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CLOTHING AND TEXTILE DIVISION
U. S. NAVAL RESEARCH AND DEVELOPMENT FACILITY
BAYONNE, N. J.

THERMAL PROTECTIVE CLOTHING FOR STRATO-LAB HIGH #5,

Under Task No. NT-F015-14-002.02(3)

INFORMAL TECHNICAL REPORT NO. 22-11/61

BUREAU OF SUPPLIES & ACCOUNTS
DEPARTMENT OF THE NAVY
WASHINGTON, D. C.

U.S. NAVAL SUPPLY RESEARCH AND DEVELOPMENT FACILITY
BAYONNE, NEW JERSEY

Task No. NT-FO15-14-002.02 (3)

November 1961

Clothing and Textile Informal Report No. 22-11/61

THERMAL PROTECTIVE CLOTHING FOR STRATO-LAB HIGH # 5

by

J. J. Anderson

Captain Herman Strock, SC, USN
Officer in Charge

ABSTRACT

An insulating garment to be worn in conjunction with the Mercury-type Navy Mark IV Full Pressure Suit was required for use by Navy Balloonists for a flight to a projected altitude of 120,000 feet. An insulation garment was designed utilizing a vacuum deposited aluminum far infrared reflective insulation system of fabrics. The insulation consisted of a four layer sandwich structure intended to reflect the intense solar heat and also reduce heat loss by conduction, convection, and radiation thereby tending to isolate the balloonist from the thermal environment. The Garment was designed to provide low weight insulation, good mobility and ease of removal in case of an emergency. The suits were worn during the STRATO-LAB High # 5 flight and contributed to the successful accomplishment of the mission.

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ACKNOWLEDGMENTS

Development work is rarely the result of individual effort, and the development of the insulated garment utilized in STRATO-LAB High # 5 was no exception. Expressions of gratitude are therefore offered to the following persons who participated in bringing this work to fruition:

To Miss Alice Stoll, Aviation Medical Acceleration Laboratory for her counsel and aid in obtaining the use of high altitude chambers for fabric insulation studies.

To Messrs. Ned Davis and John Curtin, Minnesota Mining and Manufacturing Company for their splendid cooperation in suitability testing of various samples, and for metallizing the fabric used in the insulating garment on short notice.

Last, but it should not be inferred as least, to George Higginbottom of this laboratory for his untiring efforts and for never permitting the abstract to obscure his concern for the balloonists' personal safety.

THERMAL PROTECTIVE CLOTHING FOR STRATO-LAB HIGH # 5,

UNDER TASK NO. NT-F015-14-002.02 (3)

INTRODUCTION

The Bureau of Supplies and Accounts was informed on 15 November 1960 that a high altitude balloon flight was being planned for the Spring of 1961. This flight was to carry CDR Malcolm D. Ross and LCDR Victor A. Prather, Jr. to an altitude of 120,000 feet. This Facility was instructed by BUSANDA letter W11 of 23 November 1960, to make a study of the thermal stress which could be expected and to design and construct insulating garments prior to 1 March 1961.

The flight was to be a part of the Office of Naval Research's Strato-Lab Program. This program was initiated by ONR for the purpose of developing manned and instrumented balloon flights as a reliable, relatively simple, and inexpensive method of raising instruments and a scientific observer to great altitudes above the earth for periods of from one to many hours. The program has yielded much data, not only in the field of geophysics, but also concerning the high altitude environment and its physiological effects on man operating in such an environment.

In continuation of this program, STRATO-LAB High # 5 was conceived as an experiment with a "primary objective of placing two men in a near-space environment while wearing the Mercury-type Navy Mark IV full pressure suit. Under these conditions, a rigorous test and evaluation of the suit and associated protective clothing can be made" (1). Several other experiments were also scheduled to be made during the course of the flight.

The Mercury-type Navy Mark IV full pressure suit, similar to the one shown in Figure 1, was designed to provide a habitable atmosphere at a pressure of approximately 5 psi surrounding the wearer when exposed to the near vacuum of a very high altitude flight (2), (3), (4). The suit permits adequate mobility for its occupant to perform functional flight tasks even when pressurized.

The need for an insulating overgarment stemmed from the fact that the full pressure suit was not designed to provide the high insulation necessary to protect against extreme cold for extended periods of time. In the proposed flight the balloonists would be subjected to temperatures ranging from -20° to -70°C for a period of approximately five hours. During that time they would be restricted to a low activity level, thus requiring greater insulation than provided by the full pressure suit alone.

Special aluminized reflective insulating clothing had previously been developed by this laboratory for a Strato-Lab flight in 1959. CDR Ross was the pilot of the 1959 flight and at that time reported that the insulated clothing provided satisfactory thermal protection. During that flight the only defect noted was that the neoprene compound used to coat the fabric became perceptibly stiffer at the cold ambient temperature encountered at the maximum altitude of 40,000 feet. While the stiffness did not prevent necessary movements or restrict activity, it was noticeable and it did present a somewhat annoying situation. Considering the success of this experience, and since no other clothing materials with a higher insulation-to-weight ratio were available, it was decided to proceed along the same line for this flight. The only significant departure, other than modifications considered, was the use of experimental [illegible]

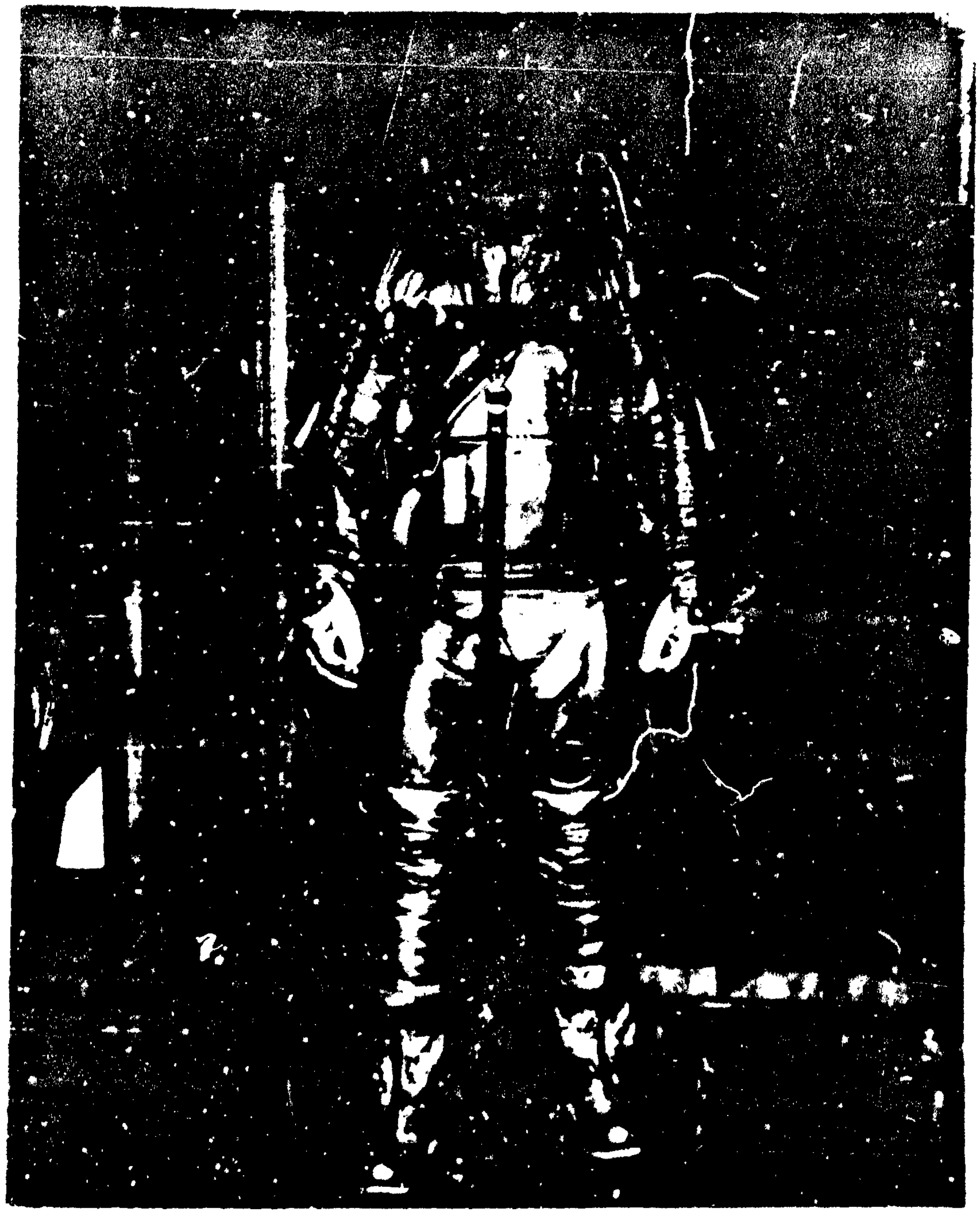


Figure 1

rubber coated fabrics which were known to have superior low temperature flexibility characteristics.

This report will discuss the physical surroundings and thermal environment the balloonists were expected to encounter at their maximum altitude, the insulation system used in a protective garment designed to be worn over the Mercury-type Mark IV full pressure suit, and the calculations used to estimate the thermal stress. The last section of the report will present the thermal data obtained during the flight.

THEORETICAL CONSIDERATIONS

Physical Surroundings: Early plans called for the flight to be made in an open gondola consisting of a platform surrounded by a 3-foot high railing. The sides, floor to railing, were to be covered with a fabric or some similar opaque material. The upper portion of the flight vehicle was to be open except for the structural members required for attaching the shrouds and the emergency parachute. An instrument and flight control console approximately 1-foot wide was to bisect the platform running from one end to the other along the centerline. Seats for the pilot and observer were to be located one on each side of the console.

Thermal Environment: Since the upper portion of the flight vehicle was to be open, direct solar radiation would be an important source of thermal energy while exposure to the cold black body sky would simultaneously result in a loss of thermal energy from the surface of the clothing to the sky by radiation. A schematic drawing of this thermal environment is shown in Figure 2.

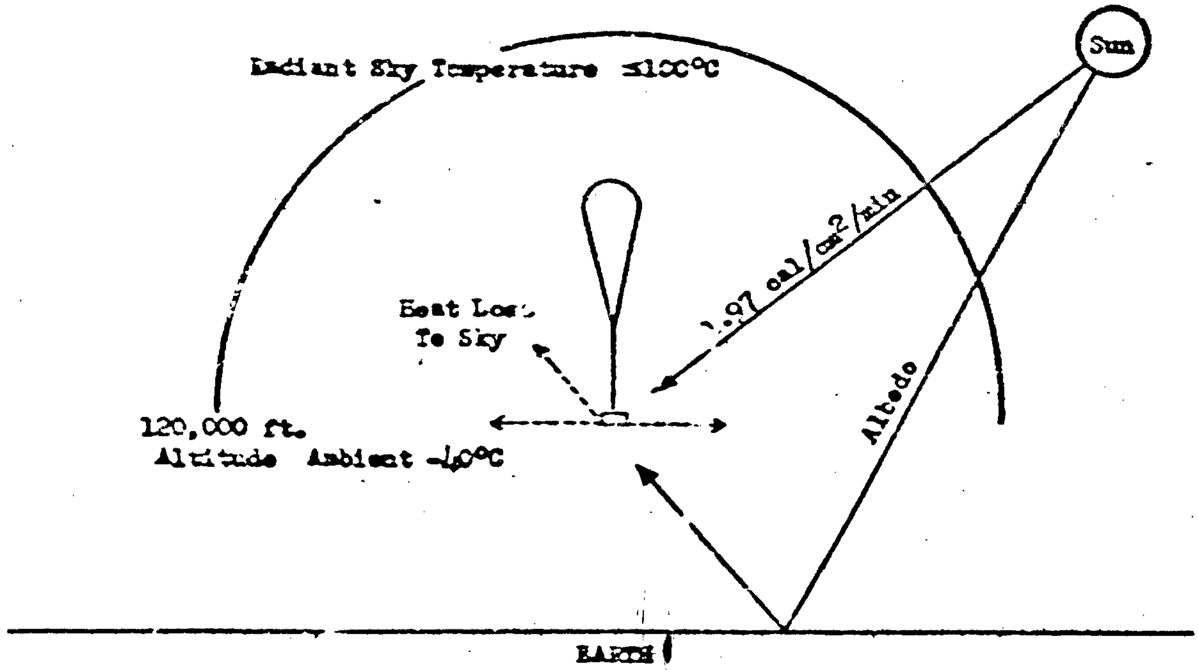


Figure 2. Schematic diagram of thermal environment.

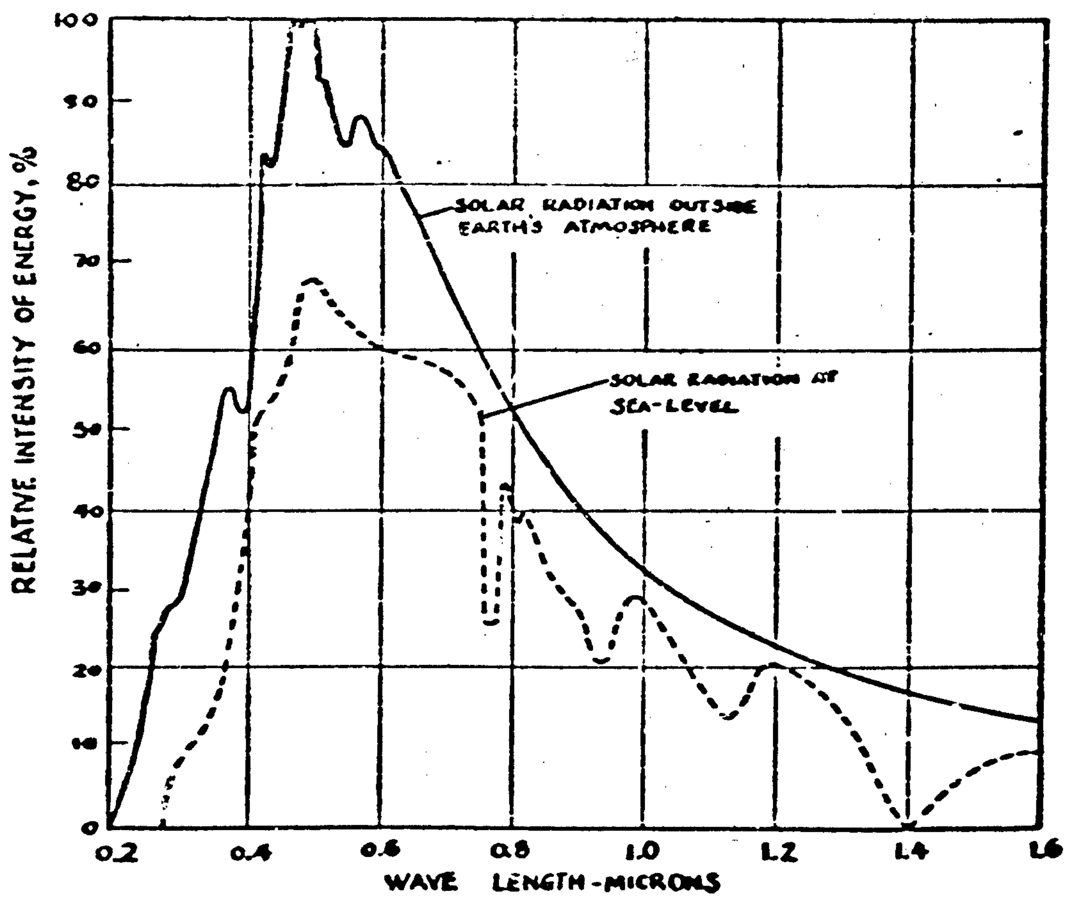
Thermal Gain: Thermal energy which would tend to produce an increase in the body temperature of the balloonists could be expected from three sources:

1. Metabolism
2. Solar energy received
3. Albedo

1. Metabolism: Due to the fact that the pilot and observer would be confined to a relatively small space, with all controls within arms length, and further restricted from high activity by the telemetering electrical leads which would connect them to the gondola, it was concluded that the body heat generation would be at the basal level of 23.5

calories per second. Of this amount it was estimated that 21 calories would be dissipated through the clothing while 2.5 calories would represent the respiratory loss.

2. Solar Energy Received: A typical curve representing the spectral distribution of solar energy is shown in Figure 3 (5), (6). The maximum intensity of solar radiation would occur at the flight zenith and was expected to be close to the solar constant of 1.97 cal/min/cm^2. This value was accepted although other values from 1.89 to 2.05 are reported in the Handbook of Geophysics (7).



TYPICAL CURVES FOR SPECTRAL DISTRIBUTION OF SOLAR ENERGY.

Figure 3

3. Albedo: As the configuration of the flight vehicle was such that the occupants would be shielded from "seeing" the earth's surface and most of the cloud cover, the affect of albedo as an additional heat source for the balloonists was not considered significant, and therefore this factor will not appear in subsequent calculations.

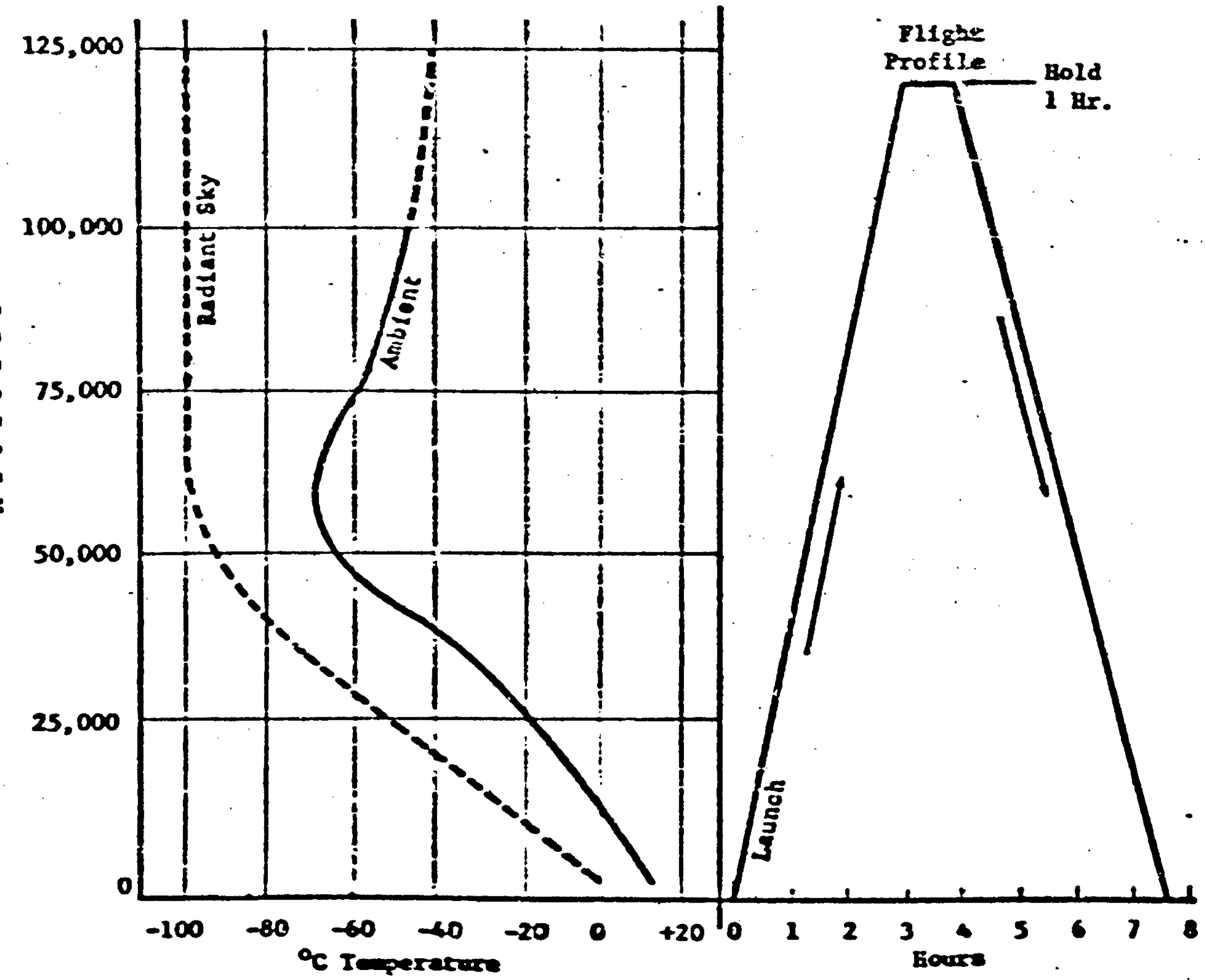
Thermal Loss: The loss of thermal energy was considered between the surface of the clothing and:

1. Ambient atmosphere (conduction-convection)
2. Radiant loss to the sky
3. Radiant loss to the flight vehicle

1. Ambient Atmosphere: The ambient temperatures at various altitudes and latitudes were available from several different sources and all showed fairly good agreement at the higher altitudes. The values for the ambient temperature were obtained from the Handbook of Geophysics (8), and are represented in Figure 4. The convective loss of heat at 120,000 feet, although in a rarified atmosphere, was expected to be close to the convective loss at sea level since the thermal conductivity does not change appreciably until much lower pressures are encountered.

2. Radiant Loss to Sky: For the purpose of this report the radiant sky temperature is taken as the equivalent "black body" temperature of the sky and the value is used in determining the ΔT used in calculating the loss of thermal energy from the outer exposed surface of the balloonist clothing to the sky. Dr. Hamel, of the University of Pennsylvania, had made some radiant sky temperature observations from an aircraft flying at an altitude of approximately 35,000 feet. His data, obtained in January, 19[illegible]

at Ladd Field, Alaska, indicated that the radiant sky temperature ranged between -70° and -120°C. While these values could not be readily confirmed by the work of other investigators, they did appear valid when compared to other similar measurements taken from the ground level in the same general location (9). It was therefore decided to use -100°C as the equivalent black body sky temperature in calculating the heat loss by radiation from the clothing surface to the sky.



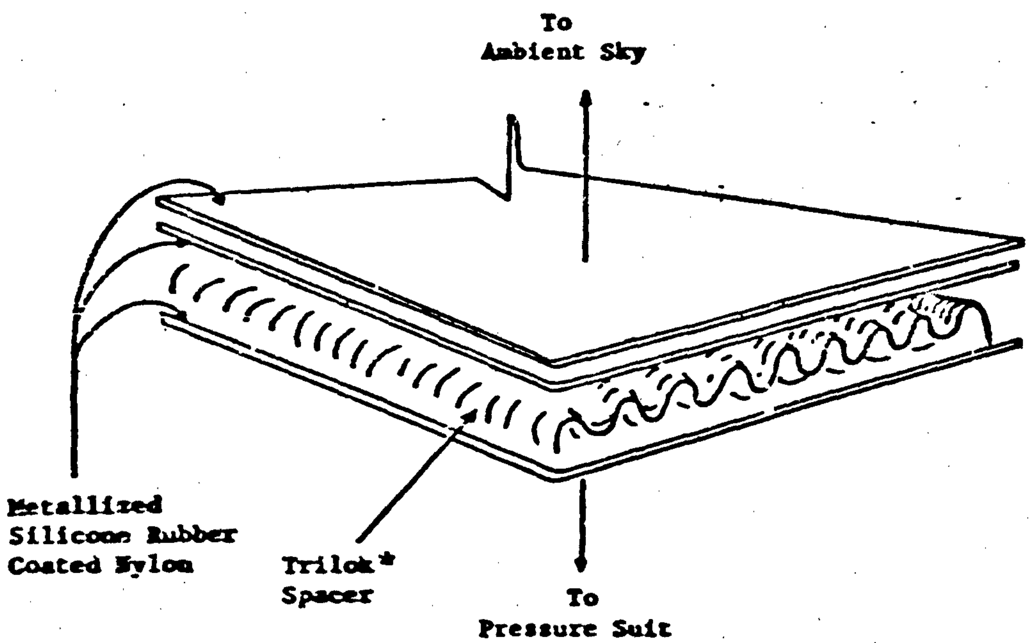
Flight and Temperature Profile

Figure 4

3. Radiant Loss to Flight Vehicle: The main body of the flight vehicle was to be constructed of aluminum and left unpainted. Since the spectral emissivity and reflectance characteristics of the vehicle would be similar to the reflectance characteristics of the aluminized clothing it was concluded that the temperature of clothing and vehicle would be almost equal and therefore no radiant exchange of energy would occur.

MATERIALS

Insulation Assembly: In addition to the Full Pressure Suit, described by previous references, the balloonists were to wear an overgarment for additional insulation. A cross-sectional view of the clothing insulation assembly is shown in Figure 5. This assembly consisted of four layers



*Registered U. S. trade mark, U. S. Rubber Company.

Cross-Sectional View of Insulation Assembly

Figure 5

which, when viewed from the inside to the outside, contained the following:

First layer: Metallized fabric, metal side facing the Trilok

Second layer: Trilok spacer

Third layer: Metallized fabric, metal side facing the Trilok

Fourth layer: Metallized fabric, metal side facing ambient atmosphere

This arrangement of fabrics and spacers was designed to provide a high insulation, low-weight system which would thermally isolate the wearer from solar heat gain and radiant sky heat loss.

The two layers of metallized silicone coated nylon with the metallized sides facing each other across the Trilok spacer provided a good low weight insulator. This arrangement formed a confined air space between the coated fabrics which retarded heat transfer by conduction-convection. The two separated metallized surfaces facing each other also provided low emissivity surfaces which greatly reduced the heat loss by radiation across the intervening air space. This combination was tested for thermal conductance in a high altitude chamber by the same method discussed in reference (10), and was found to have a thermal conductance of .57 x 10^{-4} cal/cm^2/°C/sec at 75,000 feet simulated altitude.

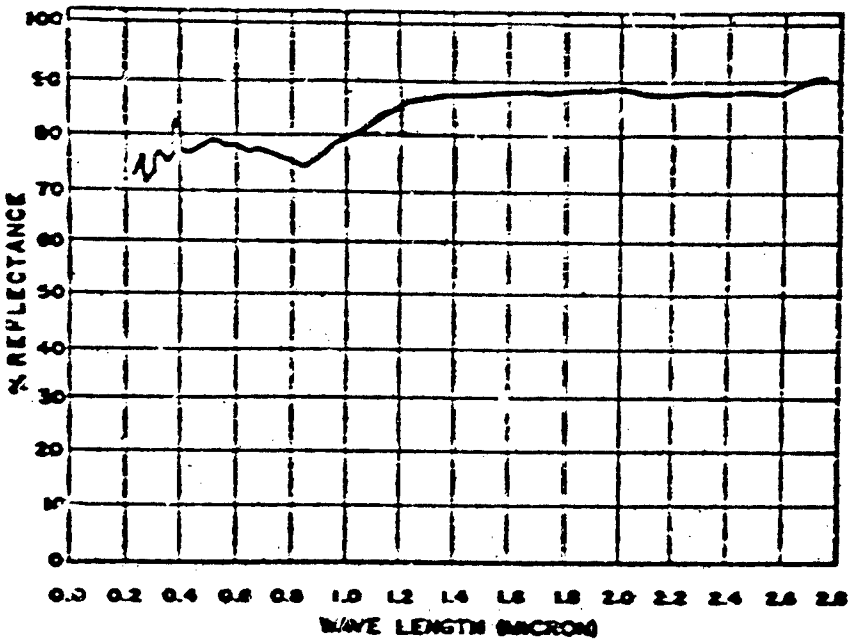
The outer metallized silicone coated nylon fabric of the garment was used with the aluminized surface facing the ambient atmosphere primarily to reduce the heat loss to the cold black body sky, and secondly to reduce the amount of solar heat absorbed by the clothing assembly. A white fabric would have served quite adequately in the secondary role since several white fabrics have a better than 70% reflectance for solar radiation (11); however, it would not have accomplished the primary purpose. Most fabrics have a high emissivity in the far infrared region of the spectrum and therefore would have been good radiators of heat to the sky, thus permitting a greater loss of heat by radiation.

Fabric: The fabric utilized in the assembly was a 2-ounce nylon taffeta conforming to Type 1 of MIL-C-19699(S&A) with a low temperature silicone rubber coating on one side. The silicone coating was formulated to have a cold crack of below -140°F and showed only very slight stiffening at -100°F. Metallizing with a thin metal film of aluminum by vacuum deposition to the silicone coating was attempted but adequate adhesion of metal to coating could not be achieved. The fabric was subsequently metallized on the uncoated side.

Spectral Reflectance of Metallized Fabric: The reflectance characteristics of the metallized silicone rubber coated nylon, metallized side exposed, is shown in Figure 6. This curve was obtained on a Beckman DK-2 spectrophotometer.

These data were adequate for the visible and near infrared; however, in order to calculate the radiant loss to the sky the emissivity in the longer wave lengths was needed.

At 100°F the energy curve would peak at 9.3 microns and at 0°F the peak would be at 10.4 microns. The emissivity at each of the temperatures are very close. Therefore, for convenience, the total normal emissivity was determined using the Stoll-Hardy radiometer with the



REFLECTANCE VS WAVELENGTH OF ALUMINIZED CLOTH

Figure 6

metal surface temperature at 100°F. The emissivity was found to be 0.18 to 0.20, and the latter figure was selected for use as a conservative value in the subsequent calculations.

Clothing Surface Area: The total area for a man clothed in a cold weather outfit is 2.64 square meters according to Winslow and Herrington (12). The exposed area would therefore be 26,400 square centimeters which, for this study, was considered to be the total exposed surface area of the garment. However, since the gondola chair would be in direct contact with the clothing, it was estimated that 3,700 square centimeters of the clothing surface area would not be exposed to either ambient air temperature, cold sky, or direct solar radiation.

To determine the clothed area of a man in a sitting position exposed to the sun, shadow area measurements were taken on a plane normal to direction of light from an overhead light source. The light was positioned directly overhead and then rotated so that it formed angles of 20°, 37°, and 45° to the vertical. It was found that a maximum of 25-30% of the total surface area was exposed at 37° while approximately 18% was exposed when the light was directly overhead. At angles greater than 37°, the area exposed decreased.

Since the flight was to be launched in the morning during the spring of the year, the sun would not be directly overhead at any time, and therefore it was estimated that a 30% value for the exposed area would be most probable.

THERMAL STRESS

The method used in determining thermal stress was not a generally accepted method. It was used in this application, however, for the following reasons:

(a) The metabolism at slightly above the basal rate could be considered constant since there would not be sufficient space in the flight vehicle to permit an activity level to produce a higher metabolic rate.

(b) The literature contained no discussions of thermal stress in similar environmental situations. There have been no previous flights to the projected altitude under comparable conditions. Flights which were close to the 100,000 foot altitudes utilized an entirely different type of flight vehicle which markedly altered the affects of the thermal environment.

(c) While the solar constant and ambient temperatures were well defined, radiant loss to the sky and convective losses to the ambient atmosphere for the complicated and irregular surface of a clothed human being were not described in the literature, and sufficient time was not available to perform the experiments which would develop this data.

(d) No test chambers were available which were capable of simulating the thermo-dynamic conditions to be encountered in this flight, or which would subject a clothed man to the unique combination of stress factors anticipated.

Thermal Stress Calculations

Thermal equilibrium is achieved when:

Q metabolism = Q ambient $\pm Q$ seat $+Q$ radiant sky $-Q$ solar

Metabolism is taken at the basal rate of 21 calories/second, respiration loss of 2.5 calories/second has already been subtracted from this figure.

Symbols:

Q - Heat gain or loss - calories/second
T_1 - Skin temperature 30°C
T_2 - Ambient temperature -40°C
T_3 - Suit surface temperature °K
T_4 - Radiant sky temperature 173°K

a - Absorptivity
e - Emissivity of fabric surface
A_1 - Total surface area of clothing, cm^2
A_2 - Area of clothing in contact with seat, cm^2
C_1 - Conductance of pressure suit, $cal/cm^2/°C/second$
C_2 - Conductance of reflective assembly, $cal/cm^2/°C/second$
C_3 - Conductance of chair cushion
C_4 - Conductance through pressure suit, insulation assembly, and chair
C_5 - Conductance through pressure suit and insulation assembly
P - Stefan-Boltzmann Constant, 1.354×10^{-12}
K - Geometric factor adjusts for body area which does "see" sky

$Q_{ambient} = (A_1 - A_2) \times C_5 \times (T_1 - T_2)$

$Q_{seat} = A_2 \times C_4 \times (T_1 - T_2)$

$Q_{solar} = \frac{\text{Solar Constant}}{60} \times (a) \times \text{Area exposed to sun}$

$Q_{radiant\ sky} = .5 \times K \times (A_1 - A_2) \times e \times \rho \times (T_3^4 - T_4^4)$

(This equation is for radiant loss from a convex body to all surroundings when the body is small in size relative to the enclosure. The factor of 0.5 above is included since in the balloon situation the radiant loss is to the hemisphere sky. Sky emissivity is taken as 1.0.)

Conductance Values.

C_1 Pressure suit .000066

C_2 Reflective insulation system .000057

C_3 Chair seat cushion .000020

$$C_4 = \frac{1}{\frac{1}{.000057} + \frac{1}{.000066} + \frac{1}{.000020}} = .0000121 \text{ cal/cm}^2/^\circ\text{C/sec}$$

$$C_5 = \frac{1}{\frac{1}{.000057} \quad \frac{1}{.000066}} = .0000306 \text{ cal/cm}^2/^\circ\text{C/sec}$$

The solution for T_3 is:

Q metabolism = Q ambient + Q seat + Q radiant sky -Q solar

$$\begin{aligned} Q_{amb.} &= (A_1 - A_2) \times C_5 \times (T_1 - T_2) \\ &= 22700 \times .0000306 \times 70 \\ &= 48.6 \text{ cal/cm}^2\text{/sec} \end{aligned}$$

$$\begin{aligned} Q_{seat} &= A_2 \times C_4 \times (T_1 - T_2) \\ &= 3700 \times .0000137 \times 70 \\ &= 3.13 \end{aligned}$$

$$\begin{aligned} Q_{solar} &= \frac{\text{solar constant}}{60} \times \text{absorptivity} \times \text{Area exposed} \\ &= 1.97/60 \times .2 \times .3 \times 22700 \\ &= 44.7 \end{aligned}$$

$$\begin{aligned} Q_{rad.\ sky} &= .5 \times K \times (A_1 - A_2) \times e \times \rho \times (T_3^4 - T_3^4) \\ &= .5 \times .7 \times 22700 \times .2 \times 1.354 \times 10^{-12} \times (T_3^4 - 173^4) \end{aligned}$$

Solving for the surface temperature of the garment, it was found that T_3 equals 20°C.

This condition would exist if equilibrium could be attained, however, in practice, this is rarely if ever achieved. Past experience in this laboratory with similar insulating assemblies indicated that with an outer clothing surface temperature of 20°C the heat loss from the body would actually be less than the metabolic rate and therefore a slow build-up of body heating could be expected. The rate of the build-up was expected to be low in comparison with the body's ability to act as a heat sink and therefore it was considered that it would not cause an appreciable rise in the deep body temperature.

Judging from the results of this solution it appeared that the insulating garment in combination with the full pressure suit would provide adequate protection.

The most significant fact gleaned from the calculations was that the body metabolism was small compared to the thermal forces against which it must be protected. The metabolic rate was estimated at 21 cal/sec, while the calculations indicated heat loss by conductivity-convection to be 48 cal/sec and heat gain from solar radiation 45 cal/sec. Since these forces are large in relation to the metabolism, the thermal equilibrium equation is very delicately balanced and a change in the conditions established could cause a heat gain or loss which would be physiologically intolerable over the intended period of the proposed flight.

Considering this situation, and in the interest of personal safety for the balloonists, it was judged that additional measures should be taken which would permit some degree of control over the thermal environment. CDR Ross had previously discussed the possibility of locating attenuating louvers on the top and sides of the flight vehicle. These louvers would be blackened on one side, reflective on the other, and controlled in such a manner that either side could face the sky. This plan was endorsed.

Since one portion of the body would be subject to a high heat gain while another area would lose heat rapidly, and when considering that neither the human body nor the clothing assembly are good conductors of heat, it was obvious that a situation could arise where one portion could become overheated while another portion would become severely chilled. To overcome this situation, it was recommended that the vehicle be rotated in flight so as to evenly distribute heat gain and loss over a greater area of the body.

CLOTHING ENSEMBLE

The reflective insulated clothing outfit designed consisted of a coverall, hood, boot covers, and a hand muff which were all sized to be worn over the high altitude full pressure suit and its accessories. The items were fabricated in the layer arrangement of aluminized impermeable fabrics, and Trilok spacer material as shown in Figure 5. The total thickness of the assembly was approximately 1/2 inch.

The coverall was made with four nylon tape fasteners, two extending the full length of the garment from shoulder to leg bottoms, and 1 on each arm from shoulder to sleeve bottom. This arrangement permitted rapid and unassisted removal of the garment if this became necessary during the flight. The boot covers were sized to be worn over shoes or insulated boots, using a slip-on style about 12 inches high and having a back slide fastener opening. The perimeter of the hood face opening was designed to be compatible with the visor of the pressure suit helmet.

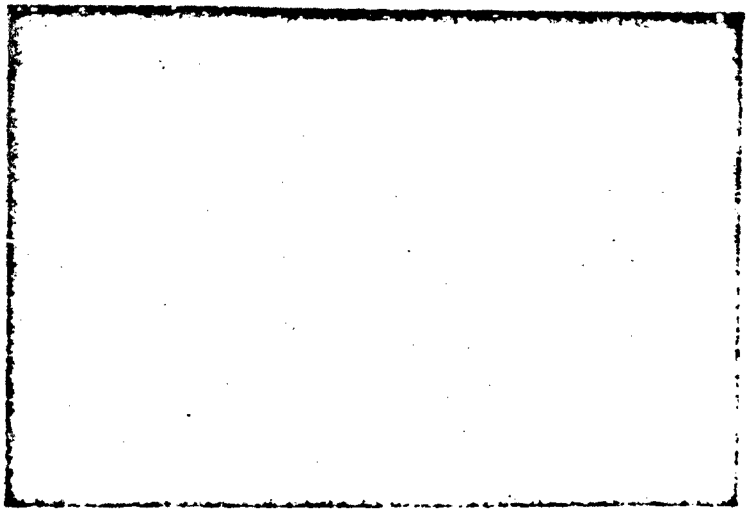


Figure 7 . . .

Partially completed leg and sleeve sections of the coveralls. Note the Trilok spacer material sewn to the entire perimeter of the aluminized fabric to facilitate handling during fabrication.

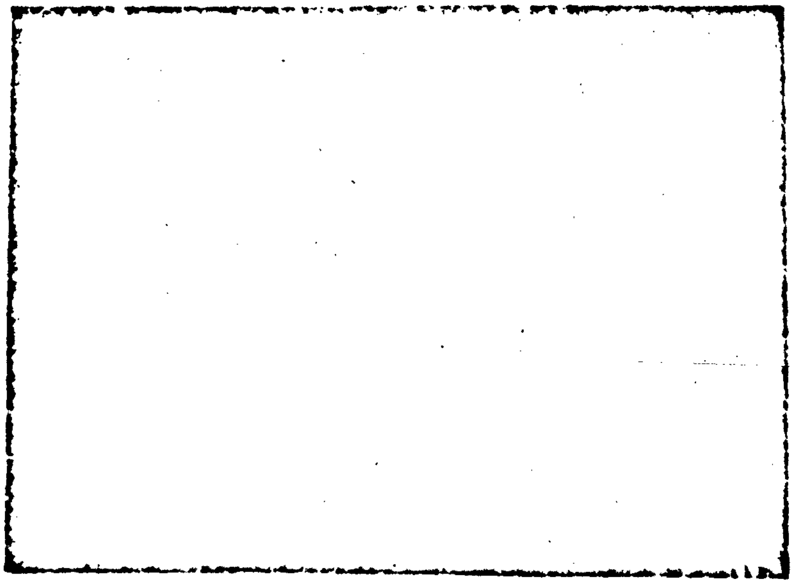


Figure 8 . . .

Sewing the Trilok spacer material to the aluminized fabric. Note the use of gloves to prevent soiling and contamination of the metallized surface from skin oils and perspiration.

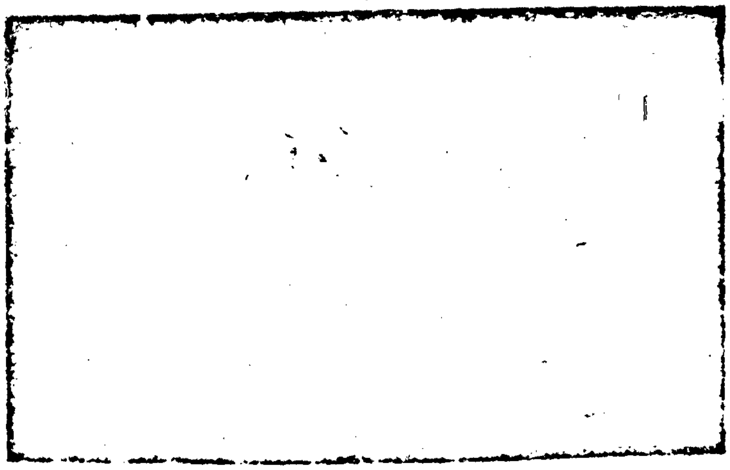


Figure 9 . . .

Designers preparing component parts of the reflective insulated coverall for final assembly.

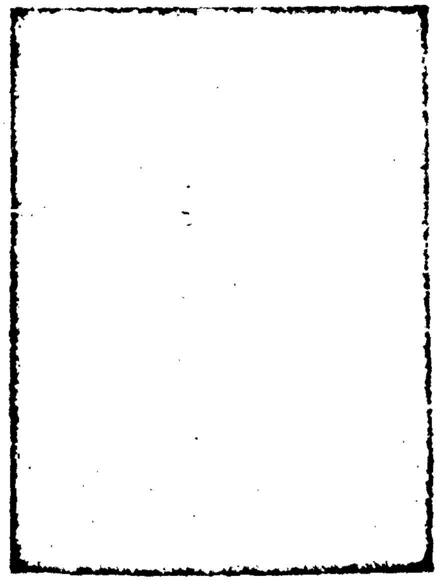


Figure 10 . . .

Front view of reflective insulated coverall and hood. The openings on the leg and sleeve are portal accommodations for the full pressure suit.

The hand muff was constructed with aluminized fabric on only one half of the surface area, while the other half was made from a dark blue/black colored woolen fabric. This design was utilized in order that the muff could be rotated depending on how cold or warm the balloonists hands were. When warm the aluminized surface would be exposed to the sun's rays to reflect the heat. When cold the black surface would face the sun to absorb heat.

STRATO-LAB HIGH # 5

Departures From Original Plan: In consideration of the thermal problem connected with this flight, it was decided that the flight vehicle would be fitted out with attenuating louvers. These louvers were slightly modified venetian blinds with the slats blackened on one side and covered with aluminized mylar on the other side. The blinds were arranged and powered so that either side of the slats could be turned outward. The blinds on the front of the gondola could also be raised or lowered.

During simulated high altitude runs in a low pressure chamber with the balloonist fully clothed, it was found that both CDR Ross and LCDR Prather experienced a severe reduction of mobility of the lower arms due to a constriction of the overgarment at the elbow when the Mark IV suit became fully pressurized. Therefore, both sleeves of each insulating garment were removed just above the elbow.

Late in the developmental program, it was decided to provide electrically heated gloves and socks as stand-by for emergency hand and foot protection. These items were manufactured with heating elements knitted together with polyester yarns to form the glove and sock. The gloves were rated at 15 watts and the socks at 21 watts. They were connected through a control rheostat. The capability of providing varying amounts of heat to the hands and the feet was thus available to each balloonist at his discretion. However, from a philosophical point of view and in view of the test objective, it was not planned to use the heat unless absolutely necessary.

Flight: The flight took place on 4 May 1961 from the flight deck of the USS ANTIETAM in the Gulf of Mexico. The balloon had a total displacement of 10,000,000 cubic feet at ceiling altitude, was inflated with helium, and lifted approximately one ton to an altitude slightly above 113,700 feet (13), (14).

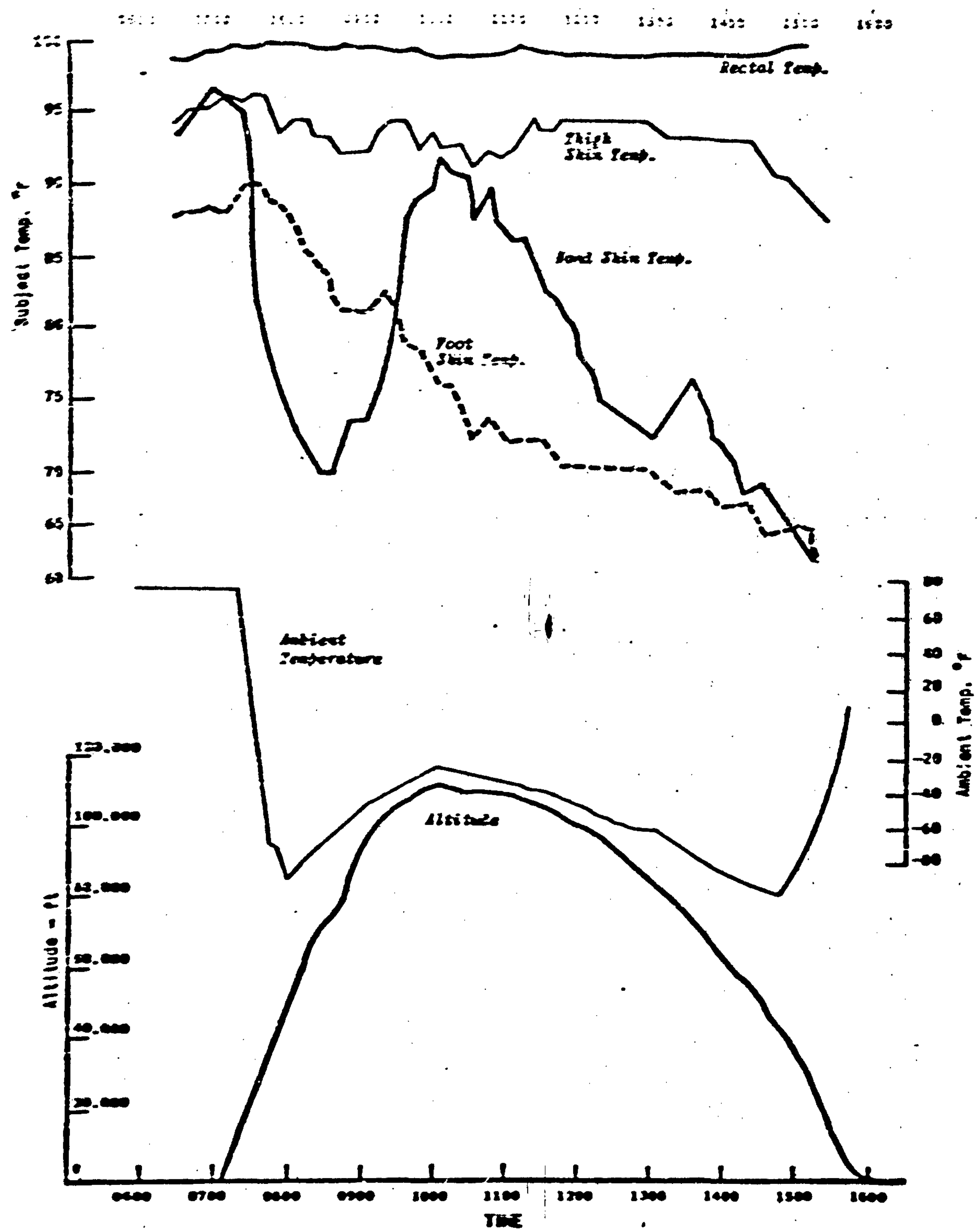
Part of the physiological data obtained consisted of skin surface temperatures of each of the balloonists. These data, together with the altitude and ambient temperatures experienced are shown in Figures 11 and 12.

Abbreviated Log of Voice Transmissions

Several tape recordings of the voice communications were made during the flight. LCDR Donald Smith, NMRI-RAM Bethesda prepared a complete log from these tapes. The communications were garbled and interrupted on several occasions, therefore, in accomplishing the transcription, LCDR Smith made no attempt to infer transmissions totally missing or to fill in the content of missing parts of transmissions which were only partially received.

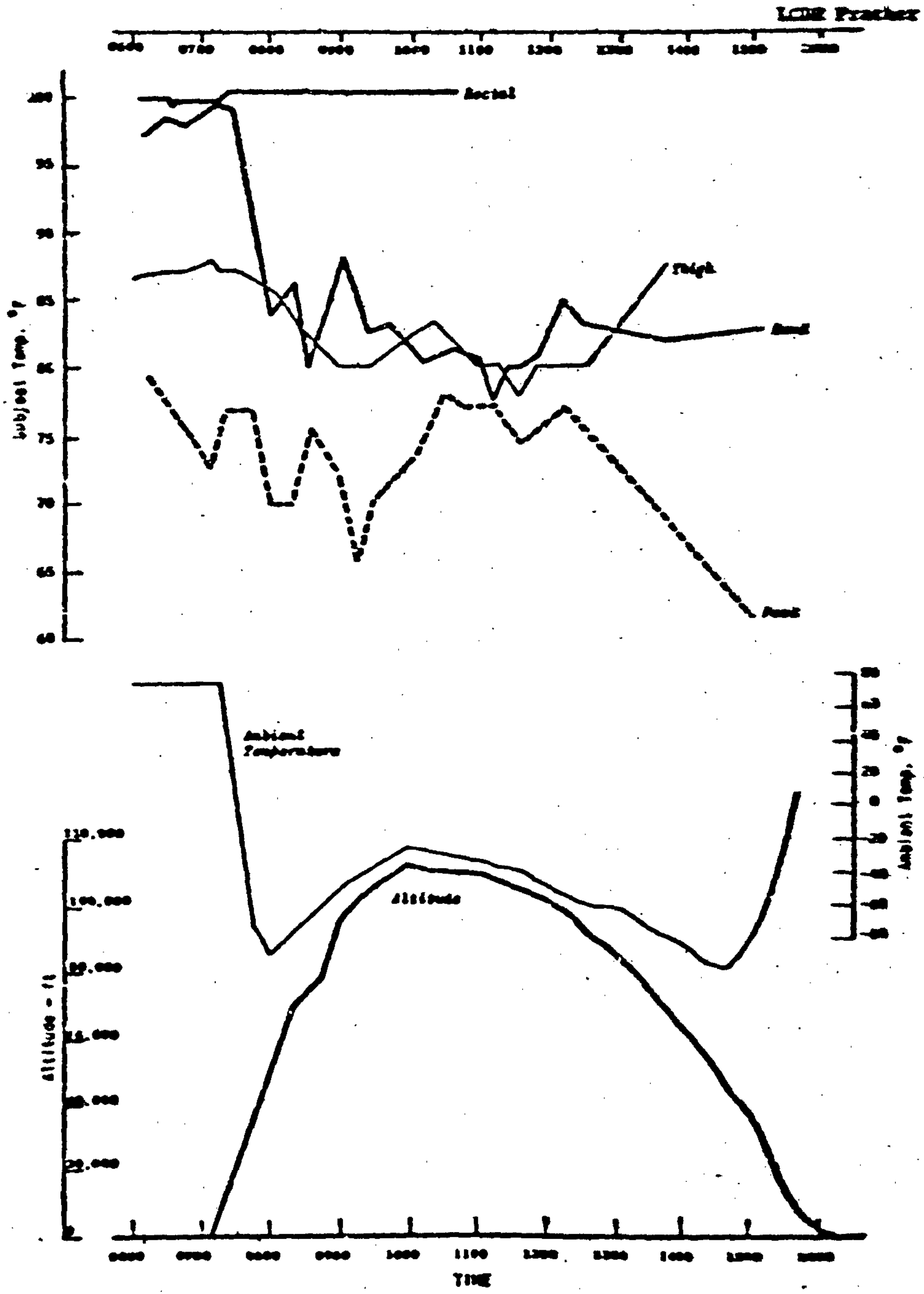
The communications extracted for this abbreviated log are limited to comments concerning thermal comfort.

Abbreviation Code	Originator
AR	CAPT. Anthony P. Rush, MC,USN, BuMed
B	CAPT. Victor G. Benson, MC, USN, AMAL, Johnsville, Pa.
L	CDR Benjamin B. Levitt, USN, ONR
P	LCDR Victor A. Prather, MC USN, NMRI-RAM Bethesda, Md.
R	CDR Malcolm D. Ross, USNR, ONR
S	CDR John W. Sparkman, USN, ONR, Minneapolis, Minn



Body Temperature During Flight

Figure 11



Body Temperature During Flight

Figure 12

Time Approx.	Altitude Approx.	Originator	Communication
0655	0.0	S	How are you doing, Mal? (Garbled) - getting warm?
		R	Yes
		P	Warmer than hell.
0708	(Official time of launch)		
0728	19,000	R	(Garbled) You might be interested in, as a matter of fact we have really cooled down. Over.
		S	It happened, huh?
		R	Affirmative
		S	Yes, how do you feel? Gordon would like to know.
		R	I feel great. Victor, come in.
		P	Okay
0731	24,000	S	How are you feeling?
		R	Feeling fine. How are you feeling, Victor?
		P	I'm beginning to get comfortable.
0743	35,000	B	Mal, Mal, this is Gordie. What is the position of your blinds now?
		R	Black side out. Over
		B	Is it getting pretty cold?
		R	Say again.
		B	Is it getting pretty cold?
		R	Well, we're not whistling Dixie
0825	68,000	AR	This is 30. Have you had to use any heat as yet?
		P	Have we used any heat as yet?
		AR	That is correct.
		P	(Garbled) gloves and sock heat as yet. No.
0834	74,000	B	38, this is 30. How do you boys (garbled) do you fellows feeling physically? Are you getting severely cold?
		R	Negative. We feel relatively fine. How do you feel Victor?
		P	Excellent. I feel real good now.
0837	76,000	B	38 this is 30. Are the position of the blinds still the same?
		P	That's affirmative. Position of the blinds - black side out. Doing well.
		B	All blinds fully closed, right?
		P	That's affirmative again.

0840	78,000	R	38 this is 30. Standby for medical monitoring figures. On Victor Prather; rectal temperature 100.2; respiration 36; pulse 100; face plate temperature 125; hand temperature 80; inner thigh temperature 82; cheek temperature 95; foot temperature 78.
		B	38, this is 30. Did you receive my last?
		P	Got most of them, Gordie, but you cut out every now and then. Understand that report was on myself.
		B	That is correct. Report on Ross follows; pulse 93; respiration 24 - correction - respiration 27; rectal temperature 99.4; thigh temperature 91.6; hand temperature 72; foot temperature 81.
0849	86,000	B	38 this is 30. How is the general comfort situation in the gondola at the present time?
		R	It's very fine. What do you expect? It's wonderful. Over.
		B	Do you feel as though you're warming up any, Mal?
		R	Yes, I would say it's warming up. Yes, I think so. How about you Victor? Do you (cut out)
		P	I would tend to agree. My right hand is in the muff. My left hand has never been in the muff. It has been outside and it is a little bit more comfortable. My feet are very very comfortable with just a little bit of toe coldness but I suspect we're going to start to warm up here in a little while.
0906	97,000	R	(Garbled) is open. I have my picture window (garbled) and Victor still has his closed. The rest of the gondola is closed up with the black side out.
		B	38 this is 30. Do you mean you have your front blind pulled up, or do you have one of the other blinds open?
		R	Sparky, I mean I have my picture window wide open. I've got the blinds clear up to the top and I am just sitting here looking at the world.
0913	100,000	S	38 from 30. Mal, have you changed the blinds around any since you've been up now.
		R	We'll have to give you a new report because Victor just changed the direction of the blind.

		R	Okay. The only thing we've - the only thing we've done with the blinds is Victor has turned his front blinds open so we can see out. He has not raised them but he has them open and mine is just raised. Completely open. Over.
0918	104,000	B	38 this is 30. Vic, do your hands or feet feel cold at this time?
		R	That's negative. Brrr! Everything is very comfortable, Gordie. Over to you Vic.
		P	I wear my muff a little bit but I don't notice it. Hell no.
0950	113,700	Maximum altitude	
0955	113,700	P	30 this is 38. The medical monitors wanted me to get the word about 10 or 15 minutes ago I was pretty warm. Been moving a little bit, and started perspiring but put the aluminum side of the blinds out just on my side of the gondola. The starboard overhead, starboard forward and starboard aft, and I think it's helped because I am quite a bit cooler now.
		S	Very good Vic. Very Good. (Garbled).
		S	How do you feel heatwise?
		P	You'r cutting out.
		S	We would like to know how Mal feels heatwise? Over.
		R	I'm fine. I'm very comfortable. Everything is just fine. Over.
1015	110,000	AR	38, 30 This is Tony. How are you boys feeling?
		R	I'm feeling fine. Victor, how about you?
		P	Likewise, Tony.
		B	What are the positions of your blinds now, Please?
		R	My blind is half - the whole front blind is half raised half raised so I am still getting a good view of things. The rest of the blinds are turned - well, Victor's are turned silver side out and mine are turned black side out.
		B	38 this is 30. Vic do you have your front blind raised at all?
		P	Why, it's up about maybe a fifth of the way. I had a Helluva lot of trouble winding it up. I don't know whether the pulley is binding or what. So I didn't want to raise it all of the way up and not be able to get it back down.

1020	110,000	B	38 this is 30. This is Gordie. Can you boys tell me something about the mobility of the suits at high altitude?
		P	Gordie, this is Vic. I am still unhappy. I don't think I can move as well as I did up there at ACEL. I still think it is that outer garment. It is Okay, though. The outer garment seems to be the right answer up here. On the way though we weren't cold at all. The only thing that bothered me was my right elbow that is in contact with the gondola and that isn't covered - (Garbled). How about you Mal?
		R	Roger (Garbled) a hundred percent. The actual mobility as Vic says - (Garbled) Philadelphia and it is restricted wish this outer garment but it's sure nice to have. We're not dancing any jigs up nere, but we're getting along fine. Thanks.
1130	108,300		
1201	103,500		
1300	88,100		
1330	77,500		
1400	67,000		
1430	58,000		
1500	40,000	B	Mal, how are you doing temperature wise? Are you pretty cold up there now?
		R	It's a little on the chilly side, Gordie.
1560	16,400		
1606	Gondola contacted water, envelope released; Official Landing Time 1602 CST		

DISCUSSION

Several days after the flight,CDR Ross was interviewed to obtain his subjective comments concerning the thermal comfort aspects of the flight. His first comment was to the effect that at no time after reaching 20,000 feet did he experience any extreme heat or cold. He reported that his personal comfort was such that he was able to perform all of the flight tasks without difficulty, and he was sufficiently comfortable that during the flight he gave very little thought to this particular consideration. He further stated that, based upon his past experience with numerous flights that even though performance of many important tasks tends to eliminate thoughts of personal comfort, when heat or cold stress does occur he has been well aware of it. Therefore, he felt that his subjective reactions were reasonably accurate.

Both balloonists noted that their arms which were on the outboard side of the gondola became noticeably cold. Although the lower portion of the insulating sleeve had been removed from both arms, only the arm on the outboard side became unusually cold. At approximately 90,000 feet CDR Ross raised his front blind in order to provide a better view. After the blind had been raised for some time (the exact time was unknown) he noted that the bottoms of his feet, which were propped up with the soles pointing toward the horizon, were getting very noticeably cold. The feet were closer to the open area than was any other portion of the body. Later when the blind was closed, the cold sensation in the feet gradually diminished.

The silicone rubber coated nylon fabric remained reasonably soft and flexible throughout the flight. This was a decided improvement over the stiffening of the neoprene coated nylon previously utilized.

An examination of the skin surface temperatures recorded during the flight reveals that at no time did either CDR Ross or LCDR Prather suffer from thermal stress. At one point during the flight CDR Ross turned on his heated gloves to determine that they were working properly. After a momentary check, the glove heat was turned off, and for all practical purposes he completed the mission profile without the use of external heat. He did report, however, that the ends of his fingers became quite chilly, almost borderline. Three weeks after the flight, the index finger of his left (outboard) hand started losing some skin which was probably indicative of minor frostbite. His foot skin temperature showed a steady drop throughout the flight, and if it can be assumed that the telemetry was recording accurately, CDR Ross was apparently losing heat slowly and steadily at a rate which was subjectively perceptible but not unduly uncomfortable.

According to the data received on LCDR Prather, all temperatures, skin and rectal, indicated that he was comfortable during the entire flight. LCDR Prather dropped his muff to the floor of the gondola and was unable to retrieve it. Therefore, he found it necessary to energize the electrically heated gloves to maintain hand comfort. He did use both the heated gloves and socks during a substantial portion of the flight. Since he did require heating of the extremities it would appear that he too was losing heat at a slow rate. This would appear true particularly since he used the heated socks.

Subsequent to the flight, it was learned that Roger Aagard of the University of Minnesota had performed work on infrared radiation divergence in the atmosphere (15). Aagards work included radiometer measurements of the sky from altitudes up to approximately 85,000 feet. His data indicated that black body sky temperatures may reach -180°C or lower at these high altitudes. From this work it was apparent that the value of -100°C used in this paper is too high and that the heat loss to the sky would be greater than the calculated value shown herein.

Upon introduction of the attenuating blinds on the flight vehicle it was anticipated that once the balloonists were above the cold zone (40,000 to 60,000 feet) they would find it necessary to turn the attenuators to the aluminum side out in order to prevent overheating. Since this condition was not reached during the actual flight, except for a relatively brief period when LCDR Prather had his aluminum side out, it became apparent that the heat loss was greater than calculated. The fact that the black body sky temperature was considerably lower than anticipated would account for this increased loss of heat.

CONCLUSIONS AND RECOMMENDATIONS

The subjective comments furnished by CDR Ross, together with the skin surface temperatures taken during the flight, indicate that there was a slow but steady body heat loss during this flight. It would therefore appear that the precautions which included the installation of attenuating louvers, wearing of an insulating overgarment, and utilization of electrically heated gloves and socks were necessary to the successful completion of the flight.

Based on limited physiological data and subjective information obtained from CDR Ross, it appears that the reflective insulation system devised and used in the overgarments designed for use by the balloonists functioned adequately. The clothing provided the added thermal insulation required by the balloonists at the extreme low temperatures experienced without adding excessive weight or further restricting their mobility.

Because of the enormously complicated nature of the interchange of energy between the flight vehicle and the thermal environment, and between the balloonists and the flight vehicle after the attenuators were installed, no attempt was made to calculate the effect of introducing the attenuators. It appears, however, that these attenuators played a major part in establishing a thermally habitable environment.

If flights in an open flight vehicle to altitudes of 100,000 to 130,000 are to be made in the future, additional data concerning the thermal environment would be useful. Of particular value would be the establishment of radiant sky temperature measurements taken from these altitudes, at various latitudes, times of the year, and day and night.

Results indicate that personnel participating in future flights of this type, and looking further to manned space exploration, will have to be provided with additional insulation to supplement the present full pressure type suit. The use of the insulation system developed for this flight and means for auxiliary heating should therefore be considered and explored.

The metallized insulation assembly utilized in this flight successfully provided a low weight, high insulation garment. Additional investigation into the feasibility of utilizing such a system in other specialized or general purpose clothing would be useful.

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