (BTU/hr.)	Source	Air Temperature (^{o}F)				
		65	70	75	80	85
500	Latent (BTU/hr.)	146	175	223	280	340
	Sensible (BTU/hr.)	354	325	277	220	160
300	Latent (BTU/hr.)	63	86	117	146	186
	Sensible (BTU/hr.)	237	214	183	154	114

Note that the net heat rejected varies between a high of 354 BTU/hr. and a low of 114 BTU/hr. depending upon man's metabolic rate and the surrounding air temperature.

Several schemes were considered to provide the thermal control required in the Emergency Cocoon. Among these are; a moveable shutter assembly (Appendix III), a series of reflective patches to vary the α and ϵ properties of the cocoon (Appendix IV) and finally a multilayer blanket of aluminized Mylar film. The Mylar-film blanket was adopted for use with the cocoon system.

The design consists of superinsulation panels (similar to the geometry of the cocoon outer layer gores) which are fabricated from 15 layers of 1/4-mil-thick, aluminized Mylar and an outer and innermost layer of 2-mil-thick, aluminized Mylar (used for tear-resistance) joined together in a manner to minimize heat loss through the insulation. (See Figure 6.) The outer layer of the assembly has the aluminized surface facing inward (Mylar surface facing outward) so that the α/ϵ value of the assembly for the surface is approximately 0.3. (See Reference 5.) (This eliminates the need for an additional coating on the outer surface.) At installation of the insulation on the cocoon, each layer was overlapped in a layer-by-layer manner with the aluminized



NODE NUMBERS	AREA ft^2
1 AND 2	4.3
3 THRU 10	3.83
11 THRU 18	5.4
19 THRU 26	3.83
TOTAL	113

Figure 4. Nodal Geometry of Spherical Cocoon

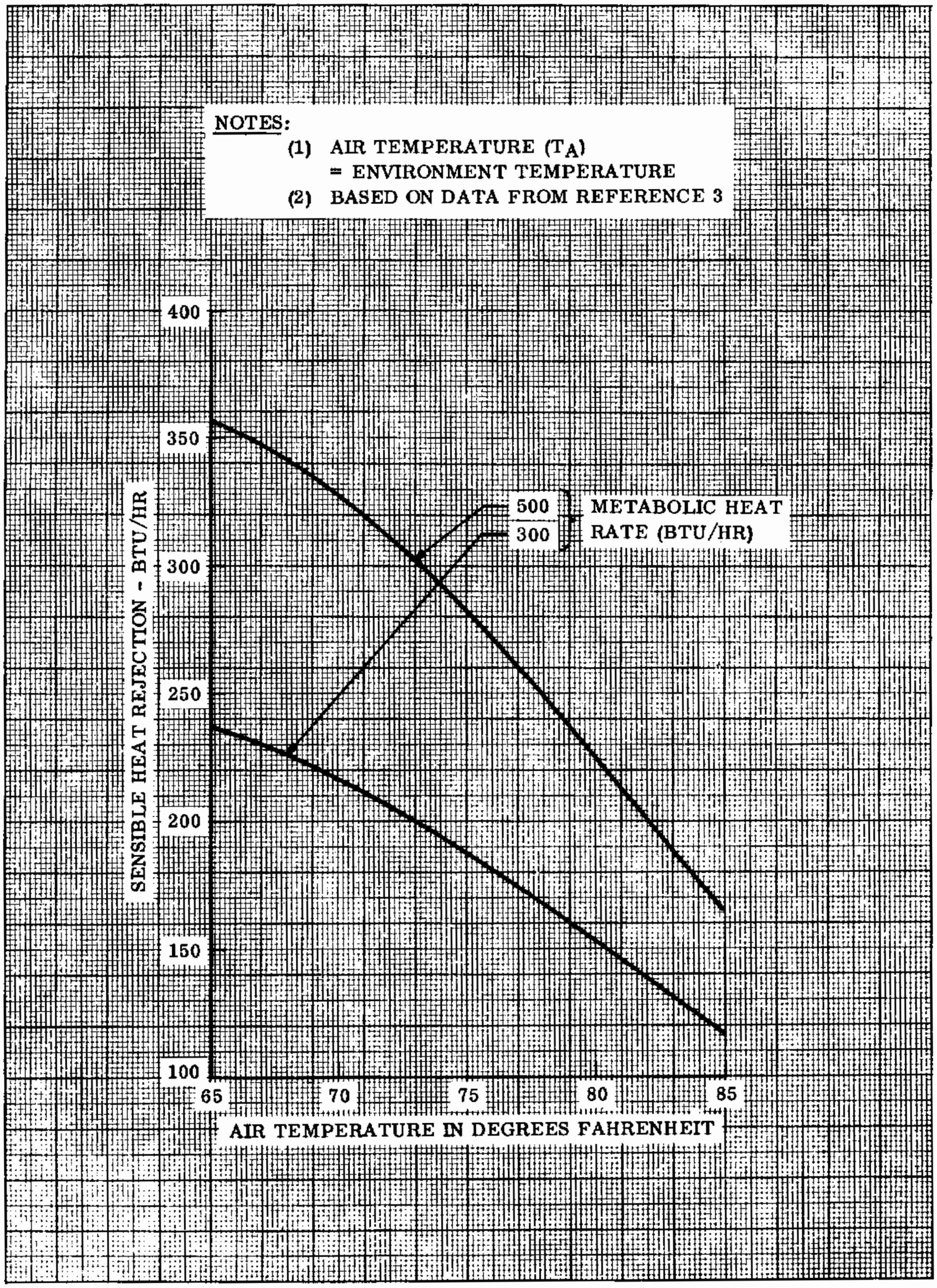
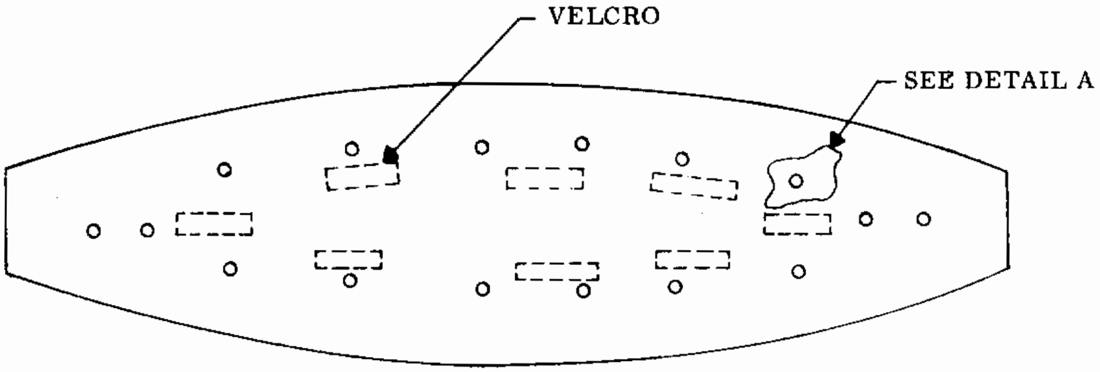
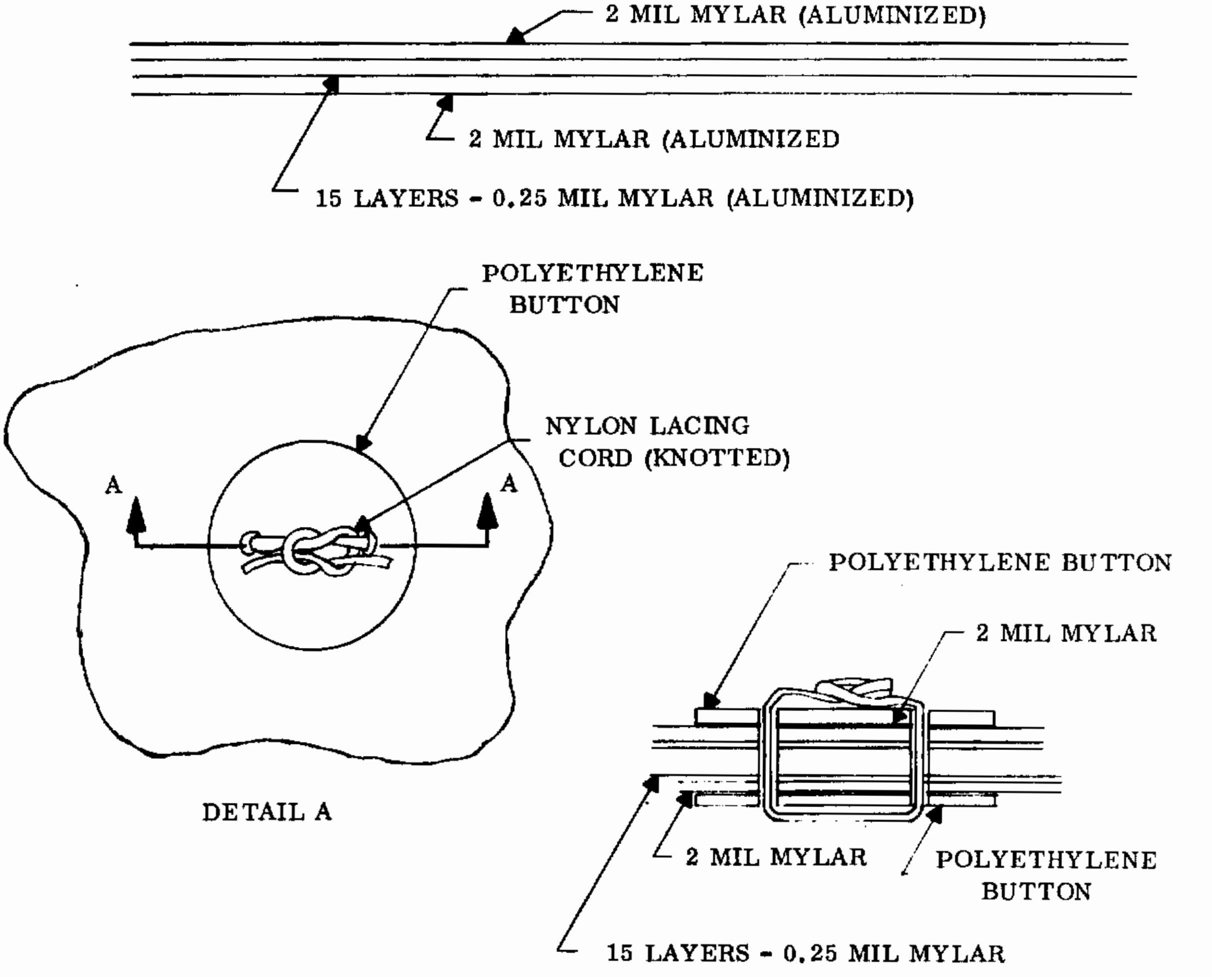


Figure 5. Man's Sensible Heat Rejection as a Function of Air Temperature



SUPER-INSULATION GORE



DETAIL A

SECTION A-A

Figure 6. Superinsulation Gore Assembly

TABLE I
INSTANTANEOUS AND AVERAGE ORBITAL HEAT FLUX INCIDENT UPON COCOON FOR HOT CASE 1

Node	S + A (BTU/hr-ft^2)	E + Qp (BTU/hr-ft^2)
1	.6	83.3
2	.4	25
3	.7	64.2
4	234.5	64.2
5	331.4	64.2
6	234.3	64.2
7	.6	64.2
8	.2	64.2
9	.2	64.2
10	.2	64.2
11	.6	31.0
12	331.5	31.0
13	468.6	31.0
14	331.2	31.0
15	.5	31.0
16	.1	31.0
17	.1	31.0
18	.1	31.0
19	.5	10.3
20	234.3	10.3
21	331.3	10.3
22	234.2	10.3
23	.4	10.3
24	0	10.3
25	0	10.3
26	0	10.3
Body Avg.	108.6	36.1

S = Solar Flux
A = Albedo Flux
E = Earth-Emitted Flux
Q_p = Flux From Parent Vehicle

TABLE II
INSTANTANEOUS AND AVERAGE ORBITAL HEAT FLUX INCIDENT UPON COCOON FOR COLD CASE

Node	A (BTU/hr-ft^2)	E + Q_p (BTU/hr-ft^2)
1	.1	23
2	0	5
3	.05	9
4	.05	5
5	.05	10
6	.05	5
7	.05	9
8	.1	18
9	.1	18
10	.1	18
11	0	4
12	0	5
13	0	25
14	0	5
15	0	4
16	0	8.5
17	0	8.5
18	0	8.5
19	0	.8
20	0	0
21	0	5
22	0	0
23	0	.8
24	0	1.5
25	0	1.5
26	0	1.5
Body Avg.	0	7.85

A = Albedo Flux
E = Earth-Emitted Flux
Q_p = Flux From Parent Vehicle

TABLE III
AVERAGE ORBITAL HEAT FLUX INCIDENT UPON COCOON FOR HOT CASE 2

Node	S + A (BTU/hr-ft^2)	E + Q_p (BTU/hr-ft^2)
1	83.5	83.3
2	145.5	25
3	95.3	64.2
4	82.4	64.2
5	63.9	64.2
6	84.9	64.2
7	98.1	64.2
8	85.1	64.2
9	64.1	64.2
10	82.5	64.2
11	120.0	31.0
12	93.0	31.0
13	28.6	31.0
14	93.6	31.0
15	120.8	31.0
16	94.0	31.0
17	29.3	31.0
18	93.5	31.0
19	141.4	10.3
20	128.1	10.3
21	107.4	10.3
22	126.4	10.3
23	139.7	10.3
24	127.0	10.3
25	108.2	10.3
26	128.7	10.3
Body Avg.	97.3	36.1

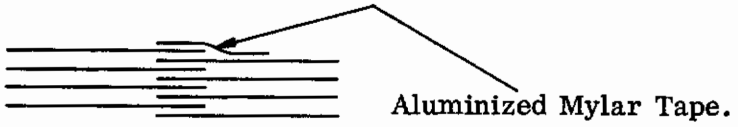
S = Solar Flux
A = Albedo Flux
E = Earth-Emitted Flux
Q_p = Flux from Parent Vehicle

TABLE IV
INSTANTANEOUS ORBITAL HEAT FLUX INCIDENT UPON COCOON FOR HOT CASE 2

Time (Min.)	Node 1		Node 2		Node 11		Node 13		Body Avg.	
	S + A	E+Q_p	S + A	E+Q_p	S + A	E+Q_p	S + A	E+Q_p	S + Q	E+Q_p
	(BTU/hr-ft^2)		(BTU/hr-ft^2)		(BTU/hr-ft^2)		(BTU/hr-ft^2)		(BTU/hr-ft^2)	
0	4.4	83.3	0	25	468.5	31	0	31	108.5	36.1
10	161.8	83.3	306.3	0	414.6	31	60.2	31	179.3	36.1
20	244.9	83.3	463.5	0	159.0	31	91.1	31	213.8	36.1
30	208.7	83.3	395.1	0	77.6	31	77.6	31	204.6	36.1
40	70.9	83.3	134.3	0	26.4	31	26.4	31	144.1	36.1
47.3	106.6	83.3	0	25	0	31	0	31	0	36.1
47.54	0	83.3	0	25	0	31	0	31	0	36.1
50	0	83.3	0	25	0	31	0	31	0	36.1
60	0	83.3	0	25	0	31	0	31	0	36.1
70	0	83.3	0	25	0	31	0	31	0	36.1
80	0	83.3	0	25	0	31	0	31	0	36.1
84.69	0	83.3	0	25	0	31	0	31	0	36.1
84.94	106.6	83.3	0	25	456.2	31	0	31	114.6	36.1
88.03	4.4	83.3	0	25	468.5	31		31	108.5	36.1

S = Solar Flux
A = Albedo Flux
E = Earth-Emitted Flux
Q_p = Flux from Parent Vehicle

Mylar layers of an adjoining panel as shown in the following sketch.



This type of fabrication will minimize edge losses from the superinsulation. The insulation blanket was attached to the cocoon with "Velcro" strips. (Adhesive-backed "Velcro" was used for this application to simplify attachment of the strips to the cocoon.)

The analysis of this design is summarized in Table V. The analysis is based on the incident heat flux given in Tables I through IV and the methods given in Appendix I and II, using the following values:

(1) $\epsilon_{EFF} = 0.025$ for superinsulation
(2) 2 windows, each 4.5 in. in diameter with $\epsilon = 1$.
(3) $\alpha/\epsilon = 0.318$ (from Reference 5)
(4) Steady-state conditions (no thermal capacitance).

Table V shows the cocoon interior temperature without heater power, and the battery power and weight required to maintain a minimum cocoon temperature of 65°F. Note that for the coldest environment (shade, with blockage) battery power of approximately 56 watts is required. Based on 50 watt-hr/lb. battery (for a discharge rate of 4 hours), approximately 5 pounds of batteries would be required for a mission whose shade time duration is 4 hours.

COMPOSITE WALL STRUCTURE

The wall is composed of two distinct layers, an outer fabric bag and an inner layer which contains the permeable membrane. Each layer is fabricated separately from gores of the respective material. For the fabric material, i.e., the outer bag, 12 gores are sewn together to form a sphere when inflated. For the inner layer, the seams of 18 gores are lapped and bonded together to form a sphere closely approximating that formed by the outer bag. The two layers are joined together at various points with adhesive so that they will inflate and deflate with a minimum of relative movement between layers.

The inner layer serves as the gas-retaining structure of the cocoon. This layer consists of the triple-ply silicone rubber membrane sandwiched and bonded between two non-woven Dacron mats. Thus the inner layer is a composite structure in itself. The technique of bonding the silicone rubber membrane between the Dacron layers was developed by the General Electric Company's Research and Development Laboratories. The material selection for the membrane backup layer was based upon a good

TABLE V
EMERGENCY COCOON WITH SUPERINSULATION AND HEATERS

Orbit	Condition	Position	(S+A)* (BTU/ hr-ft^2	(E+Q$_p$ (BTU/ hr-ft^2)	α / ϵ	$\dot{q}$ meta. (BTU/ hr.)	$\dot{q}$ sens (BTU/ hr.)	T_c** (oF)	Battery Power and Weight To Maintain T=65°F	
									(watts)	(LB***)
Hot Case 2	In Sun	Sub-Solar	214	36	.318	500	160	85	---	---
(Near Noon)	In Sun	Sub-Solar	214	36	.318	300	154	82	---	---
(Near Noon)	In Sun	Near Shade	108.5	36	.318	500	250	77	---	---
(Near Noon)	In Sun	Near Shade	108.5	36	.318	300	225	70	---	---
(Near Noon)	In Shade	No Blockage	0	36	.318	500	342	69	---	---
(Near Noon)	In Shade	No Blockage	0	36	.318	300	237	36	27	2.5
(Near Noon)	In Shade	Blockage	0	7.85	.318	500	400	57	23	2.0
(Near Noon)	In Shade	Blockage	0	7.85	.318	300	237	-1	56	5.0
Hot Case 1	In Sun	Any	108.6	36	.318	500	250	77	---	---
(Near Polar)	In Sun	Any	108.6	36	.318	300	225	70	---	---
(Near Polar)	In Shade	(See above cases)	---	---	---	---	---	---	---	---

1. $(\epsilon A_T)_e = (\epsilon A_T)$ superins. $+ (\epsilon A_T)$ windows $= (.025)(130) + (1)(.22) = 3.5$

2. $\alpha / \epsilon = 0.3$ for aluminized Mylar with Mylar surface facing outward.
(See Table I of Reference 5).

3. Steady-State conditions.

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* Average Over Cocoon
** Cocoon Temperature Without Heater Power
*** Battery Weight for a 4 Hour Shade Time Duration

balance of the following:

1. Stiffness of the final assembly - material chosen for use should not be too stiff to collapse and fold readily.
2. Bond integrity and strength between the fabric and the membrane - the material had to be compatible with the established bonding procedures.
3. Membrane support - the material had to be relatively close woven to support the membrane yet had to exhibit a high degree of porosity.

Several samples of material were tested including a Nylon fabric pattern and a unidentified non-woven fabric previously used as the standard backup material of the membrane composite. A spunbonded polyester fabric, "Reemay" weight: 1 oz/yd^2, (3.39×10^{-3} gms/cm^2) was finally chosen.

In formulating the design for the wall strucutre, an unsuccessful attempt was made to bond the silicone rubber membrane directly to the outer bag. The outer fabric failed to give adequate support to the membrane, causing the membrane to extrude through the pores in the fabric under pressure load where it could be easily damaged. Shearing forces resulted in failure of the permeable film as well. Problems were also encountered in obtaining an adequate bond between the membrane and the fabrics. It was therefore decided to utilize a separate inner layer incorporating the silicone rubber membrane.

During fabrication the inner composite layer was pressurized, and the inner layer transferred the pressure load to the outer fabric bag. The outer fabric then contained the hoop stresses generated by the cocoon internal pressure. The only stress on the intermediate layer was a compressive stress across the membrane of 5 lb/in^2 (0.352 kg/cm^2) at normal operating pressure. The Dacron fiber mat and outer fabric bag provided adequate backup to the membrane to prevent damage from this load.

The function of the outer fabric bag was to provide the strength necessary to withstand the cocoon internal pressure load of 5 psi (0.352 kg/cm^2). Burst pressure equal to 2 times the normal operating pressure was considered as the design point of the outer layer material.

The required outer fabric material strength was calculated as follows: The hoop force in the 6-ft. (183 cm) diameter inflated sphere is $= r^2 p \pi$

where r = radius, 36 inches (91.5 cm)

p = pressure differential, lbs/in^2 = 10 (burst pressure) (.703 Kg/cm^2)

$\therefore$ hoop force = $\pi (36)^2 (10) = 40,700$ lbs (18,500 Kg)

Since the tensile strength of fabrics is rated in lbs. per inch of cross section length, it is convenient to find the fabric strength required per inch. This is the hoop force divided by the circumference of the sphere, thus

$$\text{Fabric tensile strength} = \frac{40,700}{2\pi r} = 180 \text{ lbs/in } (32.1 \text{ kg/cm})$$

SEAM DESIGN - OUTER FABRIC BAG

The parameter of interest in the design of fabric seams is seam efficiency. This is calculated by dividing the tensile strength of the seam by the tensile strength of the parent material. Thus,

$$\text{Seam efficiency, } \eta = \frac{\text{seam strength}}{\text{fabric strength}} \times 100, \ \%$$

Seam efficiency depends on such factors as the type of seam, type of stitch, size of thread, and number of stitches per inch. To determine the optimum type of seam, information was obtained on the seam designs utilized in the fabrication of parachute canopies. Reference 6 indicates that a french fell seam is slightly stronger than a plain lap seam and has the additional advantage of covering and thus protecting the edges of the fabric. Figure 7 shows the details of a french fell or "lap" seam, which is designated type LS_C by Federal Standard No. 751, "Stitches, Seams, and Stitching". This type of seam is made by folding in and interlapping the edges of two plies of material so that the edges of the material are concealed and seamed with one or more rows of stitches.

The strongest type of stitch for joining fabrics is type 301, (See Reference 6.) This is a two-thread link stitch and is utilized in most common sewing machines. Figure 8 shows the details of the 301 type stitch.

However, a type 401 stitch is also useful for joining fabrics in parachute construction. This is a double lock chain stitch (Figure 9) which utilizes considerably more thread per length of seam than the type 301 stitch. The seams so joined are thus capable of greater elongation without creating excessive tensile stress in the thread itself. This is important in the construction of the cocoon for two reasons. One, a seam with a type 401 stitch is able to elongate with the elongation of the fabric under load. This helps maintain the spherical shape of the cocoon and prevent "ballooning" of the individual gores. Two, the seam will be subjected to biaxial stress. The type 401 stitch allows the seam to stretch in a longitudinal direction without putting excessive tension on the thread.

The strength of a type 401 stitch compared to a type 301 stitch can be calculated as follows: (Reference 7)

$$\frac{\eta 301 - \eta 401}{\eta 401} \times 100 = 15.7$$

where $\eta 301$ = seam efficiency with type 301 stitch
$\eta 401$ = seam efficiency with type 401 stitch

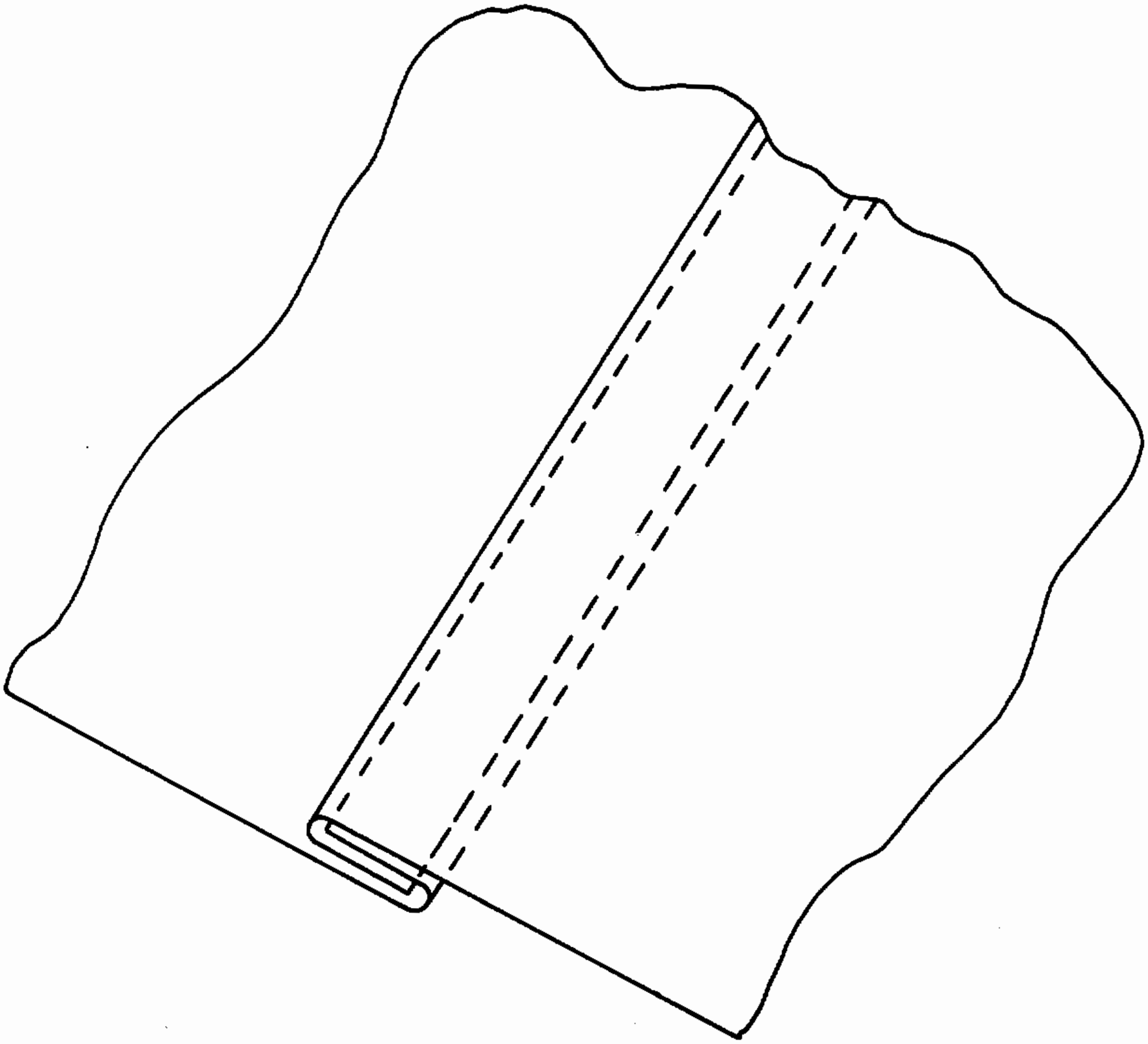


Figure 7. Type LSc Seam - Fed. Std. No. 751

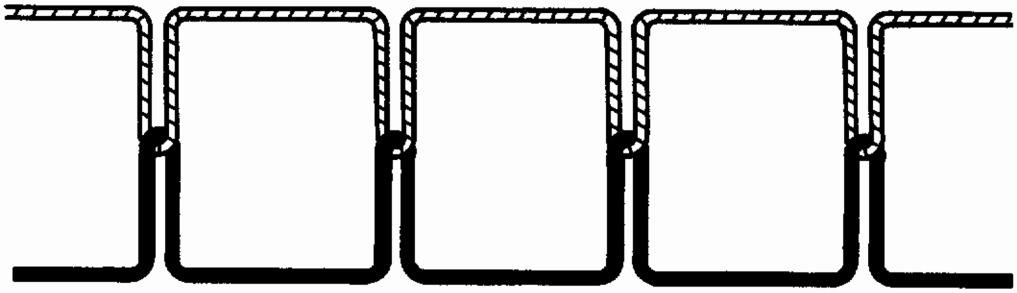


Figure 8. Type 301 Stitch - Fed. Std. No. 751

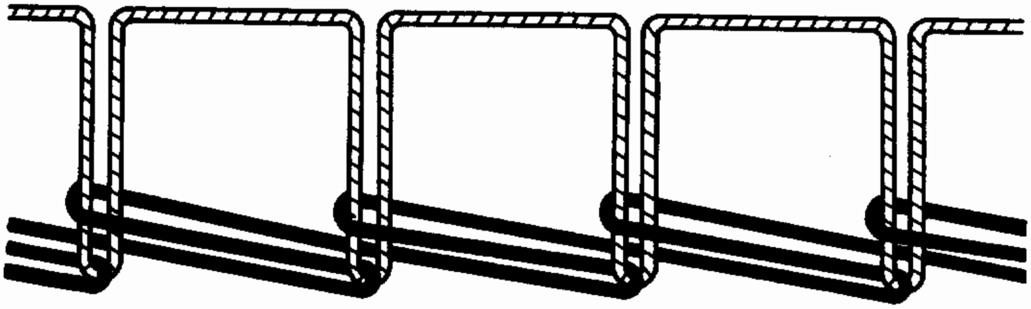


Figure 9. Type 401 Stitch - Fed. Std. No. 751

Thus, if seam efficiency with a type 301 stitch were 90%, the equivalent efficiency with a type 401 stitch would be:

$$\frac{90 - \eta 401}{\eta 401} \times 100 = 15.7$$

$$\eta 401 = \frac{90}{1.157} = 78\%$$

The seam efficiency developed with any type stitch depends on the size of the thread and the number of stitches per inch. If the thread is too small, it will fail under load. A large thread, on the other hand, requires a larger needle for sewing, with more damage to the fabric material and thus lower seam efficiencies. Table VI, taken from data of reference 7, indicates that size F thread is optimum for the fabric weights required in the Emergency Cocoon (4.5 to 7 oz/yd^2).

Table VI also shows the relationship between seam efficiency and number of stitches per inch. Generally, the seam efficiency increases as the number of stitches per inch increases. A maximum point is reached however, after which the seam efficiency decreases with an increase in stitches per inch. This occurs because the fabric is damaged by the needle as the seam is sewed, and at a certain point, the fabric damage contributes more to the weakness of the seam than the additional stitches add to the strength of the seam.

The seam design chosen for the Emergency Cocoon was 11 stitches per inch of size F thread with four rows of stitches. This would provide a seam efficiency of about 90% with a type 301 stitch, and an efficiency of about 78% with a type 401 stitch.

The required fabric strength for the outer fabric bag of the cocoon, using this seam is:

$\frac{180}{.90}$ = 200 lbs/in (35.7 Kg/cm) with type 301 stitch and $\frac{180}{.78}$ = 231 lbs/in (41.2 Kg/cm) using a type 401 stitch.

Adding a 10% design margin, these strengths become 220 lbs/in (39.3 kg/cm) and 254 lbs/in (45.4 kg/cm) respectively.

For any type of fabric, the weight is proportional to the strength. Thus, for example, a Nylon fabric of 4.3 oz/yd has a strength of about 240 lbs/in (42.8 kg/cm). Using this as a nominal point, the difference in fabric weight required when using a type 401 stitch as compared to a 301 stitch is:

$$W = \frac{4.3}{240}(254) \quad \frac{4.3}{240}(220)$$

$$W = 4.55 - 3.94 = .61 \text{ oz/yd.}$$

TABLE VI
SEAM EFFICIENCY vs. THREAD SIZE, TYPE OF STITCH AND NUMBER OF STITCHES (DATA FROM REFERENCE 7.)

	Seam efficiency (average, all samples)								
Fabric	MIL-C-8021, Type I (4.5 oz/yd^2)					MIL-C-8021, Type II (7 oz/yd^2)			
Type of Seam	$LS_C{}^2$ Δ		LS_C 4 Δ			LS_C 2 Δ		LS_C 4 Δ	
Type of Stitch	301	301	301	301	401	301	301	301	301
Thread Size	E	E	E	E	E	E	F	E	F
5 stitches/in.	54%*	59.4*	80.1%*	87.8%*	77.8%*	37.9%*	40.6%*	65.3*	68.8*
8 stitches/in.	68.4*	76*	78.7*	87.5	---	63.7*	62.5*	80.0*	92.4
11 stitches/in.	75.3	76.5	78.4	88.3	---	71.3*	78.2	80.0*	91.1
14 stitches/in.	71.8	74.2	80.4	87.8	---	---	---	---	---
8 to 11 stitches/in.	75.5	---	93.2	---	---	---	---	---	---

Notes

Δ - number indicates no. of rows of stitches, thus LS_C2 seam is a type LS_C seam with two rows of stitches.

* - indicates thread failure.

Since the surface area of the sphere is 12.6 yd.^{2} (10.5 m^2), the total weight difference is (0.61) (12.6) = 7.7 oz (218 grams). Because the weight penalty of using a type 401 stitch is small, it was concluded that this type of stitch should be utilized, due to its elongation properties as described previously.

SEAM DESIGN - INNER LAYER

The edges of the gores of the inner wall layer were overlapped and bonded together with an adhesive sealant. (See Figure 10). A small development program was conducted to determine a suitable adhesive sealant for this composite layer and as a result a room temperature vulcanizing (RTV) silicone rubber was chosen. The adhesive can penetrate the Dacron mat backing on the composite and bond directly to the membrane.

MATERIAL SELECTION - OUTER FABRIC LAYER

Strength

The outer fabric material of the Emergency Cocoon wall must have a minimum strength of 254 lbs/in (45.3 kg/cm) in both the warp and fill directions. (Warp and fill are the terms used to describe the fibers in the fabrics that run parallel to one another. The warp and fill fibers are woven at right angles to each other). Equal strength in both directions is necessary to provide equal elongation so that the cocoon will remain spherical when pressurized.

In the textile industry, the tenacity or tensile strength of a fiber is expressed as grams per denier (gpd). The denier of a fiber or yarn is a unit of weight and is equal to the weight in grams of 9000 meters of yarn. Thus the term grams per denier is a strength to weight ratio. In evaluating the strength of materials suitable for use as the outer fabric of the cocoon, the fiber with the highest tenacity, in gpd, will be best.

References 8 and 9 contain information relative to the tenacity of textile fibers. The higher tenacity fibers are listed in Table VII. Of the fibers listed, Nylon and polyester were chosen for closer examination because: (1) they are common fibers woven into many various fabrics made by many manufacturers, and (2) data on additional properties such as resistance to vacuum, temperature effects, etc., is generally well defined. Polyester fibers are manufactured under the trade names of Dacron, Fortrel, Kodel and Vycron.

Several fabric manufacturers were contacted and asked to supply samples of candidate materials. Table VIII lists the fabrics and their properties available from these manufacturers. Table VIII shows that a suitable Nylon fabric would weigh about 4.5 oz/yd^2 and a suitable polyester fabric would weight about 5.5 oz/yd^2. This would amount to a weight difference for the Emergency Cocoon of less than one pound in favor of the Nylon and, thus, is not significant to the extent of choosing Nylon over a polyester.

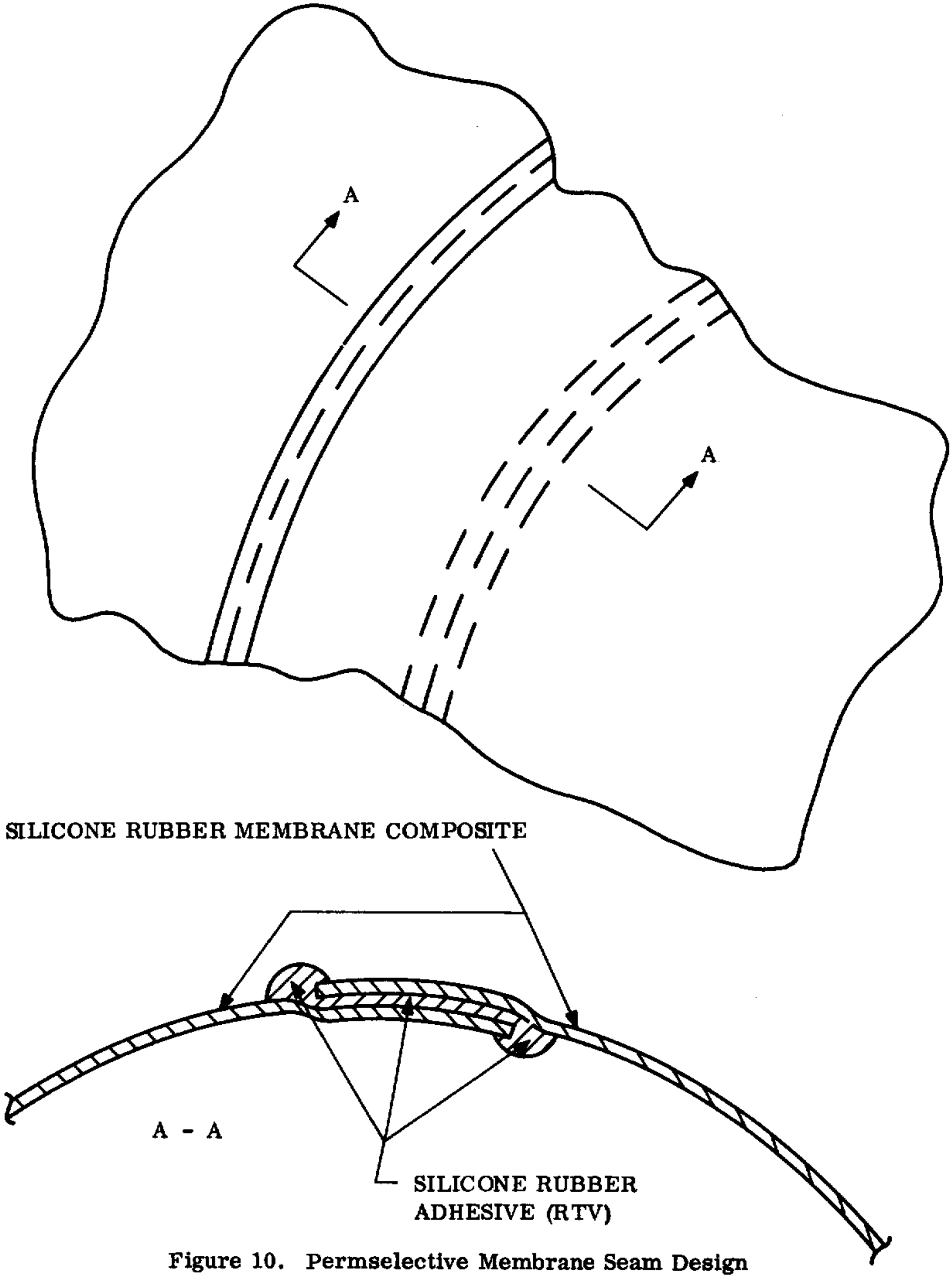


Figure 10. Permselective Membrane Seam Design

TABLE VII
FIBER TENACITY

Fiber	DRY TENACITY		WET TENACITY
	Grams per Denier	Thousands of lb. per inch^2	% of Dry Tenacity
Glass	6.0 - 7.3	195 - 237	65
Nylon, high tenacity	5.9 - 9.2	86 - 134	85
Polyethylene, high density	4.5 - 8.0	55 - 98	100
Polyester, high tenacity	6.3 - 7.8	111 - 138	100
Fortisan	6.0 - 7.0	117 - 136	95

TABLE VIII
CANDIDATE FABRICS FOR EMERGENCY COCOON WALL

Material & Style	Construction	Weight	Strength
Vycron Polyester	72 x 48 - 250 denier	4.4 oz/yd.^{2}	
Vycron Polyester	19 x 19 - 1100 denier	5.9 ox/yd^2	300 x 300 lb
Nylon	16 x 16 - 840 denier	4.2 oz/yd^2	250 x 250 lb
Nylon	166 x 112 - 40 denier warp, 70 denier fill	---	---
Rayon	94 x 60 - 300 denier	6.18 oz/yd^2	300 x 220 lb
Rayon	68 x 64 - 300 denier	5 oz/yd^2	200 x 210 lb
Fortrel	22 x 22 - 840 denier	5 oz/yd^2	22 x 220 lb
Fortrel	42 x 38	2.5 oz/yd^2	
Nylon	72 x 71	4.31 oz/yd^2	240 x 233 lb
Nylon	55 x 49	6.31 oz/yd^2	349 x 336 lb

Fabric Porosity

The porosity of the fabric should not inhibit gas transfer to and from the silicone rubber membrane. The fabric samples received, show that the relatively large denier with small thread count per inch have greater porosity than equal strength fabrics with small denier, large thread counts per inch. Porosity, in this case, means the quantity of air that can be forced through a unit area of the fabric per unit pressure drop.

Effects of Temperature

In the design of the Emergency Cocoon, the maximum external surface temperature was assumed to be 200°F, and the minimum temperature was assumed to be -50°F. These values are conservative since the calculated surface temperatures fall well within this range. In considering the effects of temperature on fiber properties, the textile industry has separated the data into two categories: (1) tensile properties of fibers tested at elevated temperatures and, (2) tensile properties of fibers tested at room temperature, after exposure to elevated temperatures. The latter data is often used as an indication of the heat degradation resistance of the fiber.

Comparison of the tensile properties of the two fibers at 200°F shows that high tenacity Dacron retains 80% of its strength while high tenacity Nylon retains but 75% of its strength. Nylon, after exposure to 200°F temperatures of 1800 hours, retains about 85% of its strength when tested at room temperatures. Dacron, on the other hand, can withstand temperatures of 250°F for 1800 hours and retain 100% of its strength, when tested at room temperature. Therefore, when considering temperature effects, Dacron is a better choice than Nylon for the outer fabric of the cocoon.

Abrasion and Wear Resistance

Nylon and the polyester fibers (Dacron, Fortrel, Kodel, and Vycron) are considered to have good abrasion and wear resistance properties. Nylon, however, is considered to be superior to any fabric for resistance to wear and abrasion. (See Reference 8.)

Resistance to Vacuum

Both Nylon and Dacron exhibit degradation when exposed for long periods in a high vacuum (Reference 10 and 11). Of the two, Nylon appears to degrade faster at a given temperature. Coatings can be used to protect the material against these effects, but these are considered a development item, and beyond the scope of this report.

The approach taken in this program was to limit the vacuum testing of the Emergency Cocoon to environments of something less than a high vacuum. A vacuum of 1×10^{-2} mm Hg is required to utilize the superinsulation of the thermal control system. However, vacuum effects on materials are not generally observed until a vacuum of 10^{-5} to 10^{-6} mm Hg has been reached. Thus, by employing a vacuum of 10^{-2} to 10^{-3} mm Hg, which is sufficient to test the life support and thermal control characteristics of the vehicle, and due to the limited duration of the vacuum testing anticipated, the effect of vacuum on the fabric method should be negligible.

Conclusions

Nylon is both stronger and more abrasion resistant than the polyester fabrics. However, these effects are not significant, since the polyester fabrics are almost the equal of Nylon in these respects. Of more significance is superiority of the polyester fabrics in resistance to temperature and vacuum. For these latter reasons, a polyester fabric (Dacron, Fortrel, Vycron, or Kodel) is considered the most suitable choice for the outer covering of the Emergency Cocoon.

As stated previously, the outer fabric bag, utilizing seams with type 401 stitches, should have a strength of 231 lbs in (41.2 Kg/cm). To provide this strength at 200°F, moreover, the polyester fabric should have a strength, at room temperature, of 231/0.8 = 289 lbs/in (51.6 Kg/cm). Adding a 10% design margin, then, results in a total required strength of 320 lbs/in (57.1 Kg/cm).

The material chosen for the outer layer was a Dacron fabric. The material was tested to a tensile strength of 439 lbs warp and 434.5 fill and weighed 8.7 oz/yd^2.

ERECTION MECHANISM

The cocoon erection mechanism provides the initial erection of the unpressurized cocoon to permit the test subject to enter the cocoon and close the hatch. It also supports the cocoon while the subject is preparing to leave the enclosure.

Several methods of erection were considered including an umbrella like mechanism and a series of pressurized pockets fabricated into the cocoon structure. The method chosen was a variation of this latter method and was related to the former method in that ribs are used to support the cocoon.

The umbrella-like method mentioned above imposed several limitations and requirements on the design, among which were: (1) the mechanism would not permit the structure to collapse completely, and (2) it required the use of a center post which would decrease the amount of useable space available inside the cocoon. Also, the man would have to enter the structure to erect it. Note that if the man could enter the cocoon before it has been erected, the erection mechanism would not be necessary.

The use of several pressurized pockets to erect the cocoon effectively overcomes the limitations of the umbrella system by using air pressure to raise the enclosure. This removes the requirement for a center post and permits the complete collapse of the structure. Also, the man does not have to enter the cocoon to erect it. However, the pressurized pocket scheme does have the drawback of reducing the effective area of membrane available. This problem was almost completely overcome by the erection method finally considered for use with the cocoon.

The cocoon erection mechanism (Figure 11) consists of a distribution manifold, three lengths of collapsible tube, and the necessary valving for pressurizing and venting the tubes. The distribution manifold is located at the access port, and metal clips are used to connect the manifold to the hatch ring. The erection tubes are 1.5 inches in diameter and are made of polyethylene sleeve covered with Dacron fabric. The tubes are sewn to the cocoon outer surface along a seam and are pressurized to approximately 15 psi to provide for the erection of the cocoon. Fittings are provided on the end of the manifold to facilitate pressurization. The erection system installed on the cocoon was a conceptual arrangement and was not required to lift the entire weight of the cocoon assembly in a 1 "g" environment.

HATCH

A hatch was provided to permit manned occupancy of the Emergency Cocoon. The size of the hatch was based on data presented in Reference 3 and 12. The hatch utilizes the internal pressure of the cocoon to provide the necessary sealing force on the O-ring seal, thereby, eliminating the need for latches, dogs, locks, etc., to open or close the hatch. The hatch is easily removed from the inside or outside of the cocoon when the cocoon pressure is equal to ambient.

The hatch opening in the composite wall of the cocoon is formed by wrapping the flexible wall around a ring of 1/4 inch-aluminum rod. The rod serves two purposes. (1) It simplifies fabrication of the hatch opening in the composite wall. The rod was formed into a ring of the correct dimensions to fit in the groove formed by the two hatch rings and the ends of the cocoon gores were then wrapped around the rod and stitched in place. This insured a uniform opening of the correct dimensions in the composite wall to match the hatch ring interface. (2) The rod prevents the fabric from the possibility of slipping between the hatch rings when under a load.

Two hatch rings are provided, one on either side of the composite wall. They are assembled using 1/4 - 20 machine screws. During assembly, the face of the rings that contacts the composite wall was treated with silicone rubber adhesive sealant to effect an airtight seal. The hatch cover was next inserted into the cocoon, and the hatch cover retaining ring bolted to the hatch rings. The retaining ring contains two O-ring seals, one to seal against the hatch rings, and the other to seal against the hatch cover. When in place and pressurized, the hatch cover is forced against the O-ring in the retaining ring, making a good seal. An observation port is located in the center of the hatch cover.

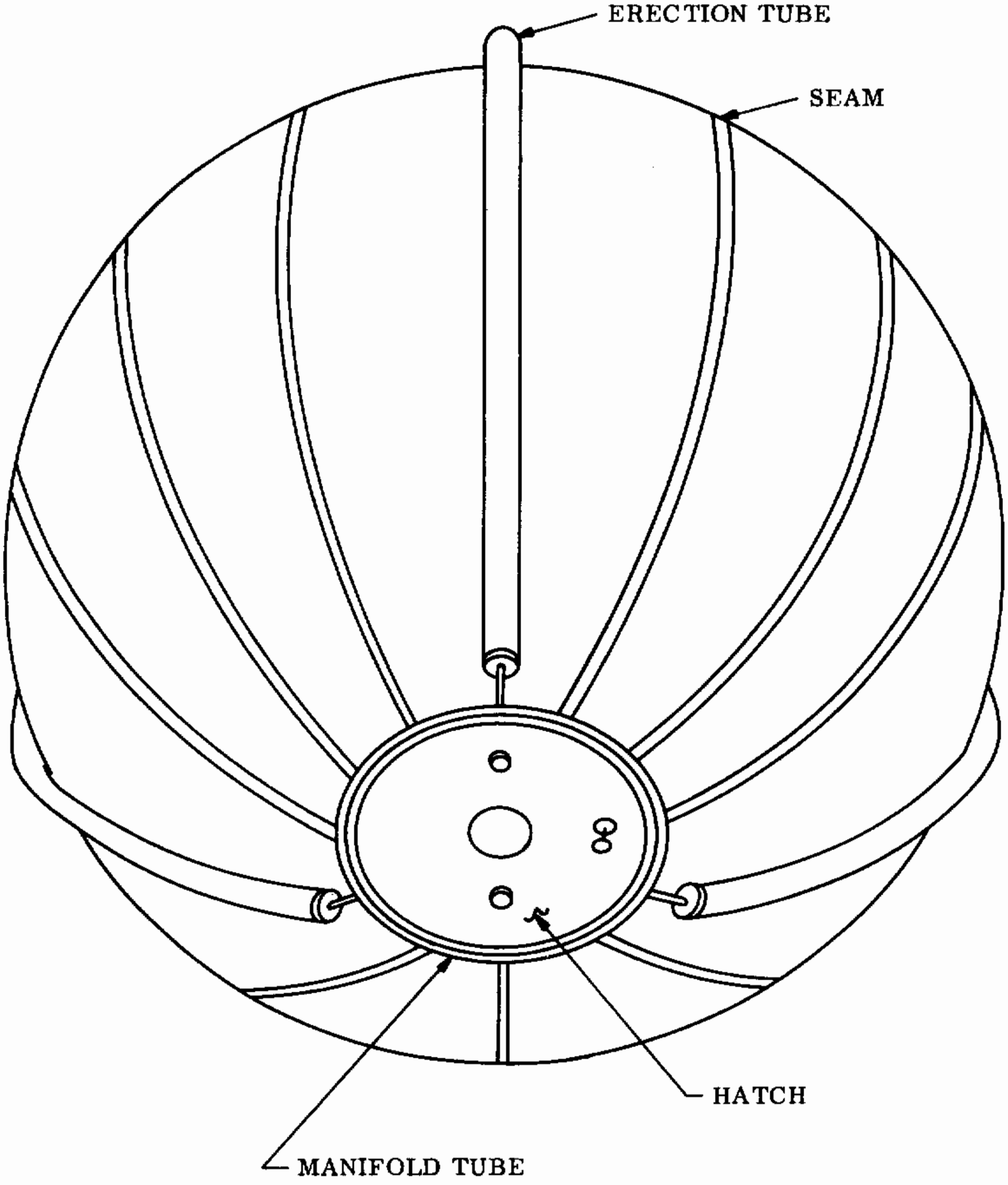


Figure 11. Emergency Cocoon Configuration

OBSERVATION PORT

The observation port is located directly opposite to the hatch. Its construction is somewhat similar to the hatch, with the opening in the composite wall being fabricated by folding and stitching the fabrics over a ring of aluminum rod. Two rings are then bolted to either side of the tubing and wall. RTV adhesive applied to the rings effects the air tight seal. A transparent plastic plate held between the two rings, forms the observation port.

FLOOR

The floor of the cocoon provides physical protection for the cocoon walls and permits easy movement of the test subject within the cocoon. It is fabricated from rigid polyurethane foam capable of supporting compressive loads of approximately 25 psi without excessive deformation of the foam. A sheet of aluminum honeycomb sandwich is bonded to the polyurethane foam to form a walking surface. The floor is fabricated in sections contoured to conform roughly to the curved inner surface of the cocoon to facilitate passage through the hatch. The foam is cut away on the underside to permit passage of the air within the cocoon to the membrane material under the floor. The membrane area masked off by the floor in this position is approximately 3 sq. ft. (2780 cm^2). The sections of the floor are joined together to form a flat walking surface. The floor was cut away in the area that would normally be located under the couch to provide for mounting the small fan and heater provided as called for in the thermal analysis.

COUCH

A couch was designed as part of the Emergency Cocoon System to permit manned testing of the atmosphere control capabilities of the cocoon by permitting the subject to assume a resting position. The couch was a standard commercial deck chair, modified for use and stowage within the cocoon.

PRESSURIZATION CONTROLS

To operate the Emergency Cocoon System, provisions were made to, (1) pressurize the erection tubes and thus erect the cocoon, (2) pressurize and maintain the cocoon at 5 psi above ambient using oxygen, and (3) depressurize the cocoon from 5 psi to ambient from either the inside or outside of the cocoon. In addition, a safety relief valve was provided to prevent inadvertent overpressurization of the Emergency Cocoon.

The gas supplies and regulation equipment necessary to perform these functions were not required to be included within the cocoon system. Rather, in this program, they are considered external to the system and are thus treated as ordinary items of test equipment, i.e., equipment required to check out and evaluate the cocoon system. Therefore, penetrations have been provided in the hatch to supply gas from the external regulation equipment to the cocoon interior. The following items (Figure 12) were mounted on the hatch plate:

(1) A manual vent valve for depressurizing the cocoon
(2) A safety relief valve, set to crack open at 5.5 psig.
(3) A fitting for connection of the oxygen line used to supply pressurization gas to the cocoon
(4) An Observation Port

There are two requirements which must be met when sizing the manual vent valve. (1) It must allow the cocoon to decompress in a reasonable time period. (2) It must not, when opened, create an explosive decompression condition or one where the decompression rate is equal to or exceeds 0.5 psi per second (35.2 grams/cm^2-sec). Rates above this limit could result in irreversible physiological damage to the test subject.

When the vent valve is first opened, the cocoon pressure will drop rapidly, then more slowly as the Δ P decreases. The effect of valve orifice size on this initial decompression rate, and on total time to decompress was calculated as follows:

Isothermal Decompression

$$\frac{P}{P_o} = e^{-\left(\frac{2}{K+1}\right)^{\frac{1}{K-1}} \sqrt{\frac{2g\ KTR}{K+1}} \left(\frac{C_D\ A_t}{V}\right)}$$

where P_o = initial cocoon pressure = 5 psi
P = cocoon pressure at time, t, (sec), psi
K = ratio of specific heats = 1.4
$g = \frac{32.2\ \text{lb.f}}{\text{lbm}} \quad \frac{\text{ft.}}{\text{sec}}{}^2$
T = cocoon temperature = 530°R
R = gas constant of cocoon atmosphere, $\frac{\text{ft. - lb.f}}{\text{lbm - }^\circ\text{R}}$
C_D = valve coefficient of discharge = 0.8
A = valve orifice area, ft.^{2}
V = cocoon volume, = 113 ft.^{3}
t = time, sec.

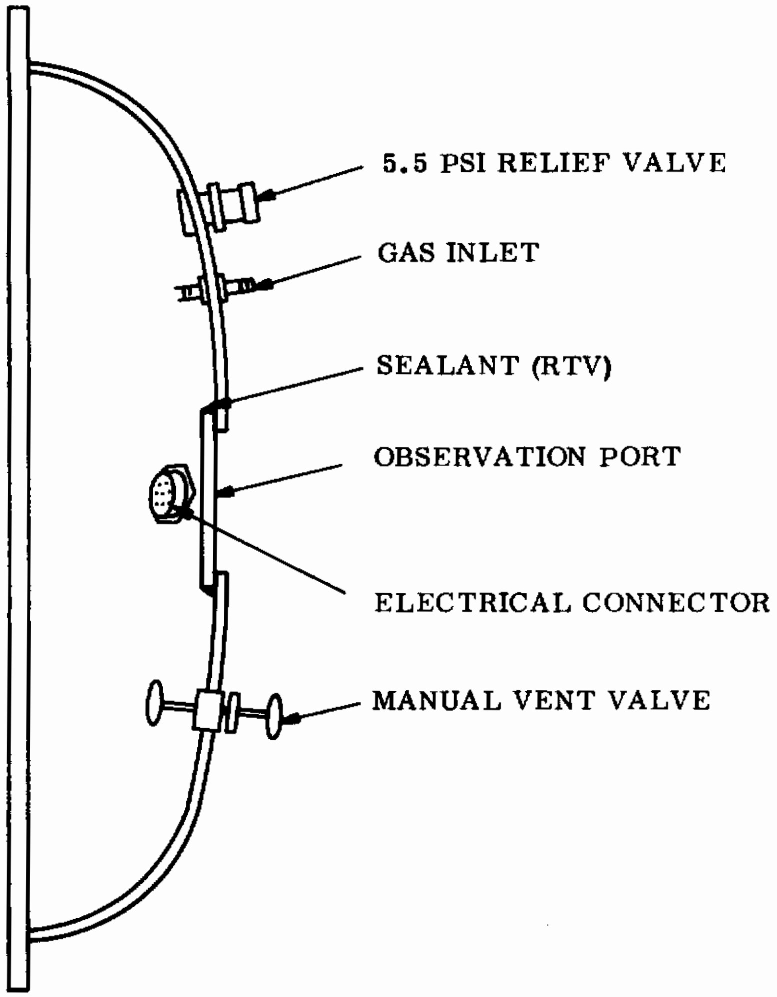


Figure 12. Cocoon Hatch Configuration

thus

$$\frac{P}{P_o} = e^{-4.96\ At}$$

A valve was designed (Figure 13) to provide a compromise between decompression time and valve size and weight. This valve is adjustable and is capable of operating with the following characteristics:

Initial Decompression Rate (from 5 to 4.5 psi)

$$\frac{4.5}{5} = e^{-4.96 \left[\frac{\pi\ (1)^2}{(4)\ (144)}\right] t}$$

$t = 3.9$ sec

This is well below the critical limit of 0.5 sec.
Decompression time (time for cocoon pressure to reach 0.125 psi)

$$\frac{0.125}{5} = e^{-4.96 \left[\frac{\pi\ (1)^2}{(4)\ (144)}\right] t}$$

$t = 136$ sec. $= 2$ min. 16 sec.

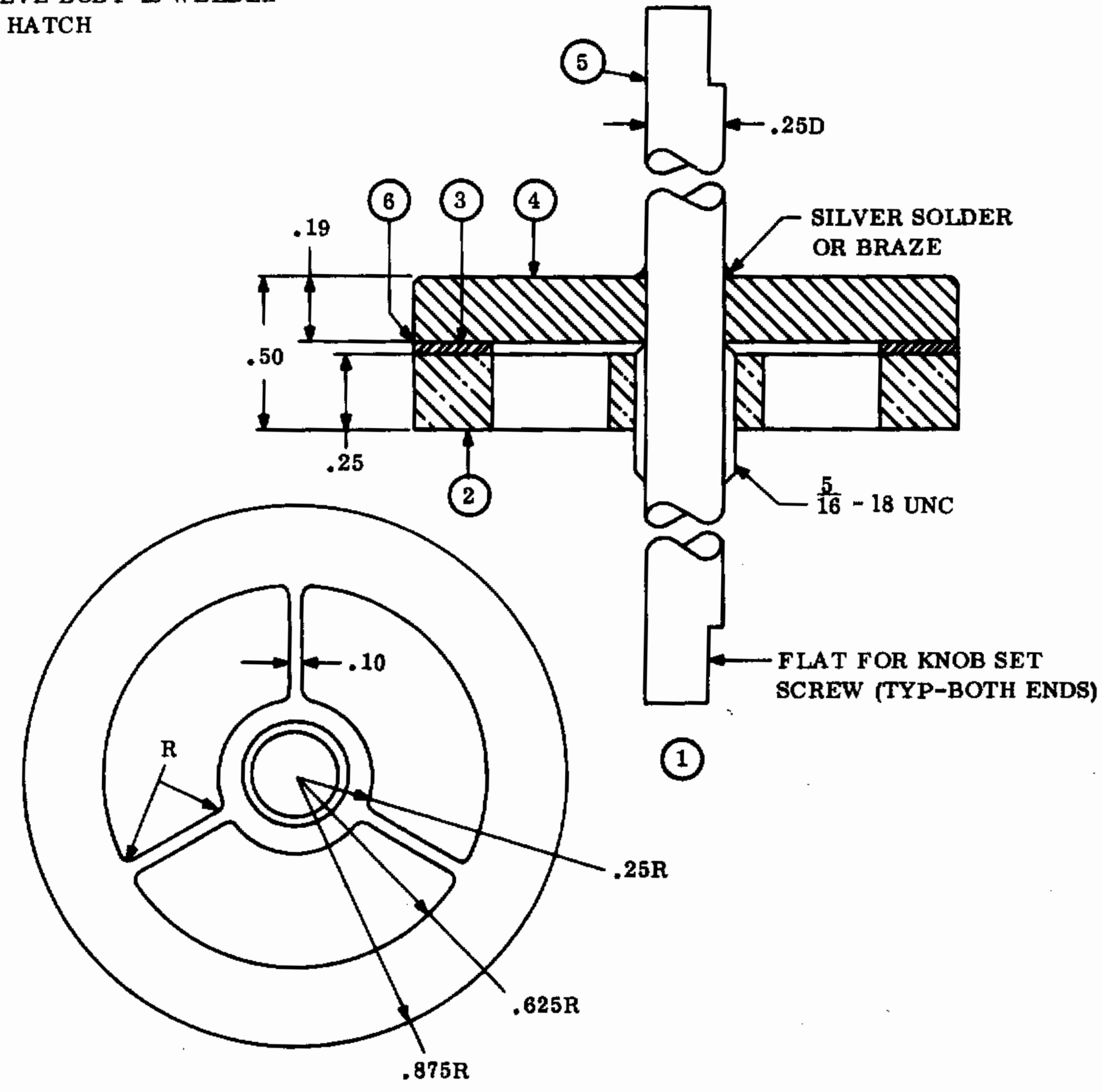
This is considered a reasonable time to allow for decompression of the cocoon. Larger valves could be used to shorten the decompression time without exceeding the maximum decompression rate, however, the physical size of the valve becomes large and relatively cumbersome.

LIST OF PARTS

1. VENT VALVE ASSEMBLY
2. VALVE BODY - 6061-ALUM
3. SILICONE RUBBER GASKET
4. VALVE PLUG - BRASS
5. VALVE STEM - BRASS
6. R. T. V. ADHESIVE

NOTE:

VALVE BODY IS WELDED
TO HATCH



VALVE BODY DETAIL

Figure 13. Cocoon Vent Valve

SECTION III

FABRICATION

The outer bag or pressure retention layer of the cocoon was fabricated by sewing 12 gores (sections of fabric cut to provide a desired shape when joined) of Dacron polyester fabric together to form a sphere when inflated. The gores were joined using a french fell seam with four rows of size F Dacron thread sewn with a type 401 stitch.

The inner bag is composed of a composite of a 0.00371 cm permselective silicon rubber membrane sandwiched and bonded between two layers of nonwoven Dacron polyester fabric. The composite is supplied in sheets 23" wide by 58" long. The gores for the inner bag were cut to the same general shape as the sections of a volley ball. This shape permitted maximum use of the membrane material. The gores were joined together using a lapped seam with three to four applications of RTV silicone rubber adhesive.

The assembly technique used in fabrication of the inner bag consisted of placing a rubber sounding balloon (inflated diameter of 8 ft) inside the outer bag and inflating this assembly. The pressure was raised to 5 psig (1018 mmHg) to attain the maximum size to be experienced by the outer bag during operation of the cocoon. When the outer bag and balloon assembly had reached 5 psi, the inner bag gores were taped to the outside of the outer bag in the proper relationship to the hatch and observation port, and the gores were then bonded together. This operation was performed on 3 gores at a time. When the 6 sections containing 3 gores each had been completed they were again placed over the outside of the outer bag and the seams formed by the 6 sections were bonded. An effort was made during this fitting procedure to crease or fold the gores to permit them to assume a more nearly spherical shape when assembled. When the 6 sections (18 gores) had been assembled, the outer bag and balloon assembly were deflated and removed from the inner bag through a hole cut in the relative location of the hatch for this purpose. Following removal of the outer bag, the balloon was removed, as was the hatch and observation port blank and the respective rings for these items.

The inner bag was now placed on the inside of the outer bag and cutouts were made in the inner bag for the hatch and observation port. When this had been completed, the cocoon was assembled.

The floor of the cocoon is a three-piece assembly composed of 0.25-inch thick aluminum honeycomb sandwich surface supported by blocks of polyurethane foam. Polyethylene blocks were bonded to the foam to support the assembly above the surface of the cocoon, thereby permitting air to circulate under the floor. This feature also permits exposure of the permselective composite beneath the floor to the cocoon atmosphere, thereby increasing the total area available for permeation. The polyurethane foam was bonded to the aluminum honeycomb sheet with adhesive.

The reclining chair is a standard deck chair modified to permit use within the cocoon. The modification consisted of shortening the chair in the area of the lower leg support, the substitution of nuts and bolts for rivets to permit disassembly for installation, and the substitution of a Nylon net fabric in place of the plastic strips normally found on chairs of this type.

An external support structure was also fabricated to support the Emergency Cocoon in the laboratory, and permit manned occupancy.

SECTION IV

TEST PROGRAM

Extensive testing was planned for the Emergency Cocoon to include a checkout test in a laboratory environment and a thermal vacuum test in the space environment simulator. (See Appendices for respective test plans.) The thermal vacuum test was to be conducted to provide an indication of the adequacy of the design under conditions simulating those of space. A system was to be provided that would have simulated the presence of a man within the cocoon during the test and instrumentation was being prepared to provide information on the thermal and atmospheric control systems. The test was to include operation of the space environment simulator and solar simulation equipment.

The checkout plan was formulated to permit comparison of the system performance with the permeation data obtained as a result of the materials evaluation tests described previously. This test program included pressurizing the cocoon to proof pressure levels (6.65 psig) and observing and measuring the amount of stretch of the cocoon structure. Observations made during the tests indicated that the outer layer of the cocoon stretched approximately 8%, for an increase in size of the structure from 65 inches in diameter at less than 1 psi to approximately 71 inches in diameter at 6 psi. The physical shape of the cocoon was not exactly spherical, but instead it was flattened in the areas of the hatch and the observation port. An important part of this test program involved leak checking the cocoon structure. The cocoon leak rate was found to be extremely high, and an extensive effort was made to overcome the problem. Attempts were made to locate and seal the leaks with a relatively low viscosity version of the widely used RTV sealant because of its ability to flow through the Dacron fabric layer of the membrane composite seal to the silicone rubber membrane. Several methods of leak detection were used, including the following: The human ear, a halogen leak detector, an ultrasonic leak detector, and a soap bubble test.

In spite of all efforts to repair the cocoon, the leak rate of the structure increased. A soap bubble test was performed on the entire structure to determine the extent of the problem. The test indicated widespread leakage over the entire surface of the cocoon. In addition, during the test periods several sections of the membrane composite was observed to have delaminated (that is, the inside layer of the Dacron mat had separated from the silicone rubber membrane). Following the determination of the extent of the leakage in the cocoon, further effort to correct the leakage was stopped.

SECTION V

FAILURE ANALYSIS

The leakage and delamination observed in the composite (i.e. Dacron - silicone rubber - Dacron) permselective wall of the cocoon persisted in spite of all attempts to locate and seal the leaks. The procedure utilized in these attempts was to pressurize the cocoon and locate and mark the leaks by using external leak detection devices (e.g., the ultrasonic or halogen leak detector). The cocoon would then be deflated, and a technician would enter the cocoon through the hatch, whereupon the cocoon would be reinflated. The technician applied RTV-112 sealant to the marked leaks from the inside of the cocoon. After waiting for the sealant to cure, the cocoon would be deflated and the technician would exit.

A great many leaks were sealed in this manner, but the cocoon leak rate increased rather than decreased. Also, areas appeared where the inner nonwoven Dacron fabric delaminated from the silicone rubber membrane. The many inflation/deflation cycles on the cocoon apparently destroyed the integrity of the perselective membrane. Accordingly, the program was redirected to determine the cause of the leakage and delamination, and thus a failure analysis was initiated. Tests on the composite perselective layer were performed to determine the following:

(1) Did the leakage result form composite delamination?
(2) What caused the delamination?
(3) Is the delamination a function of the manufacturing process? That is, the bond strength higher on one side of the composite than on the other as a result of manufacturing?
(4) If delamination does not cause the leakage, what does?
(5) What are possible solutions to the problems.

TEST RESULTS

The individual tests that were performed are summarized below:

Test I

A tensile test was performed in a manner which placed a stress on the silicone rubber membrane and Dacron nonwoven fabric bond, similar to that occurring in the cocoon due to stretching the composite during the pressurization of the cocoon. This test showed that the bond strength between the Dacron fabric and silicone rubber membrane was not equal on both sides of the membrane (i.e., there was a "weak" side bond and a "strong" side bond). This test indicated a tensile load of approximately 0.65 kilograms/cm would be sufficient to cause delamination of the weak membrane/backup material bond. From observations made in the cocoon during other tests it appears possible that this load could have been developed within the structure, thus causing the delamination observed in the cocoon.

Test 2

Weights were again applied as in Test 1, but this time tension was applied in two perpendicular directions at the same time. Results of this test closely verified those of Test 1.

Test 3

The cocoon structure was pressurized to determine the magnitude of the leak problem. The leaks were found by brushing a soap/water solution onto the cocoon. The quantity of leaks observed was extensive and covered the entire cocoon surface.

Test 4

A membrane composite sample, backed with heavy Dacron as used in the cocoon outer layer was pressurized to determine the effects of pressure on the supported composite material. The sample was pressurized to 12 psi with no membrane failure being observed. The test was concluded at that point because the support layer tore loose from the test fixture. No delamination was observed on the composite following disassembly of the test sample.

Test 5

A fatigue test was performed on a supported composite sample. This test consisted of cycling the sample approximately 1500 times between 5 psi and 0.25 psi. No significant change in the membrane was observed during the test. At the conclusion of the test, the sample was pressurized to 5 psi for approximately 17 hours with no change in membrane condition.

Test 6

Several tests involving various methods of creasing the membrane were conducted with the results consistently indicating that the failure of the membrane was due to folding or creasing. As a followup to this test, a delaminated sample was creased in a manner as near as possible to that used on the nondelaminated samples. This test indicated a marked decrease in the occurrence of leaks in the delaminated sample. In addition, a sheet of plain membrane (1.5 mil thick, silicone rubber completely unbacked) was severly creased and folded prior to testing and showed no sign of leakage.

Test 7

A partially delaminated gore was removed from the cocoon. It was found that:

(1) The weak bond side of the gore was toward the inside of the cocoon.
(2) The leaks in a random portion of the gore appeared to be in areas showing signs of previous creasing. (The backup layers of the composite appeared white in the crease areas.

TEST CONCLUSIONS

Delamination of the composite was investigated and found to result from stresses set up in the composite due to stretching of the fabric during cocoon inflation (Tests 1 and 2). Test 1 also showed that the membrane-Dacron bond was weaker on one side than the other and that delamination occurred within the cocoon when the weak side bond was on the inside (Test 7). It is possible, therefore, to eliminate the delamination entirely by placing the strong bond to the inside during fabrication of the cocoon.

The leakage was not caused by delamination or pressure (Tests 3, 4, 5). Rather, leakage was caused by creasing or wrinkling the composite layer, which created a row of leaks along the fold or crease line (Test 6). Since the cocoon is an inflatable structure, there were many such folds and creases in the composite due to the inflation/deflation cycles.

The nature of the permselective composite is such that it forms a hard, permanent crease when folded, much like that of paper as opposed to woven cloth. The stresses developed in this hard crease are sufficient to tear the silicone rubber membrane. This may be caused by the fact that, in a fold, the outer Dacron layer must stretch, and the inner Dacron layer must compress. The silicone rubber, being bonded between both, is thus torn. Or, the Dacron fibers themselves may punch holes in the membrane as they squeeze together in a fold. It is also significant that in samples with the Dacron fabric bonded to one side only of the silicone rubber membrane (the other side left bare), creases did not result in leakage. The use of a different backup material in the composite structure, one that does not form a "hard" crease or have soft fibers, may eliminate this leakage.

Earlier in the program, composite samples were fabricated utilizing a light woven Nylon. These samples were unsatisfactory in that the bond strength between the Nylon and silicone rubber membrane was poor. However, during the failure analysis, these samples were folded and creased in the same manner as the Dacron-silicone rubber composite used in the cocoon. The Nylon samples showed no leakage along these creases. Also, a bare silicone rubber membrane was folded and creased with no evidence of damage resulting. These tests again indicate that a material change may solve the problem.

Composite samples were fabricated using the Nylon woven fabric, with a different primer to increase the bond strength. Samples were fabricated with both the Dacron nonwoven fabric and the Nylon, using both the standard primer, previously used in preparing the composite for the cocoon, and the new primer. The Dacron samples were used as controls to check permeation data. Permeation tests were conducted and showed that the new primer did not effect the permeation rates of the silicone rubber. (The rates obtained for both primers were identical to those obtained earlier in the program). Bond strength tests showed however, that, the Nylon backed composites were still lacking in this respect. Bond strengths were considerably lower than the Dacron material. A light woven Dacron material, with handling properties similar to the Nylon, might exhibit sufficient bond strength and crease-leakage resistance to be useful in this program. However, time precluded the procurement, fabrication, and testing of such samples.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

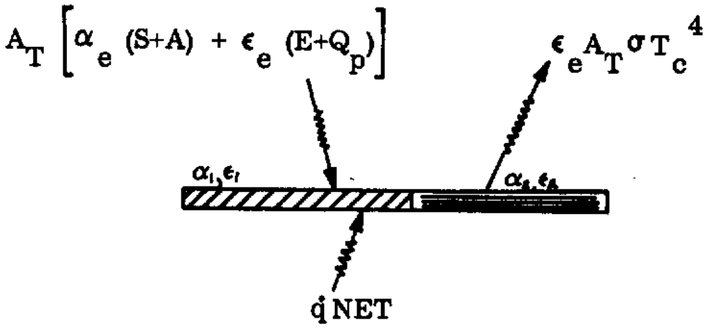
This program established the feasibility of designing and constructing a manned inflatable structure with a permselective wall for extravehicular or emergency space use. However, the objectives of demonstrating and testing the performance characteristics of the Emergency Cocoon were not fully met. To meet these objectives, a solution must be found to the maintenance of a leak-tight permselective membrane which is incorporated into an inflatable wall. A start toward this solution was made in the failure analysis conducted on the cocoon composite wall. The cause of the excessive leakage was found, and indications of means for preventing this leakage resulted.

Recommendations for future action required to meet the program objective take two different forms. (1) The silicone rubber permselective membrane can be laminated to different materials which will prevent leaks from occurring at fold lines. Effort is needed, in this approach, to define the required materials, which could range from a light Dacron cloth to a relatively thick open cell foam, necessary to protect the membrane. The probability of success appears high in this approach, since the bare silicone rubber membrane can, by itself, withstand severe creasing and handling without damage. (2) The walls of the cocoon can be made impermeable, and a fixed noninflatable permselective membrane gas exchanger utilized on the inside to remove CO_2 and H_2O. This approach eliminates the folding, moving, creasing, etc. of the membrane within an inflatable wall, and thus eliminates the leakage problem. It is also adaptable to use of other permselective membranes, such as the cellulose acetate membrane developed by the G.E. Research and Development Center. This latter membrane, although not adaptable to an inflatable wall, could be used in a fixed gas exchanger with increased performance resulting due to its very high separation of CO_2 and O_2. The results of further follow-on effort being conducted at this time on the cellulose acetate membrane, may make this latter approach the more desirable of the two.

APPENDIX I

COCOON TEMPERATURE (Tc)

Taking a heat balance on an isothermal surface with two different coatings (1 and 2):



$$WC_p \frac{dT_c}{dt} = A_T \left[\alpha_e (S+A) + \epsilon_e (E+Q_p)\right] - \epsilon_e A_T \sigma T_c^{\,4} + \dot{q}NET \qquad (1)$$

Dividing by $\epsilon_e A_T$

$$\frac{WC_p}{\epsilon_e A_T} \frac{dT_C}{dt} = \frac{\alpha_e}{\epsilon_e} (S+A) + E + Q_p - \sigma T_c^{\,4} + \frac{\dot{q}NET}{\epsilon_e A_T} \qquad (2)$$

For steady-state conditions, $\frac{dT_c}{dt} = 0$ and equation (2) becomes

$$\sigma T_c^{\,4} = \frac{q\,NET}{\epsilon_e A_T} + \left(\frac{\alpha}{\epsilon}\right)_e (S+A) + E + Q_p \qquad (3)$$

where

$$\alpha_e = \alpha_1 P + \alpha_2 (1-p)$$

$$\epsilon_e = \epsilon_1 P + \epsilon_2 (1-p)$$

$$P = \frac{A_1}{A_T} \; ; \; (1-p) = \frac{A_2}{A_T} \; ; \; A_T = A_1 + A_2$$

$$\left(\frac{\alpha}{\epsilon}\right)_e = \frac{\alpha_e}{\epsilon_e} = \frac{\alpha_1 P + \alpha_2 (1-p)}{\epsilon_1 P + \epsilon_2 (1-p)}$$

If surface 1 has a coating and surface 2 is superinsulation (aluminized Mylar):

*Since $\frac{\alpha_{SUP}}{\epsilon_{SUP}} = \frac{\alpha_{AL}}{\epsilon_{AL}}$ (i.e., outer coating is aluminum)

$$\alpha_2 = \alpha_{SUP} = \epsilon_{SUP} \frac{\alpha_{AL}}{\epsilon_{AL}} = \epsilon_{SUP} \left(\frac{\alpha}{\epsilon}\right)_{AL}$$

$$\epsilon_2 = \epsilon_{SUP}$$

Hence:

$$\left(\frac{\alpha}{\epsilon}\right)_e = \frac{\alpha_1 P_1 + \epsilon_{SUP} \left(\frac{\alpha}{\epsilon}\right)_{AL} (1-p)}{\epsilon_1 P + \epsilon_{SUP} (1-p)} \qquad (4)$$

Equations (4) in conjunction with equation (3) may be used to find T_c for a partially superinsulated cocoon (i.e., superinsulated shutters partially opened).

NOMENCLATURE USED IN THIS APPENDIX

A_T	Total area	ft^2
α	Solar absorptivity	dimensionless
A	Albedo heat flux	$BTU/hr\text{-}ft^2$
C_P	Specific heat capacity	$BTU/lbm\text{-}^oF$
E	Earth-emitted infrared radiation	$BTU/hr\text{-}ft^2$

---

*For proof of this, see Appendix II

ϵ	Emissivity	dimensionless
$\mathcal{F}$	Radiation configuration factor	dimensionless
Q_p	Heat flux from parent vehicle	$BTU/hr\text{-}ft^2$
$\dot{q}_{NET}$	Net heat rejection	BTU/hr
$\dot{q}_{METABOLIC}$	Metabolic heat generation	BTU/hr
S	Solar heat flux	$BTU/hr\text{-}ft^2$
T	Temperature	^oF
t	Time	hr

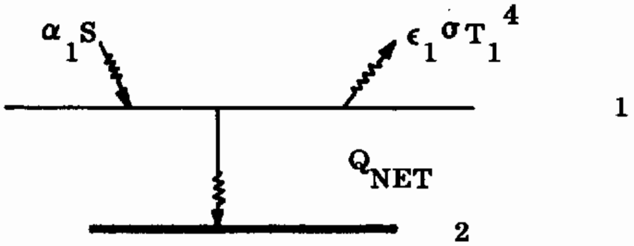
SUBSCRIPTS USED IN THIS APPENDIX

AL	aluminum
e	effective
SUP	superinsulation
W	white cloth
1	surface 1
2	surface 2
c	cocoon

APPENDIX II

DERIVATION OF EFFECTIVE α/ϵ

Consider heat balances on the following two surfaces



For a heat balance on Surface 1:

$$\alpha_1 S = Q_{NET} + \epsilon_1 \sigma T_1^4 \tag{1}$$

To obtain T_1 in terms of T_2:

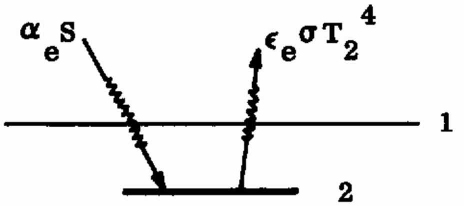
$$Q_{NET} = \mathcal{F}_{12} \sigma (T_1^4 - T_2^4) , \therefore \sigma T_1^4 = \frac{Q_{NET}}{\mathcal{F}_{12}} + \sigma T_2^4 \tag{2}$$

Substituting equation (2) into (1)

$$\alpha_1 S = Q_{NET} + \frac{\epsilon_1 Q_{NET}}{\mathcal{F}_{12}} + \epsilon_1 \sigma T_2^4 = (1 + \frac{\epsilon_1}{\mathcal{F}_{12}}) Q_{NET} + \epsilon_1 \sigma T_2^4 \tag{3}$$

Hence:

$$\left[\frac{\alpha_1}{1 + \frac{\epsilon_1}{\mathcal{F}_{12}}} \right] S = Q_{NET} + \left[\frac{\epsilon_1}{1 + \frac{\epsilon_1}{\mathcal{F}_{12}}} \right] \sigma T_2^4 \tag{4}$$



For a heat balance on Surface 2:

$$\alpha_\epsilon S = Q_{NET} + \epsilon_e \sigma T_2^4 \tag{5}$$

Comparing equations (4) and (5) shows:

$$\alpha_\epsilon = \frac{\alpha_1}{1 + \frac{\epsilon_1}{\mathcal{F}_{12}}}$$

$$\epsilon_c = \frac{\epsilon_1}{1 + \frac{\epsilon_1}{\mathcal{F}_{12}}}$$

Therefore:

$$\frac{\alpha_e}{\epsilon_e} = \frac{\alpha_1}{\epsilon_1}$$

Applying this to superinsulation (with an aluminized surface coating) yields:

$$\frac{\alpha_{SUP}}{\epsilon_{SUP}} = \frac{\alpha_{AL}}{\epsilon_{AL}}$$

NOMENCLATURE USED IN THIS APPENDIX

A_T	Total area	ft^2
α	Solar absorptivity	dimensionless
A	Albedo heat flux	$BTU/hr\text{-}ft^2$
C_P	Specific heat capacity	BTU/lbm-^oV
E	Earth-emitted infrared radiation	$BTU/hr\text{-}ft^2$
ϵ	Emissivity	dimensionless

$\mathscr{F}$	Radiation configuration factor	dimensionless
Q_p	Heat flux from parent vehicle	BTU/hr-ft^2
$\dot{q}$ NET	Net heat rejection	BTU/hr
$\dot{q}_{METABOLIC}$	Metabolic heat generation	BTU/hr
S	Solar heat flux	BTU/hr-ft^2
T	Temperature	°F
t	Time	hr

SUBSCRIPTS USED IN THIS APPENDIX

AL	aluminum
e	effective
SUP	superinsulation
W	white cloth
1	surface 1
2	surface 2
c	Cocoon

APPENDIX III

THERMAL CONFIGURATION (SHUTTER SYSTEM)

PASSIVE SYSTEM

A purely passive means of thermal control using coatings with fixed α and ϵ properties was investigated and found to be unsatisfactory for application to the Emergency Cocoon. The analysis performed during the investigation showed that it is possible to select a cocoon coating for a particular orbit in which the cocoon always remains in the sun (e.g., hot case 1). In this case the effect of variations in the metabolic heat generation rate are minimized due to the relatively low magnitude of the $\dot{q}NET/\epsilon_e A_T$ term in the following equation (Equation (3) from Appendix I):

$$\sigma T_c^4 = \frac{\dot{q}NET}{\epsilon_e A_T} + \frac{\alpha}{\epsilon}_e (S+A) + E + Q_p$$

(ϵ_e = .35 for case cited above)

Temperature control between 65° and 85°F, thus can be achieved by passive coatings for an orbit in the sun.

However, for an orbit in which the cocoon passes from the sun into the shade of either the parent vehicle or the earth (e.g., hot case 2), the large variation in solar and albedo (S + A) heat fluxes incident upon the cocoon does not allow selection of a coating to give temperature control within specification, since large variations in the cocoon's environment and internal heat generation exist. e.g., selecting a coating with α and ϵ properties which would maintain an 85°F cocoon temperature during the hot environment of the orbit would allow the cocoon temperature to drop to -165°F during the cold environment. This would mean approximately 750 watts of heater power would be required to maintain the cocoon temperature at 65°F during the cold environment.

In addition, for an orbit in which the cocoon is in the shade at all times (e.g., cold case — cocoon is either in shade of earth or parent vehicle), the variation in possible metabolic heat generation rates does not allow selection of an emissivity which would keep the cocoon temperature within specification. This may be seen from the following equation:

$$\sigma T_c^4 = \frac{\dot{q}NET}{\epsilon_e A} + E + Q_p$$

(For example, an effective emissivity which would maintain T_c = 75°F for a metabolic heat generation rate of 500 BTU/hr would give T_c = 38°F at q metabolic = 300 BTU/hr.)

Therefore, designing the cocoon with a fixed-property α/ϵ coating for temperature control would place too great a restriction upon the orbital paths allowed.

SEMIPASSIVE SYSTEM

In keeping with the requirement for a temperature control system of as passive a nature as is possible, the semipassive shutter system depicted in Figures 14 and 15 was selected. This type of system uses α and ϵ properties as a means of temperature control as does the fixed property coating system; however, the shutters allow these properties to be varied in order to achieve the heat balance necessary for temperature control within specification. Shutter systems have been demonstrated successfully on Nimbus and Advent satellite systems built by G. E. in the past.

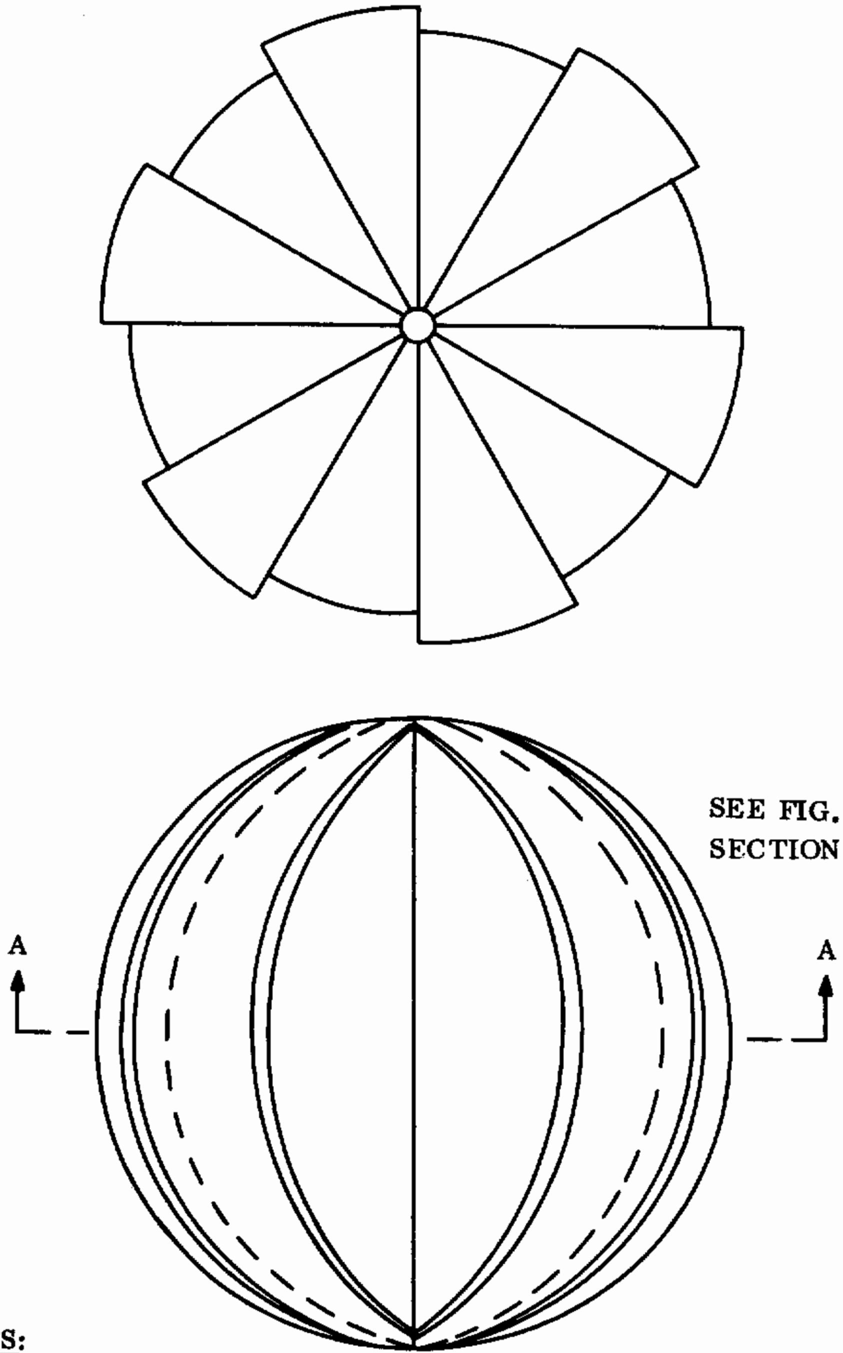
The shutter system shown in Figures 14 and 15 makes use of fixed inner shutters and movable outer shutters which are superinsulated (multiple-radiation-barrier-type insulation) for low heat loss. Rotating the outer shutters into an open position allows greater heat rejection by increasing the effective emissivity of the cocoon.

Note that the method of attachment of the superinsulation to the shutters is a critical consideration, since a low heat leak to space is required during a cold orbital environment. Rather than using a Nylon bolt type of fastener, the superinsulation should be attached at the edges of the shutters in a manner similar to that shown in Figure 16.

The outer layer is made thicker than the other layers if additional strength is required. The layers of insulation must not be crushed together during or after fastening to the shutters, as performance could seriously be affected.

As a prime method of control, the shutters may be rotated manually from within the cocoon (the rotating rod will penetrate the cocoon). However, it may be advisable, due to large environmental excursions in an orbit and an anticipated low thermal inertia of the assembly, to consider a thermostatically controlled stepping motor for shutter rotation. This, however, would require power and would be more of an active control type system.

If heat leaks are greater than the expected values (e.g., 165 BTU/hr with T_c = 70°F for the cold case), some heaters may be required for maintaining the cocoon temperature during the cold portions of the orbits.



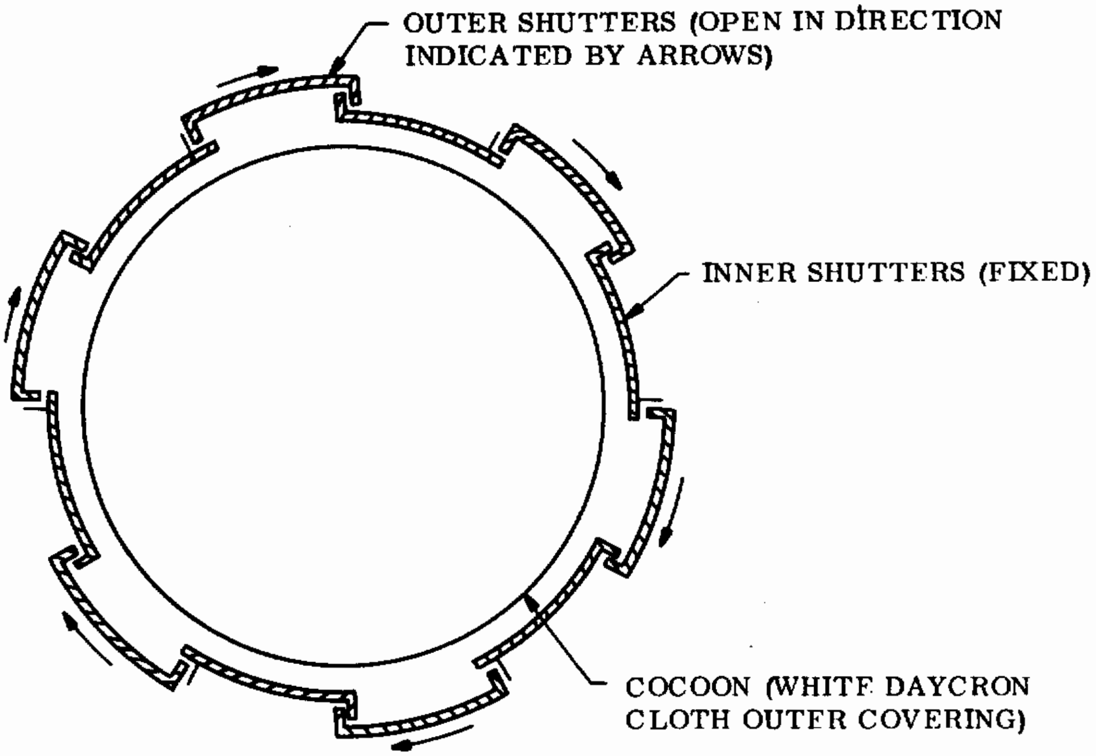
SEE FIG. 15 FOR
SECTION "A-A"

NOTES:

(1) SKETCH NOT TO SCALE

(2) 12 SHUTTERS ARE SHOWN (6 FIXED AND 6 MOVEABLE); HOWEVER, THE FINAL DESIGN MAY USE 8 SHUTTERS (4 FIXED AND 4 MOVEABLE)

Figure 14. Shutter Configuration



NOTES:

(1) SKETCH NOT TO SCALE

(2) ▨ INDICATES 15 LAYERS (1/4 INCH THICKNESS) OF SUPERINSULATION (ALUMINIZED MYLAR MULTIPLE RADIATION BARRIAR TYPE INSULATION, 1/4 MIL THICKNESS PER LAYER)

(3) 12 SHUTTERS ARE SHOWN (6 FIXED AND 6 MOVEABLE); HOWEVER, THE FINAL DESIGN MAY USE 8 SHUTTERS (4 FIXED AND 4 MOVEABLE)

Figure 15. Section A-A of Figure 14

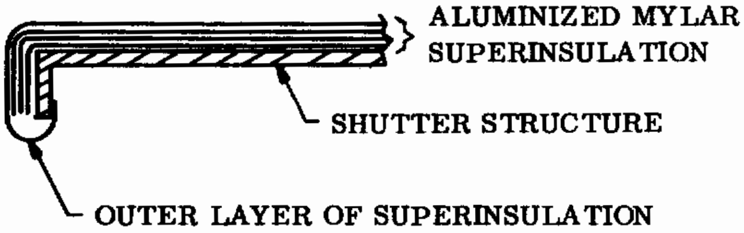


Figure 16. Attachment of Superinsulation to Shutters

Due to its high emissivity, a white Nylon cloth covering the inside of the cocoon would help to reduce the thermal gradients which may be experienced around the circumference of the cocoon. Forced air may also be required from the standpoint of reducing thermal gradients as well as preventing thermal stratification of the air or local areas of high concentration of contaminants (CO_2 or H_2O vapor). The forced air would also aid in sensible heat removal from man.

THERMAL PERFORMANCE

The thermal performance of the Emergency Cocoon was analyzed by taking a heat balance (Appendix I) on the cocoon for the hot and cold orbit extremes. The average cocoon temperature (T_c) was calculated for shutters-open and shutters-closed cases. These values, then, describe the range of temperature control for the cocoon based on the coating properties shown in Figures 17 and 18. The following temperatures describe the range of control:

	Hot Case		Cold Case	
	Shutters Open	Shutters Closed	Shutters Open	Shutters Closed
Average T_c (°F)	38	360	-155	*70

*with $q_{METABOLIC}$ = 500 BTU/hr and shutter losses

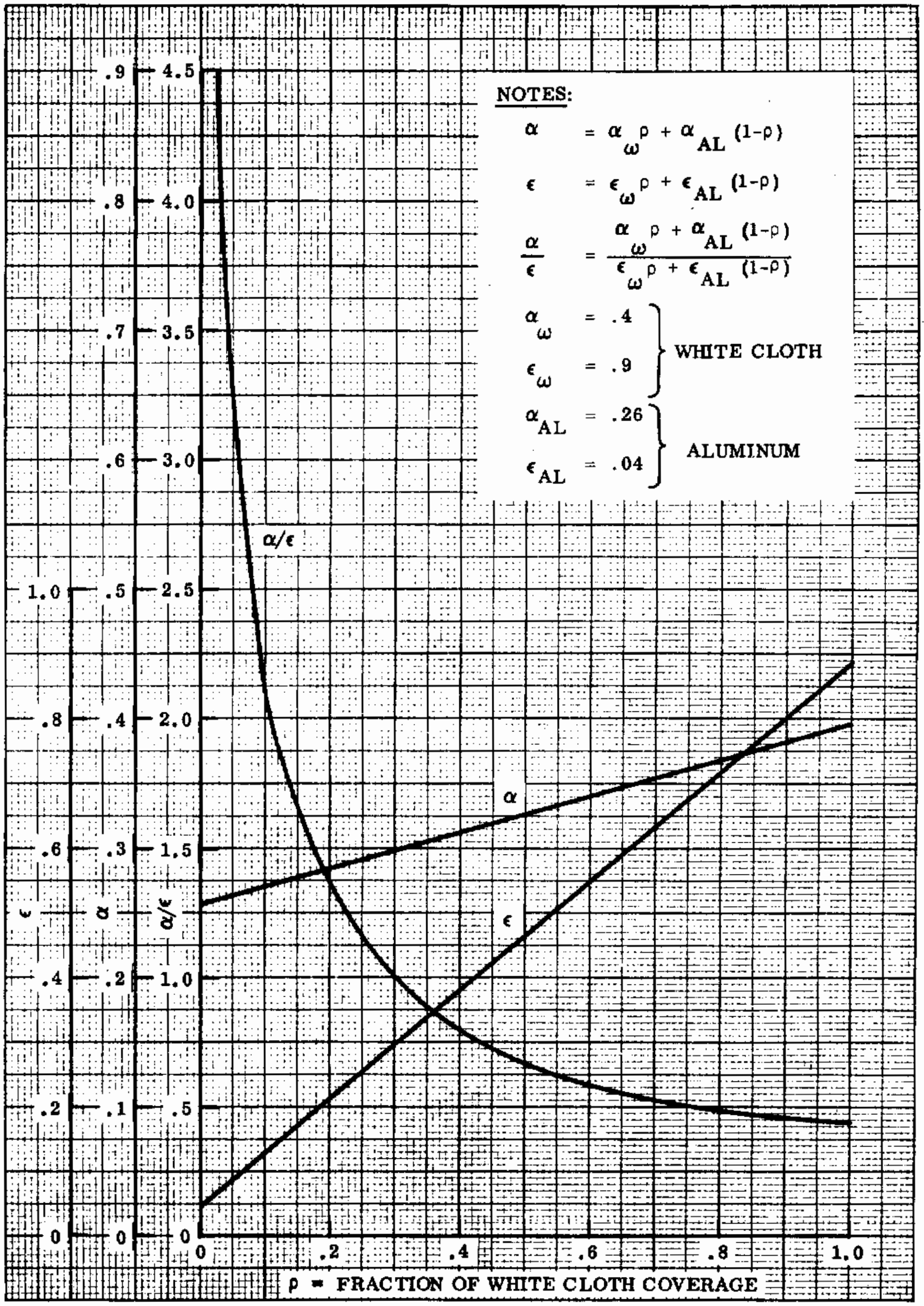
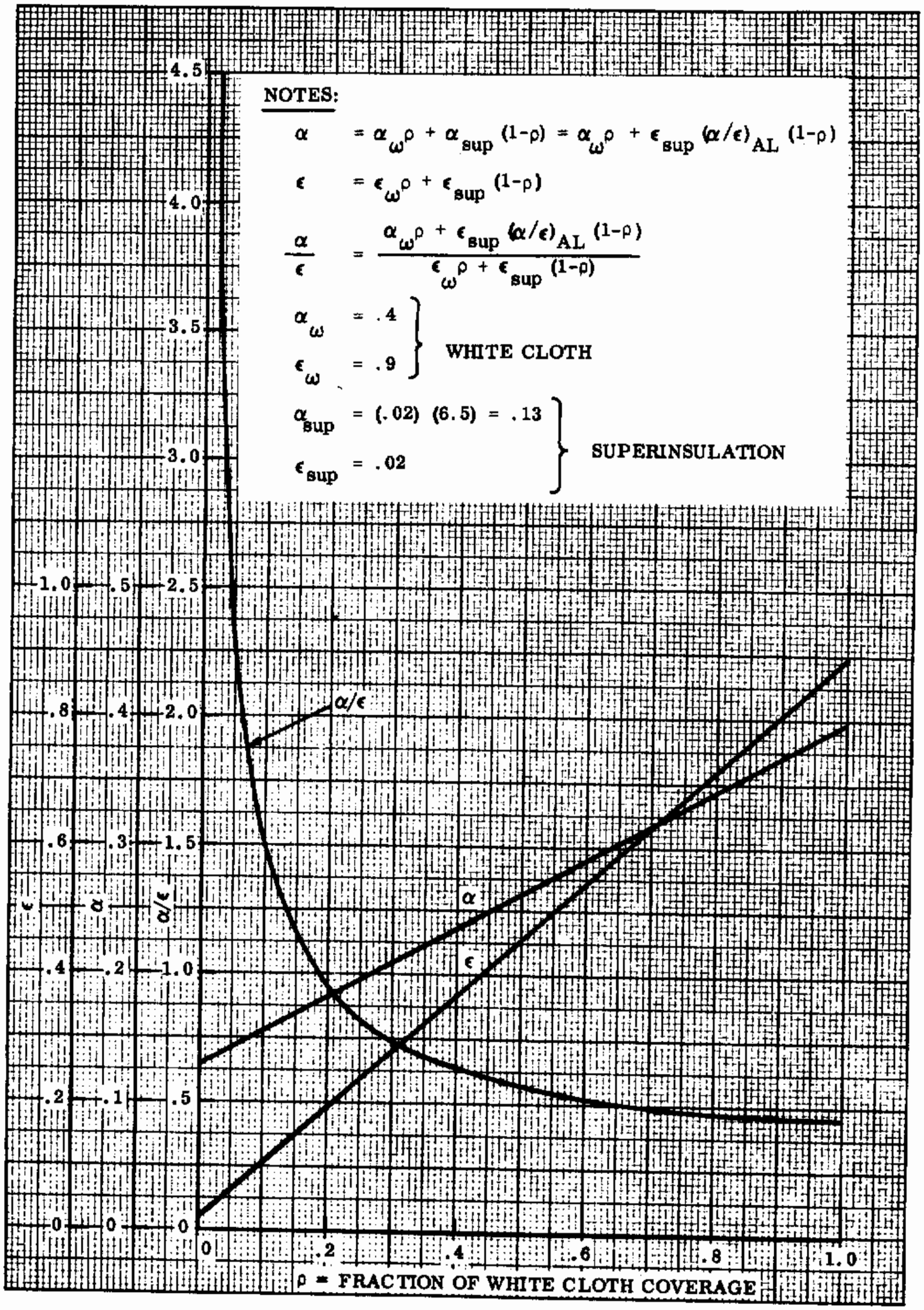


Figure 17. Coating Properties for Patching of Aluminum and White Cloth



NOTES:

$\alpha = \alpha_{\omega}\rho + \alpha_{sup}(1-\rho) = \alpha_{\omega}\rho + \epsilon_{sup}(\alpha/\epsilon)_{AL}(1-\rho)$

$\epsilon = \epsilon_{\omega}\rho + \epsilon_{sup}(1-\rho)$

$$\frac{\alpha}{\epsilon} = \frac{\alpha_{\omega}\rho + \epsilon_{sup}(\alpha/\epsilon)_{AL}(1-\rho)}{\epsilon_{\omega}\rho + \epsilon_{sup}(1-\rho)}$$

$$\left.\begin{aligned}\alpha_{\omega} &= .4\\ \epsilon_{\omega} &= .9\end{aligned}\right\}\ \text{WHITE CLOTH}$$

$$\left.\begin{aligned}\alpha_{sup} &= (.02)\ (6.5) = .13\\ \epsilon_{sup} &= .02\end{aligned}\right\}\ \text{SUPERINSULATION}$$

Figure 18. Coating Properties for Patching of Superinsulation and White Cloth

An analysis was made to determine the worst thermal gradients which could exist around the circumference of the cocoon. Using the method of Reference 13, it was found that for hot case 1, node 13 could be at 115°F while nodes 24 through 26 could be at -30°F. However, this assumes no rotations of the cocoon which would aid in averaging the surface temperatures of the cocoon. Local condensation and/or freezing the water on the walls could be a problem which will be evaluated during testing.

Thermal testing of the cocoon may show that patching of the superinsulated shutters with white paint may be desirable to decrease the cocoon temperature under maximum heat flux conditions. (This would be particularly true if the superinsulation has a low enough effective emissivity to maintain the cocoon temperature satisfactorily in the cold case.) An example of the patch coating would be to paint the outer (rotating) shutters white and leave the inner (fixed) shutters aluminized. Patching the shutters with white paint would also substantially reduce the thermal gradient around the cocoon, since they would not have to be opened as far in the hot case (i.e., the effect of solar and albedo heat fluxes is attenuated).

Due to the large range of thermal control possible with the shutters open, heat transfer from man to the walls of the cocoon should be accomplished largely by thermal radiation (Reference 14). However, some forced convection may be required. Testing will show the nature and magnitude of this requirement if it exists.

APPENDIX IV

THERMAL CONFIGURATION, FIXED COATINGS

INTRODUCTION

During the interim design review held on the Emergency Cocoon, concern was expressed that the thermal control system, consisting of movable and fixed external shutters, was relatively complex, bulky, and, being a fixed structure, would detract from the acceptance of the inflatable cocoon for future space use. Accordingly, it was decided to investigate fixed property thermal coatings that could be applied to the external surface of the cocoon. The coatings would be designed to maintain acceptable temperatures during periods of maximum heat flux, and heaters would be utilized to maintain temperatures during periods of lower heat flux.

THERMAL CONTROL ANALYSIS

When the Emergency Cocoon is in the shade, a low emissivity thermal coating is required to minimize heat losses. In the sun, however, it is the α/ϵ ratio that determines the cocoon temperature. The white Dacron fabric used for the outer layer of the cocoon exhibits a relatively low α/ϵ ratio. If this fabric were used as is, the cocoon equilibrium temperatures in the sun would be too low. Therefore, it is possible to "patch" the white cloth with a low emissivity coating, having a relatively high α/ϵ ratio. The amount of percentage of surface covered by the coating can be adjusted to provide the α/ϵ ratio desired. In this process, the overall emissivity of the cocoon surface is also reduced, minimizing heat loss during periods of minimum heat flux.

Two low-emissivity coatings were selected for the analysis, aluminum and gold. Figure 19 shows the range of α/ϵ ratios that can be obtained by patching the white Dacron with gold. Figure 17 shows the same values for aluminum. Table IX shows the α/ϵ values required to maintain the cocoon temperature at the maximum value indicated, when the cocoon is subjected to maximum heat flux.

Two orbits were selected for analysis. These are shown in Figure 20. The sunlit portion of the near equatorial orbit (hot case 2) provides the maximum heat flux on the Emergency Cocoon. In this orbit, the least amount of aluminum or gold patching is required to obtain the proper α/ϵ ratio. The emissivity of the cocoon surface is, therefore, relatively high. This means that during the shade portion of the orbit, the maximum amount of heater power is required to maintain the cocoon temperature. This orbit is, therefore, a "worst case" condition.

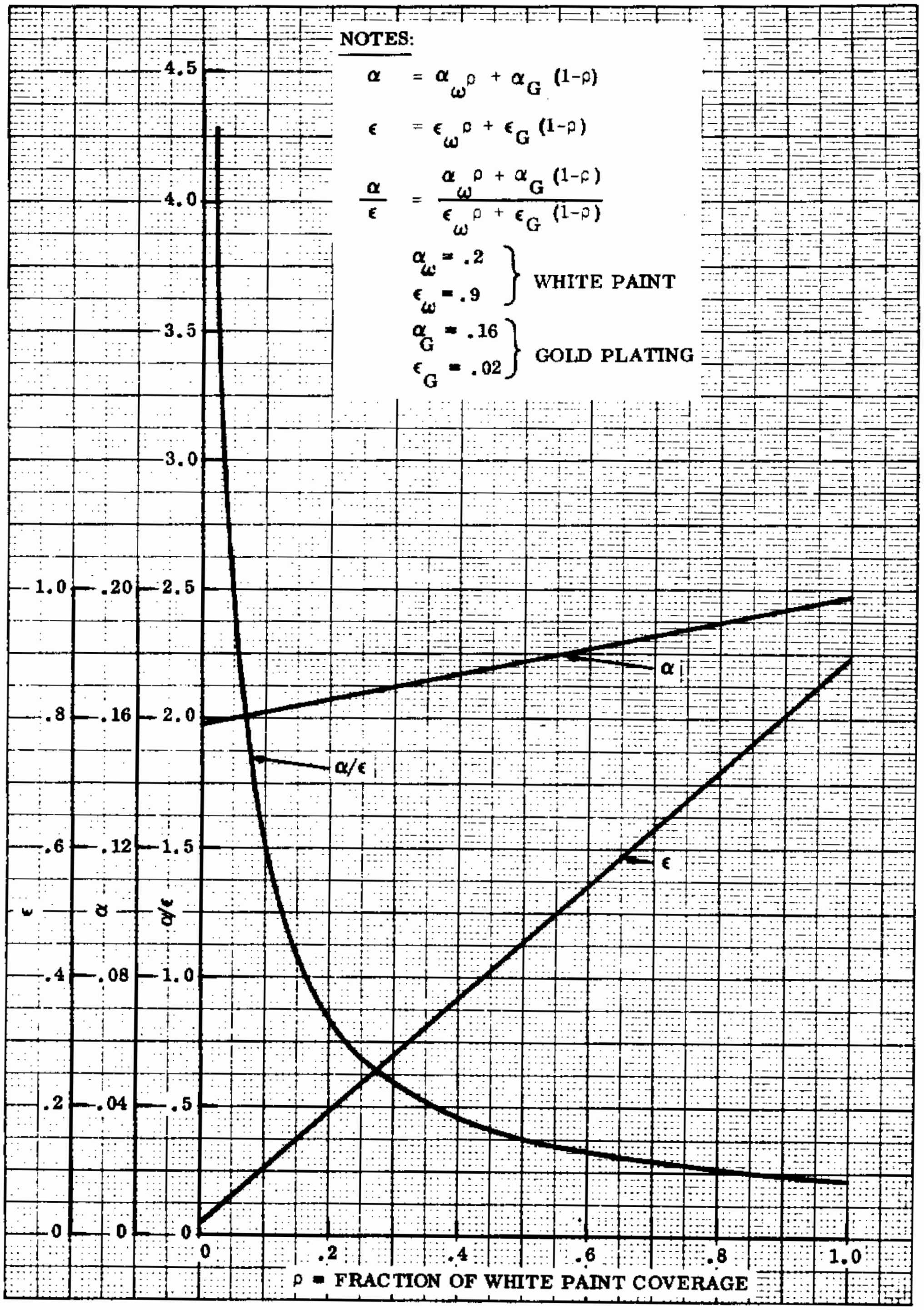


Figure 19. Coating Properties for Patching of Gold Plating and White Paint

TABLE IX

HEATER POWER REQUIREMENTS FOR α/ϵ COATING SYSTEM

A. Orbit Based on Hot Case 2

Coating	Min. Temp. (°F)	Max. Temp. (°F)	Coating Properties $(\alpha/\epsilon)_e$	Coating Properties ϵ_e	Heater Power Required in Shade (Watts)
White Dacron with Aluminum Patches	65	85	.525	.685	2,570
	32	85	.525	.685	1,735
	65	100	.62	.555	2,070
	32	100	.62	.555	1,400
White Dacron with Gold Patches	65	85	.525	.33	1,200
	32	85	.525	.33	800
	65	100	.6	.283	1,020
	32	100	.6	.283	680

Body-Averaged Values for Instantaneous Flux		S + A (BTU/hr-ft^2)	E + Q_p (BTU/hr-ft^2)
	Max.	213.8	36.1
	Min.	0	36.1

B. Orbit Based on Combination of Hot Case 1 and Cold Case

Coating	Min. Temp. (°F)	Max. Temp. (°F)	Coating Properties $(\alpha/\epsilon)_e$	Coating Properties ϵ_e	Heater Power Required in Shade (Watts)
White Dacron with Aluminum Patches	65	85	1.03	.3	1,437
	32	85	1.03	.3	1,070
	65	100	1.18	.25	1,185
	32	100	1.18	.25	940
White Dacron with Gold Patches	65	85	1.00	.17	780
	32	85	1.00	.17	575
	65	100	1.11	.15	680
	32	100	1.11	.15	500

Body-Averaged Values for Instantaneous or Time-Averaged Flux		S + A (BTU/hr-ft^2)	E + Q_p (BTU/hr-ft^2)
	Max.	108.6	36.1
	Min.	0	7.85

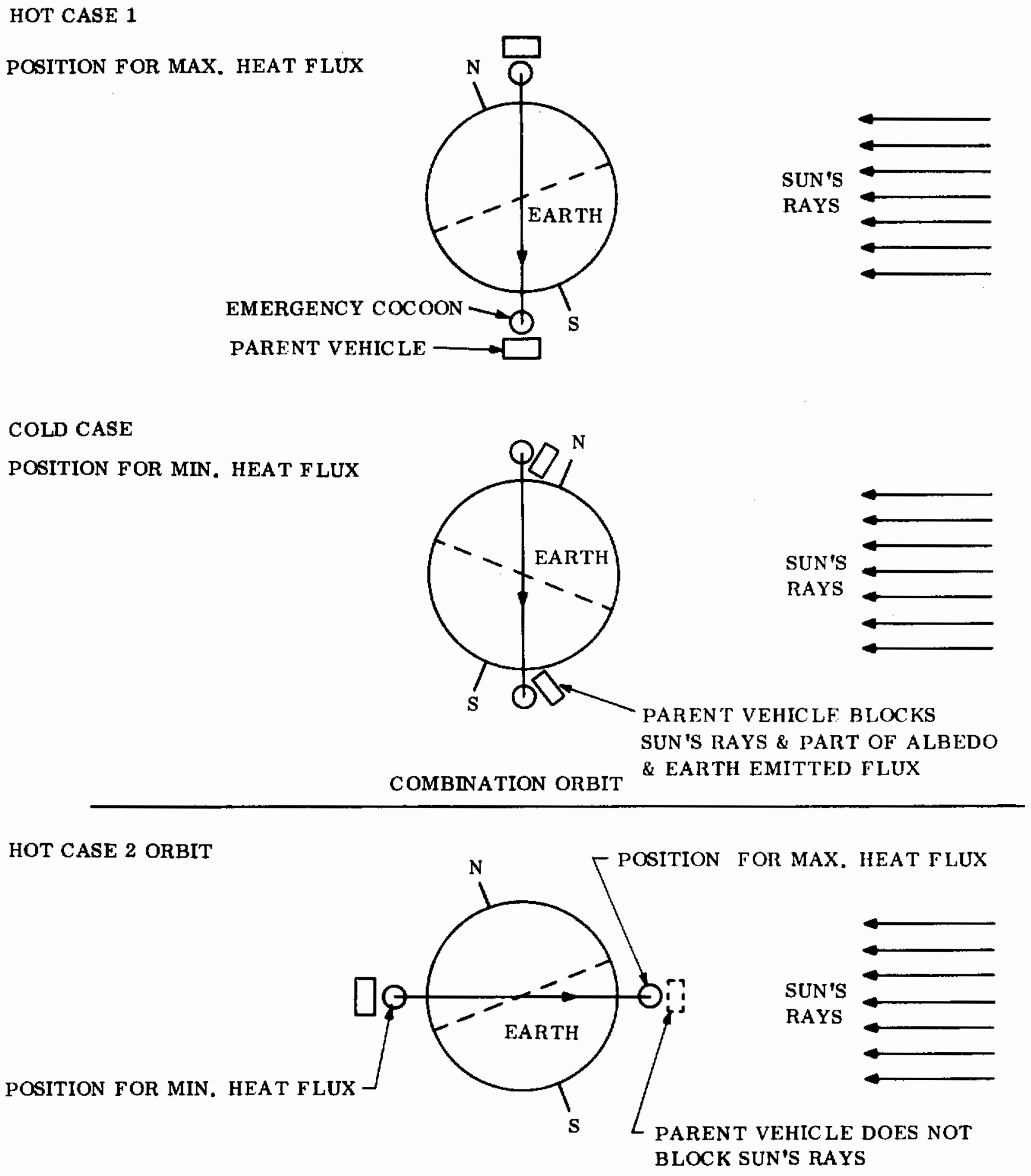


Figure 20. Orbits and Configuration — Thermal Analysis

In the near-polar orbit (hot case 1 and cold case), the external heat flux is minimized, due primarily to the reduced albedo heat flux. This allows the maximum use of the aluminum or gold coating. The overall emissivity of the cocoon is therefore relatively low. In the cold case associated with this orbit (cocoon shielded from parent vehicle), the minimum amount of heater power is required to maintain the cocoon temperature. This orbit is thus the "best case" condition.

Table IX shows the heater power required to maintain the cocoon temperature at the values indicated during the cold portion of hot case 1 and 2. For orbits other than the two analyzed, the heater power required will fall between the values shown in the table. In general, as the orbit inclination increases, the amount of heater power required will decrease.

As seen, the heater power requirements can be minimized by utilizing a gold coating rather than aluminum. This is due to the lower emissivity of gold. In addition, the heater power required can be reduced by allowing the cocoon temperature to vary beyond the specification limits of 65° to 85°F. If the cocoon temperature can exceed 85°F, more gold or aluminum coating can be utilized, reducing the effective emissivity of the cocoon. Also, if the temperature can fall below 65°F, less heater power is required to maintain this temperature.

TRADE-OFF ANALYSIS

Weight

The use of fixed thermal property coatings described above was compared with the movable shutter system proposed in the interim analysis and design study report. Battery energy densities as shown in Figure 21 were used in calculating weights for the coating systems shown in Table IX. The various coating systems were designed so that they would allow the maximum average temperature of the cocoon to occur during the hottest conditions of the orbit (cocoon in sun); battery power would then supply heaters with enough dissipation to maintain the minimum average temperature of the cocoon during the coldest conditions of the orbit (cocoon in shade).

The thermal control system weights for the α/ϵ systems and the shutter system are shown in Figure 22 for all systems maintaining the cocoon temperature 65° and 85°F.

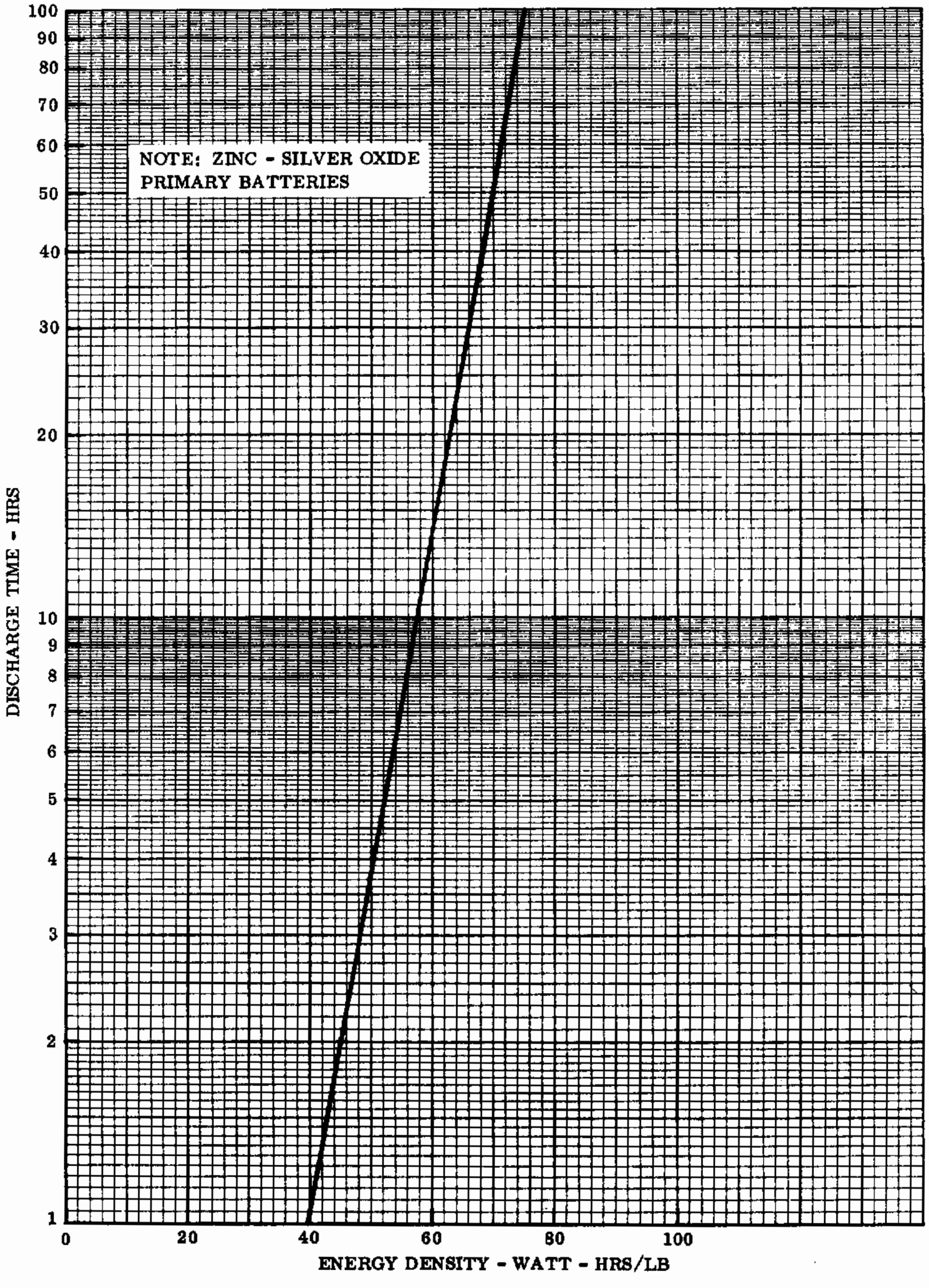
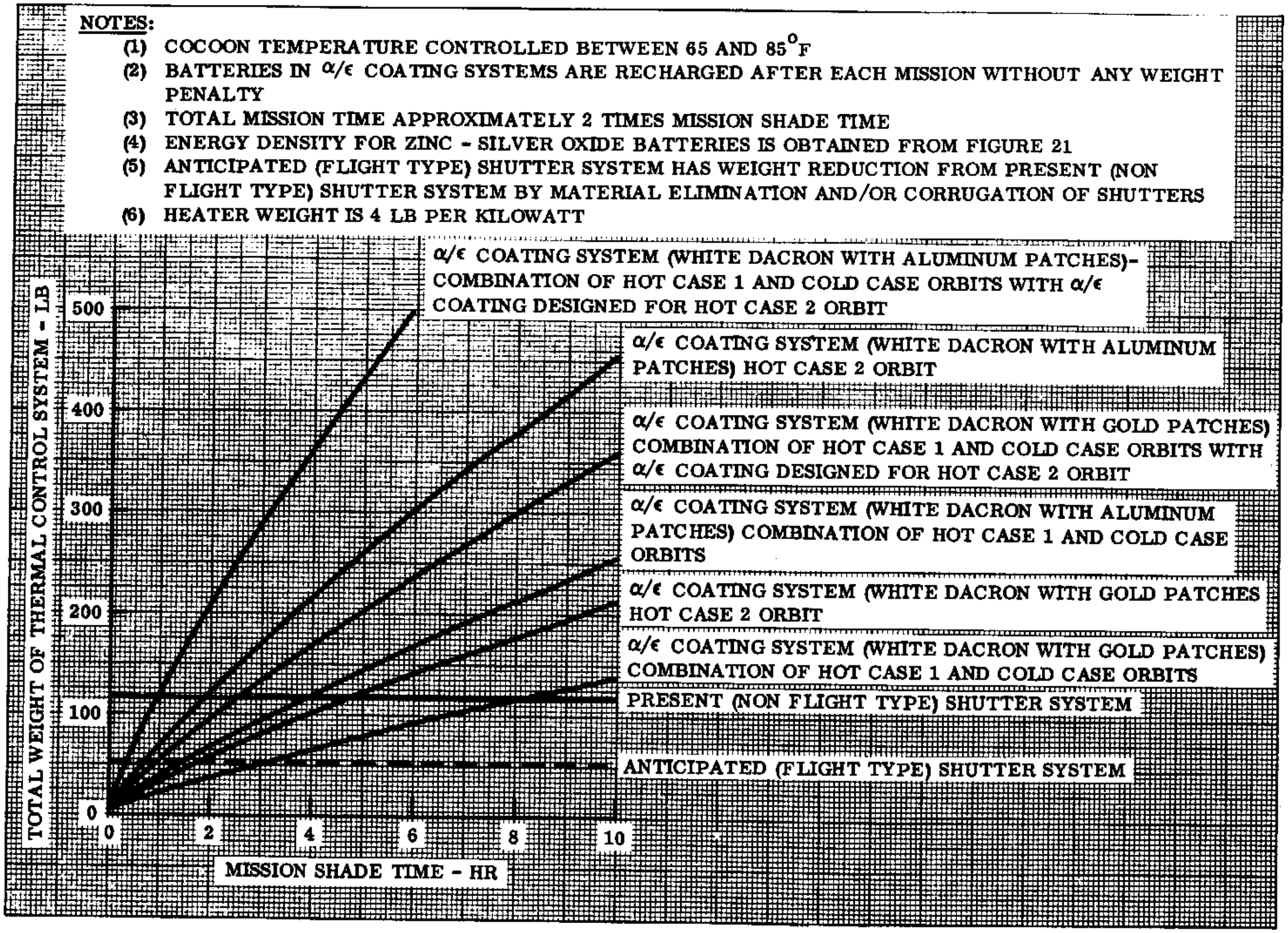


Figure 21. Battery Energy Density



NOTES:

(1) COCOON TEMPERATURE CONTROLLED BETWEEN 65 AND 85°F

(2) BATTERIES IN α/ϵ COATING SYSTEMS ARE RECHARGED AFTER EACH MISSION WITHOUT ANY WEIGHT PENALTY

(3) TOTAL MISSION TIME APPROXIMATELY 2 TIMES MISSION SHADE TIME

(4) ENERGY DENSITY FOR ZINC - SILVER OXIDE BATTERIES IS OBTAINED FROM FIGURE 21

(5) ANTICIPATED (FLIGHT TYPE) SHUTTER SYSTEM HAS WEIGHT REDUCTION FROM PRESENT (NON FLIGHT TYPE) SHUTTER SYSTEM BY MATERIAL ELIMINATION AND/OR CORRUGATION OF SHUTTERS

(6) HEATER WEIGHT IS 4 LB PER KILOWATT

Figure 22. Thermal Control System Weight for Various α/ϵ Coating Systems

A breakdown of the component weights for the shutter system is given as follows:

Component	Weight (lbm)	
	Present (Non-Flight) Shutter System	Anticipated (Flight Shutter System
Aluminum Shutters	80	40
Angles	19	0
Doublers and Hubs	15	10
Superinsulation	4.5	4.5
Total	118.5	54.5

Figures 23 and 24 show the effect of relaxing these temperature limits on the weights of the α/ϵ coating systems. (Figure 23 is for an orbit based on hot case 2, whereas Figure 24 is for an orbit based on the combination of hot case 1 and the cold case.)

Figure 25 shows the weights of the α/ϵ coating systems for the case 1 orbit, when the α/ϵ coating has been designed for the hot case 2 orbit. These weights are seen to be greater than those for the hot case 2 orbit since more heater power is required. (See Table X.)

The ordinate values of these curves (Figures 22-25) for a shade time of zero hours represent the heater weights only (no batteries). These heater weights were based on a design weighing approximately 4 lbm per kilowatt as follows:

Nichrome wire with the following properties is used for the heater design:

B and S no. 24 (.0201 inch diameter)
Specific gravity = 8.3
Resistance = 1.49Ω ft. of length

Hence, WEIGHT PER FOOT = $(\pi/4)\ D^2$ = .0114 lbm/ft. of length

For wire plus insulation, use .025 lbm/ft. of length

Using 25 volts D.C. as the battery source and 2 amperes of current in the wire:

2 amps x 25 volts = 50 watts per path
1000 watts/50 watts/path = 20 parallel paths
$P = IV = V^2R$ $\qquad R_{\text{per path}} = 625/50 = 12.5$ per path

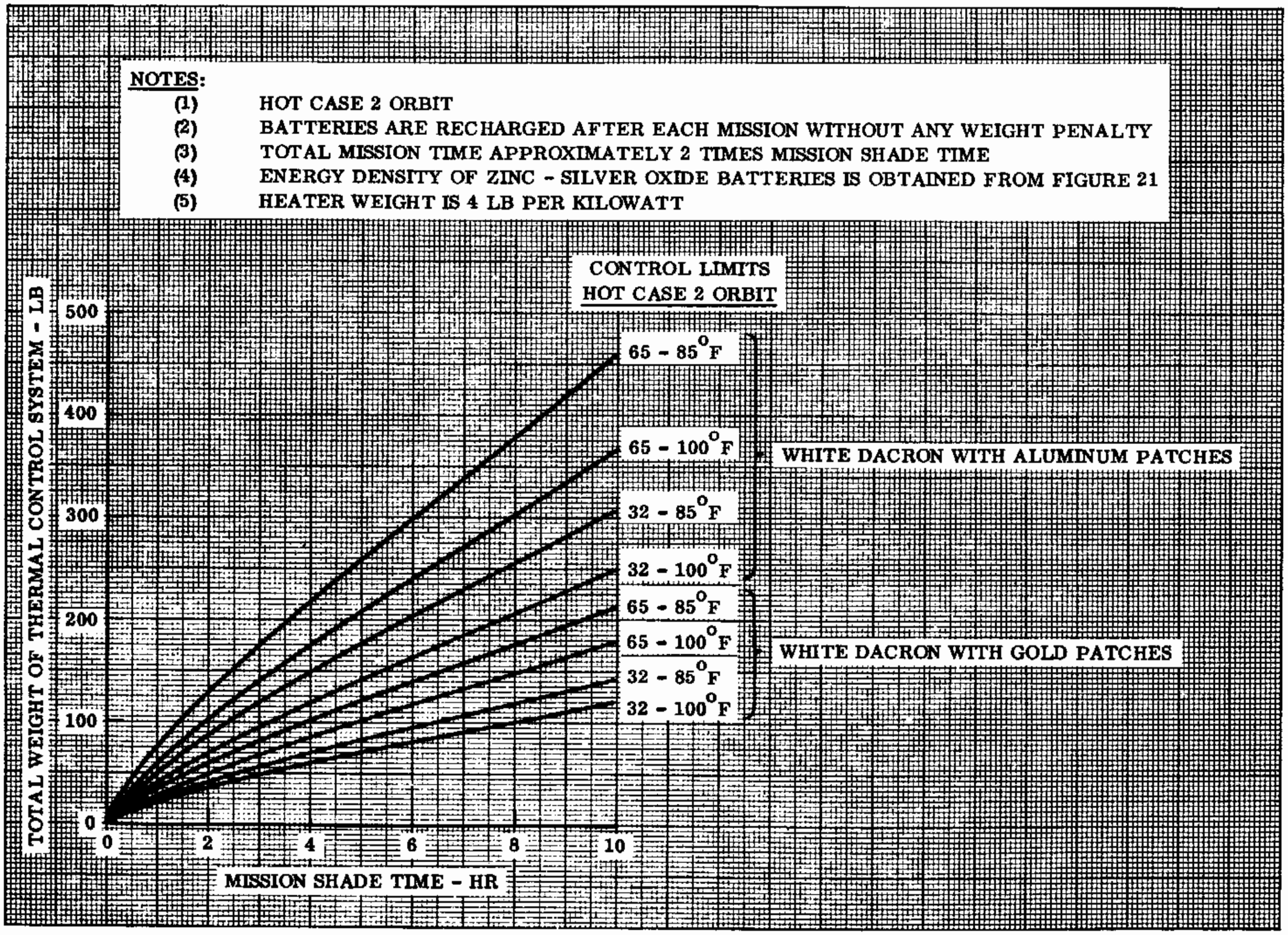
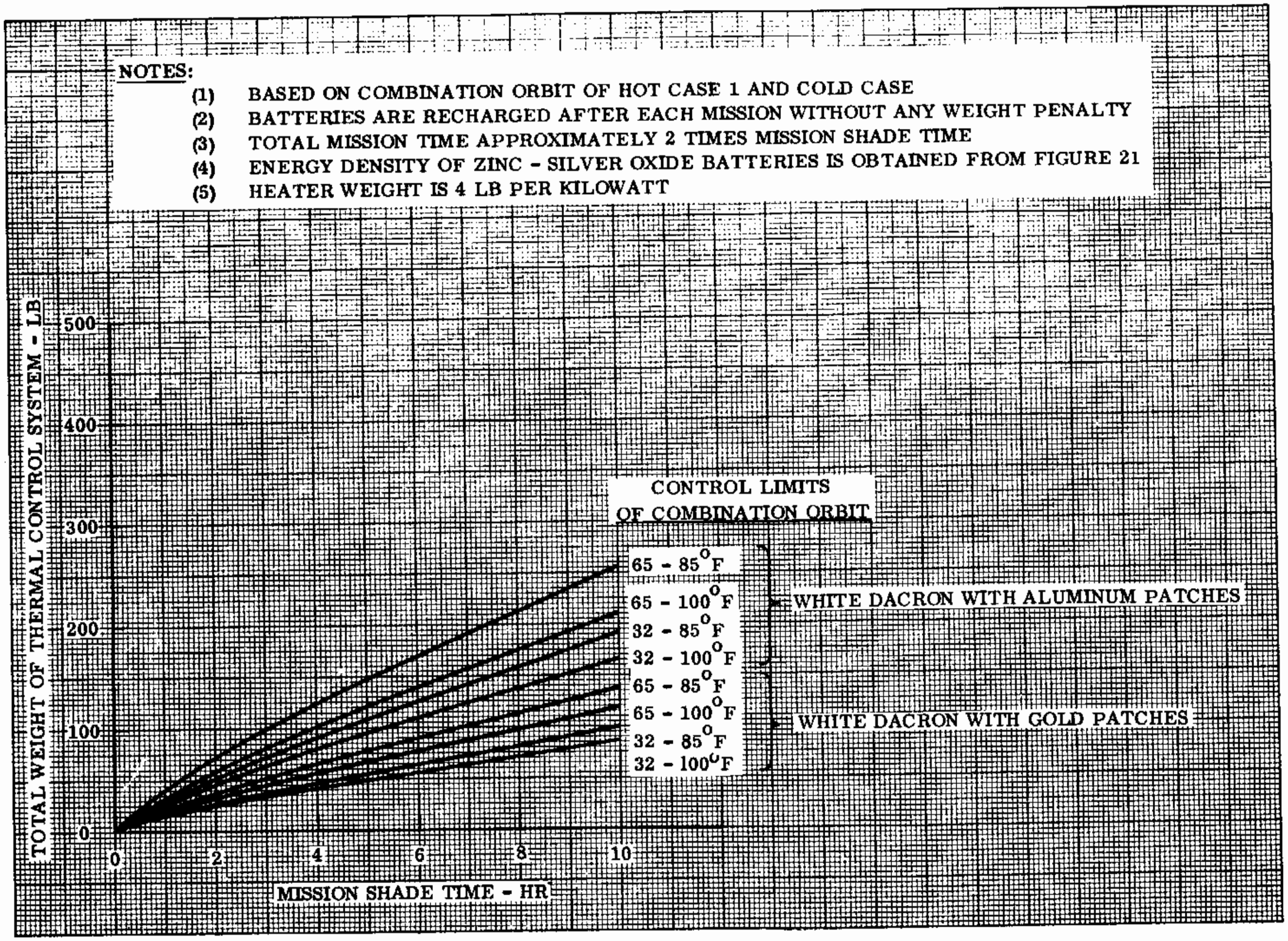


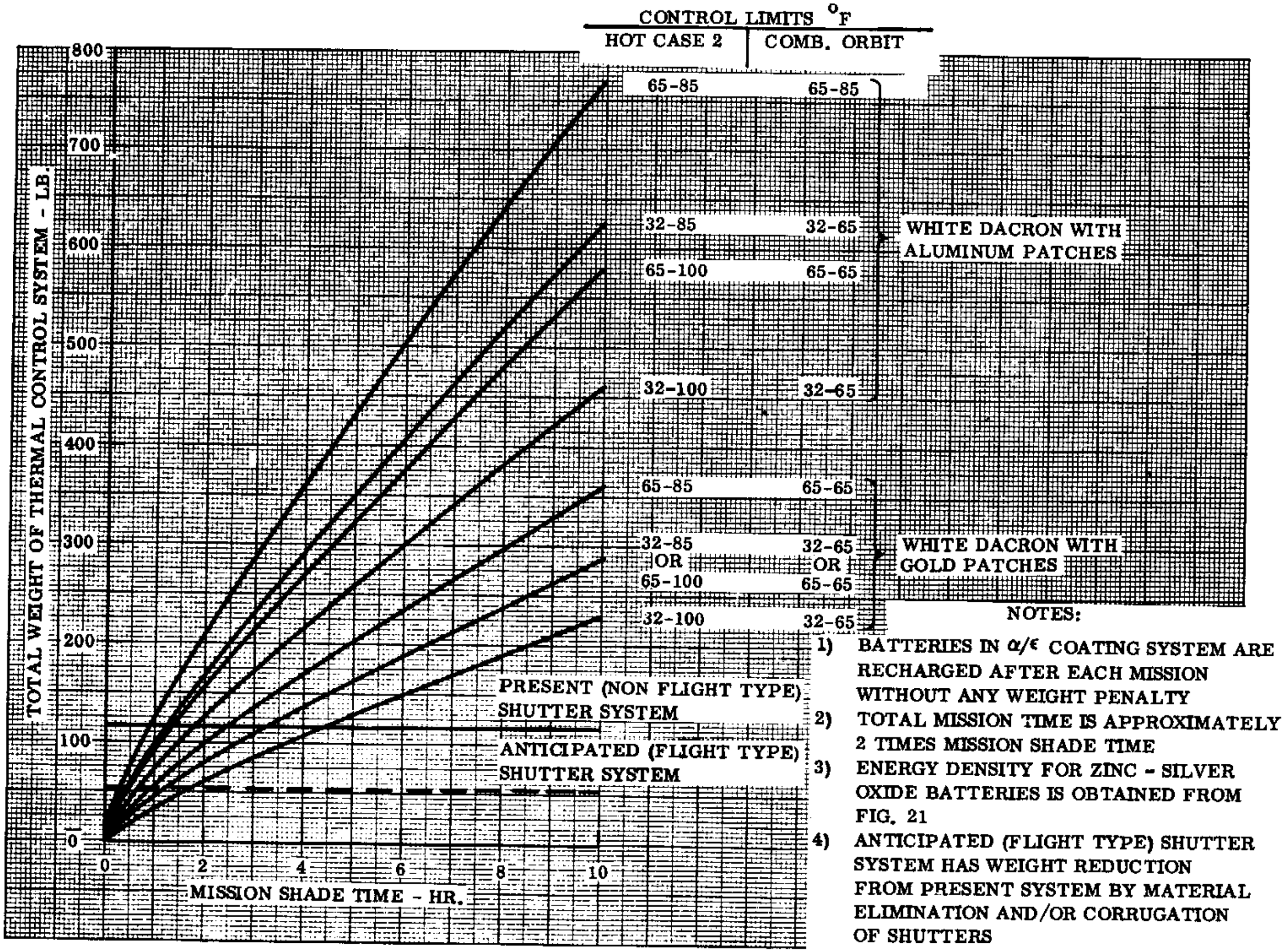
Figure 23. α/ϵ Coating Thermal Control System Weight for Various Control Limits — Hot Case 2 Orbit



NOTES:

(1) BASED ON COMBINATION ORBIT OF HOT CASE 1 AND COLD CASE
(2) BATTERIES ARE RECHARGED AFTER EACH MISSION WITHOUT ANY WEIGHT PENALTY
(3) TOTAL MISSION TIME APPROXIMATELY 2 TIMES MISSION SHADE TIME
(4) ENERGY DENSITY OF ZINC - SILVER OXIDE BATTERIES IS OBTAINED FROM FIGURE 21
(5) HEATER WEIGHT IS 4 LB PER KILOWATT

Figure 24. α/ϵ Thermal Control System Weight for Various Control Limits — Combination Orbit



NOTES:

1) BATTERIES IN α/ϵ COATING SYSTEM ARE RECHARGED AFTER EACH MISSION WITHOUT ANY WEIGHT PENALTY
2) TOTAL MISSION TIME IS APPROXIMATELY 2 TIMES MISSION SHADE TIME
3) ENERGY DENSITY FOR ZINC - SILVER OXIDE BATTERIES IS OBTAINED FROM FIG. 21
4) ANTICIPATED (FLIGHT TYPE) SHUTTER SYSTEM HAS WEIGHT REDUCTION FROM PRESENT SYSTEM BY MATERIAL ELIMINATION AND/OR CORRUGATION OF SHUTTERS
5) HEATER WEIGHT IS 4 LB PER KW.

Figure 25. α/ϵ Thermal Control System Weight for Combination Orbit (Based on Hot Case 1 and Cold Case) when α/ϵ Coating is Designed for Hot Case 2 Orbit

TABLE X

HEATER POWER REQUIREMENTS FOR α/ϵ COATING SYSTEM DURING COMBINATION ORBIT (BASED ON HOT CASE 1 PLUS COLD CASE) WHEN α/ϵ COATING IS DESIGNED FOR HOT CASE 2 ORBIT

Coating	Operating Temperatures During Hot Case 2 Orbit		Coating Properties for Hot Case 2 Orbit		Operating Temperatures During Combination Orbit		Heater Power Required for Combination Orbit	
	Minimum (^oF)	Maximum (^oF)	$(\alpha/\epsilon)_e$	ϵ_e	Minimum (^oF)	Maximum (^oF)	In Shade* (Watts)	In Sun (Watts)
White Dacron with Aluminum Patches	65	85	.525	.685	65	65	3,365	970
	32	85	.525	.685	32	65	2,540	970
	65	100	.62	.555	65	65	2,715	540
	32	100	.62	.555	32	65	2,045	540
White Dacron with Gold Patches	65	85	.525	.33	65	65	1,585	430
	32	85	.552	.33	32	65	1,185	430
	65	100	.6	.283	65	65	1,350	270
	32	100	.6	.283	32	65	1,010	270

---

*Shade of Parent Vehicle

$L_{\text{per path}} = 12.5\Omega / (1.49\Omega/\text{ft}) = 8.4$ ft.

Total weight of 1000 watt heater (20 parallel
paths) = 20 paths x 8.4 ft/path x .025 lbm/ft.
= 4.2 lbm.

Heater weight is approximately 4 lbm/1000 watts

Design

The use of a fixed thermal control coating does have a definite advantage in simplicity of design. Movable shutters, on the other hand, are large and more complex, requiring moving parts, which would detract from the overall appearance and usefulness of the Emergency Cocoon as an inflatable structure.

Efforts are underway to devise methods for applying a gold coating to the cocoon fabric. The possibility for utilizing the process which produces "Foylon" (an aluminum foil coated fabric) to apply a gold foil to a fabric is being investigated. The possibility of vacuum depositing gold on fabric is also being determined. The gold foil could also be applied to the fabric with adhesives.

Conclusions

Figure 22 shows the tradeoff time for the two α/ϵ coatings as a function of the mission time spent in the shade (cold portion of each orbit). Tradeoff time is defined as that point at which battery weight equals the weight of the shutter system. As seen, for a gold-Dacron coating, the fixed α/ϵ system is optimum for missions of up to 6 hours for the "best" orbit and 3.6 hours for the "worst-case" when compared to a flight weight shutter system. Mission time is assumed as two times the shade time. As also seen, gold patching is about twice as effective as the aluminum. In fact, aluminum is shown to be relatively ineffective since tradeoff times are so short.

The fixed-coating system is less flexible than the shutter system in handling all possible orbits. For example, if the coating were designed to handle the maximum orbital heat flux (hot case 2), and then the vehicle were flown in the hot case 1 orbit, the heater power required would increase, because the heat flux decreases. This would decrease the tradeoff time to 2 hours. However, in considering a flight vehicle, it is most likely that a particular orbit or a narrow range or orbits will be utilized. Thus, the coating would be designed for these orbits only and the tradeoff time would be between 3.6 and 6 hours.

Figures 23 and 24 show the effect on system weight if the temperature control limits are relaxed. By so doing, the mission times for which a fixed α/ϵ system is optimum can be stretched out to 11 hours for the best case and 7.2 hours for the worst case.

APPENDIX V

EMERGENCY COCOON CHECKOUT PLAN

OBJECTIVE

This plan will describe the steps to be taken to assure proper operation of the cocoon system following fabrication.

TEST DESCRIPTION

The test will be performed at ambient conditions of temperature and pressure will consist of evaluating the structural integrity of the cocoon and the permeation rate of the composite layer assembly.

PERFORMANCE

The cocoon will be capable of retaining a 6.65 PSIG differential pressure (344 mm Hg) without exhibiting signs of structural weakness (breaking threads, etc.). Permeation through the cocoon will be in accordance with the formula $Q = PrA\Delta P/T$, with the term Pr (permeation rate), for the gases used below, being equal to the following:

Gas Used	Pr cc (STP) -cm/sec-cm^2-cm-Hg
Oxygen	60×10^{-9}
Nitrogen	28×10^{-9}
Water	3800×10^{-9}
Carbon Dioxide	320×10^{-9}

TEST PROCEDURE

Note: The cocoon being tested is considered to be a deliverable item and, therefore, all possible care should be exercised to maintain the cocoon in a safe, clean condition. Sharp objects or material that may cause the structure to become damaged or dirty should be kept away from the cocoon. Table XI lists the test equipment required.

Test

The testing will proceed as follows:

(1) Assemble the cocoon outer bag and hatch and place a 14 ft. diameter rubber balloon inside the cocoon. Provisions must be made to inflate and deflate this balloon while it is within the cocoon.

TABLE XI

TEST EQUIPMENT REQUIRED FOR EMERGENCY COCOON CHECKOUT

	Item	Quantity	Range
1.	Relative humidity sensor and meter	3	0-100 mm Hg.
2.	Press gage	1	0-50 PSI
3.	Oxygen supply	200 ft^3	Bottled 1200 PSI
4.	Nitrogen supply	200 ft^3+	Bottled 1200 PSI
5.	Carbon Dioxide supply	200 ft^3	Bottled 1200 PSI
6.	Gas press regulator	1	0-10 PSI
7.	Gas shut off valves	2	0-3000 PSIG
8.	Water metering valve	1	0-3000 PSIG
9.	Stop Watch (Clock)	1	—
10.	Misc. Hose and Tube		—
11.	Vacuum Cleaner	1	—
12.	O_2 Analyzer	1	0-800 mm
13.	CO_2 Analyzer	1	0-100 PPM

(2) Upon completion of the cocoon assembly the balloon will be inflated to a differential pressure of 5 mm Hg and the cocoon outer surface will be visually inspected for weak or defective areas. Particular attention will be given to the areas around the hatch, observation port and along the seams of the cocoon.

(3) Upon completion of the visual examination at 5 mm Hg, differential pressure, inflate the cocoon to 6.65 PSI (344 mm of Hg) differential pressure using air and/or nitrogen gas. This inflation will be performed slowly and visual examination of the cocoon will be made during the inflation period. At the first indication of damage, the inflation of the cocoon will be stopped until the extent and location of the damage has been determined. If the damage is not severe, the inflation will continue until the desired pressure level is reached. This pressure level will be maintained for approximately 5 minutes after which the circumference of the cocoon will be measured to determine the final size of the structure. The shape of the cocoon will be observed for uniformity. The size and shape of the inflated structure will be placed in the Cocoon Log Book.

(4) Upon completion of the measurements of the cocoon the silicon rubber membrane, Dacron mat composite gore will be placed over the cocoon and bonded together to form the semi-permeable membrane layer. (Note: extreme care must be exercised during this operation to prevent damage to the cocoon outer bag or the semi-permeable composite.

(5) Following completion of the composite layer assembly on the inflated cocoon the cocoon will be deflated and the composite assembly will be removed from the cocoon outer layer and preparations will be made for the cocoon assembly.

(6) When the semi-permeable membrane layer has been assembled into the cocoon, the cocoon will be sealed and inflated to 5 mm of Hg differential with air and inspected for leaks or damage. All leaks found are to be repaired.

(7) Upon completion of the leak check, the differential pressure of the cocoon will be increased to 6.65 psi (344 mm of Hg) using nitrogen. This pressure will be maintained for approximately 5 minutes after which the cocoon will be measured, inspected, and deflated to 5 psi differential. The physical measurement and inspection of the cocoon will be made and logged. At this time a test will be made to determine the permeation rate of the cocoon. (See Figure 26.)

The test will consist of timing the pressure decrease of the cocoon and comparing the measured rate to that rate given in the published data (Reference 1).

(8) Upon completion of the nitrogen permeation test the cocoon will be evacuated and the tests for oxygen and carbon dioxide permeation will be run. The test procedure will be the same as that described in stpes (6) and (7) of this test plan, except that oxygen or carbon dioxide will be substituted for nitrogen. (Note: In the event of a failure or leakage during the test, large fans will be used to prevent buildups in the partial pressure of carbon dioxide in the area.)

(9) The results of the nitrogen, oxygen, and carbon dioxide permeation tests, will be compared to determine if the correct relative permeation rates (reference 1) for the gases used are being obtained (e.g., $\mathrm{Pr\ CO_2/Pr\ O_2} = 5.34$, $\mathrm{Pr\ CO_2/Pr\ N_2} = 11.4$).

The test results, to be acceptable, should provide a ratio similar, or greater than, that shown in the example. In the event the resulting ratios are 10% lower than those given above, the cocoon will be leak checked using either a halogen leak detector or a helium mass spectrometer leak detector, depending on the difficulty encountered in locating the leak. All leaks found will be repaired. At the completion of the leak check, all of the permeation tests will be repeated. This procedure will be repeated until the desired separation (relative permeation rates) is obtained.

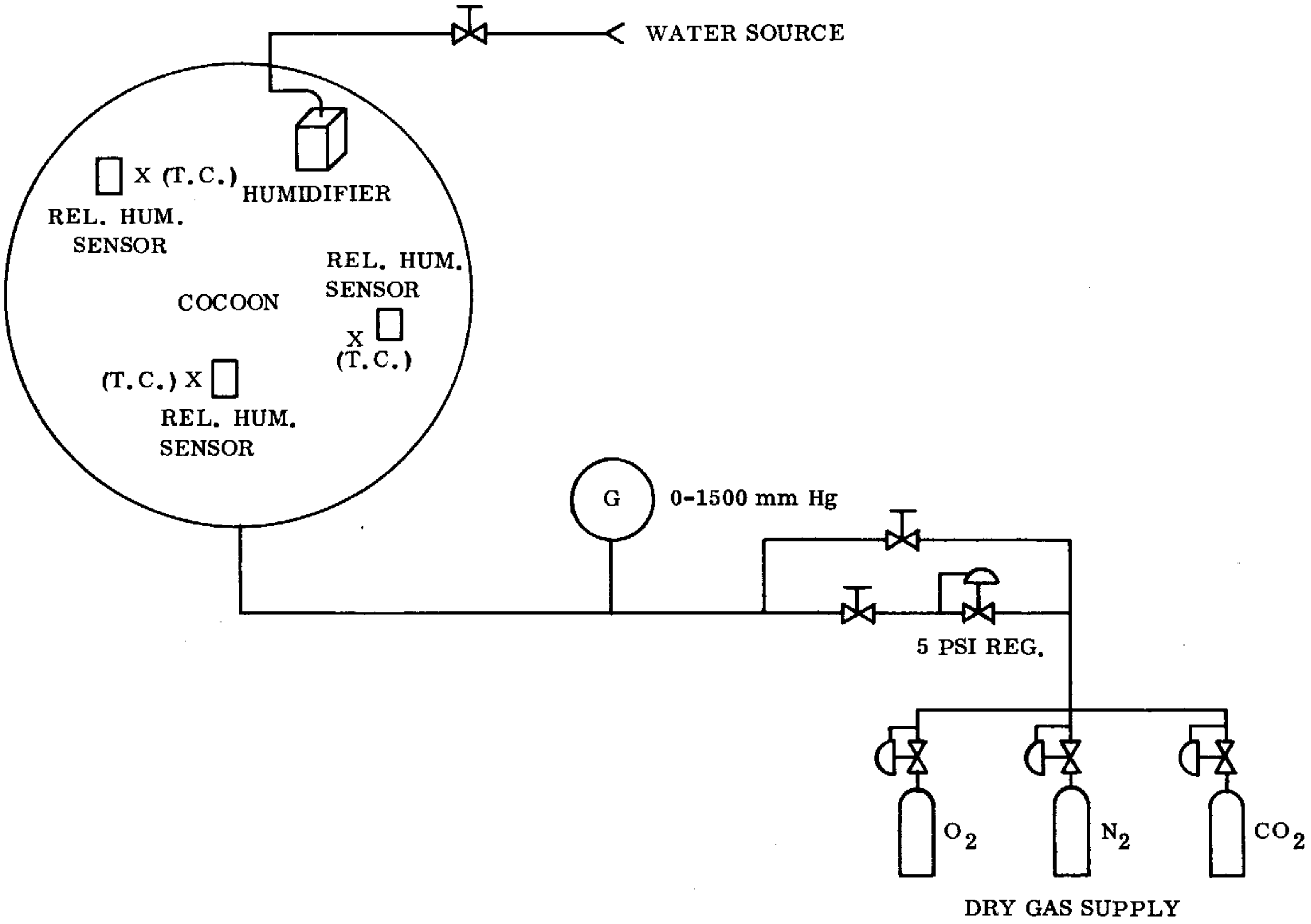


Figure 26. Emergency Cocoon Checkout Test Schematic

(10) The test for water permeation will be run following completion of the gas-permeation tests. This test will require the placement of relative humidity sensors and a humidifier within the cocoon, pressurizing the cocoon with air to 765 mm Hg absolute, and increasing the relative humidity within the cocoon to a level higher than that outside the cocoon. The test will consist of timing the decrease to a permeation rate which can be compared with the published rate.

(11) At the conclusion of the tests, measurements of the cocoon will again be made and recorded and the cocoon will be deflated and stored.

APPENDIX VI

SPACE ENVIRONMENT SIMULATOR TEST PLAN

TEST ITEM DESCRIPTION

The Emergency Cocoon is a 71-inch diameter spherical structure composed of a Dacron cloth pressure retention layer and a composite layer composed of Dacron paper and a silicone rubber membrane. The silicone rubber membrane is in effect a semi-permeable barrier which permits gases to pass from the cocoon at varying rates dependent upon the solubility of the gas in the membrane. The cocoon to be tested is an operating prototype of an emergency enclosure being considered for space use which has the capability of passive carbon dioxide and water vapor partial pressure control. The result of this capability is that only oxygen and a small amount of heat are required to maintain the well-being of the subject within the structure.

TEST OBJECTIVES

The objectives of this test are as follows:

a. Determine the thermal characteristics of the cocoon in a vacuum when exposed to solar loads of approximately 130 watts per square foot average and sink temperatures of $-280^{\circ}F$.
b. Evaluate the effectiveness of the thermal control system of the cocoon.
c. Determine the material compatibility of the cocoon with the environment of space.
d. Evaluate the emergency cocoon atmosphere control system concept.

TEST DESCRIPTION

The test will be performed in the Space Environment Simulator and will require the use of at least one quadrant of the solar system as well as the LN_2 shroud. The test will simulate conditions to which the cocoon will be exposed in space and will also simulate the heat and gas production loads of a man within the cocoon. The temperature of the cocoon surfaces (inside and outside) will be monitored as well as the air temperature inside the cocoon. In addition the capability of continuously monitoring the cocoon atmosphere will be provided.

The gas supply rates to the cocoon will be monitored to permit evaluation of the permeation rates of the cocoon wall. Cocoon pressure will also be monitored during the test.

PRETEST PROCEDURE

Cocoon Preparation

(1) Provisions will be made to support the cocoon in the chamber. The support should cause a minimum of thermal interference during the test.
(2) The observation port will be removed, and a plate containing approximately 50 thermocouple penetrations as well as penetrations for relative humidity and gas analysis monitoring will be installed in its place.
(3) The thermocouples will be attached to the inside of the cocoon in the locations indicated in Figure 27 and provisions will be made for supporting the thermocouples used to measure the air temperature within the cocoon.
(4) Provisions will also be made for lifting the cocoon into the simulator while inflated. This can be accomplished by the use of an auxiliary lifting fixture affixed to the cocoon.
(5) Sensors for cocoon total pressure and relative humidity will be installed.

Chamber Preparation

(1) The cocoon support structure must be installed in the location that will permit the cocoon to rest in the most desirable portion of the solar beam.
(2) The solar beam should be scanned and an intensity plot made of the quadrant to be used in the test, in order to permit valid interpretation of the thermal data to be obtained.
(3) Thermocouple leads and readout devices should be provided to permit rapid readout of the 100 thermocouples and be placed in and on the cocoon. All necessary cold junctions, etc., should be provided.
(4) Provisions should be made to permit continuous closed cycle cocoon gas samples to be run to an external gas analyzer circuit, as shown in Figure 27.
(5) Provisions will be made for remote monitoring of the relative humidity within the cocoon atmosphere, as shown in Figure 27.
(6) Oxygen, carbon dioxide, water supply lines, and electrical power for the heater must also be provided in the chamber. (See Figure 27.)

Test Procedure

(1) The cocoon mounting fixture used in the test will be installed in the simulator.
(2) Thermocouples and other readout and monitoring devices will be installed in the cocoon; upon completion of this task, the cocoon will be sealed up and pressurized to 1.5 PSIG.
(3) The cocoon will be placed in the simulator and the final temperature and atmosphere sensing connections will be made (including gas supply and vent lines, etc.).

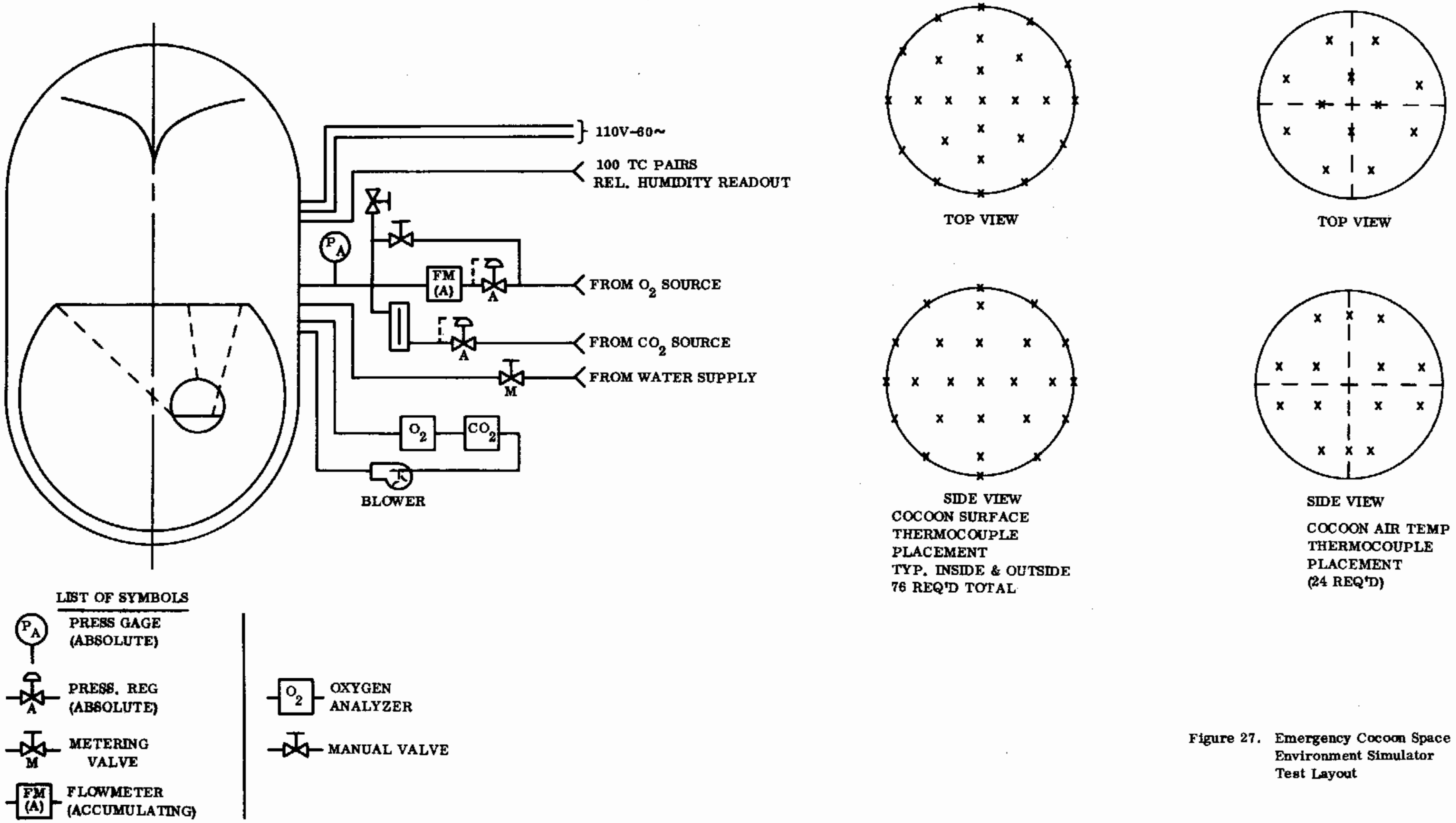


Figure 27. Emergency Cocoon Space Environment Simulator Test Layout

(4) Upon completion of the cocoon preparation, the simulator will be sealed and the readout systems checked out.

(5) At the completion of final checkout, the chamber will be pumped down to 1×10^{-4} torr or better.

During pumpdown, care must be exercised to assure that the differential pressure between the cocoon and the chamber does not exceed 5 psi. The admission of liquid nitrogen into the chamber should be done in accordance with normal startup procedures and during which time the cocoon temperature should be monitored closely.

After the chamber has been pumped down, and the LN_2 shroud has been cooled down, the solar system should be turned on and cycled to simulate a 100 to 300 N.M. equatorial orbit of the cocoon (45 min. ON, 45 min. OFF). This cycle should be repeated until the cocoon temperature cycles stabilize. After stabilization, the cocoon will be exposed to a constant solar load until thermal stabilization is reached. At this time, the test can be concluded.

During the thermal test and also during chamber pump-down, the cocoon will be supplied with carbon dioxide at rates that will simulate the metabolic rates of a man. Oxygen will also be supplied to makeup for leakage and permeation from the cocoon to chamber, and hold a constant cocoon pressure of 5 psia. An internal humidifier will provide the humidity in the cocoon, however, it will require water from an external source through the water supply line.

The oxygen, CO_2, and water supplied to the chamber will be closely monitored to provide information on the permeation and leakage of the cocoon.

A heater will be provided with the cocoon to maintain the cocoon temperature between 65° and 85°F during varying simulated orbital conditions.

The gas load to the chamber due to the permeation and leakage through the cocoon wall be as follows:

O_2	4.17 cc (STP/Sec)
CO_2	10.3 cc (STP/sec)
H_2O	(rel. hum.) = 3 lb/hr

The cocoon atmosphere pressure, temperature, pO_2, pCO_2, and relative humidity will be monitored and recorded during the test.

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Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* General Electric Company Missile and Space Division King of Prussia, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE APPLICATION OF PERMSELECTIVE COMPOSITE TECHNIQUES FOR ATMOSPHERE-THERMAL CONTROL OF EMERGENCY AND EXTRAVEHICULAR MANNED SPACE ASSEMBLIES

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report, May 1965 - August 1966

5. AUTHOR(S) *(Last name, first name, initial)*

Withey, David J.
Glanfield, Edward J
Dohner, Clark V.

6. REPORT DATE April 1967	7a. TOTAL NO. OF PAGES 85	7b. NO. OF REFS 14

8a. CONTRACT OR GRANT NO. AF 33(615)-2850	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 6373	
c. Task No. 637302	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	AMRL-TR-66-224

10. AVAILABILITY/LIMITATION NOTICES

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Aerospace Medical Research Laboratories, Aerospace Medical Div., Air Force Systems Command, Wright-Patterson AFB, O. 45433

13. ABSTRACT

This program encompasses the analysis, research, design, fabrication, and testing of an exploratory laboratory model of an emergency or extravehicular space assembly using permselective membrane techniques for atmosphere control. The purpose of this effort was to develop an advanced concept which would depart from the traditional approach utilized in spacecraft design by transferring most of the atmosphere-thermal control functions from the associated hardware subsystems to the enclosing structure. A silicone rubber permselective composite incorporated into the pressure retention wall of the enclosing structure permits selective permeation of carbon dioxide, water vapor, and contaminant gases to space with minimal oxygen permeation. In addition, the use of superinsulation on the exterior surface of the structure provides passive radiant thermal control. This, in conjunction with the permselective composite material, substantially reduces the weight, volume, and power requirements of environmental control subsystems required for a manned emergency and extravehicular assembly. While the permselectivity of the silicone rubber composite was determined, the final structure was subject to a large amount of leakage. This resulted in the cancellation of the full scale test program and in redirection of the project effort to include a failure analysis to determine the cause and solution to the leakage problem.

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Silicone rubber						
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