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A THERMAL CONTROL SYSTEM FOR THE KS-87B CAMERA

Hugh W. Davis

Air Force Avionics Laboratory
Wright-Patterson Air Force Base, Ohio

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A THERMAL CONTROL SYSTEM
FOR THE KS-87B CAMERA

HUGH W. DAVIS, MAJOR, USAF

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FOREWORD

This report is the result of my attempt to design, construct, and test a thermal control system which would maintain a constant temperature throughout the lens assembly of an aerial camera. This work was conducted under Project 7646-05-08, "Thermal Blanket for High Performance Cameras."

Conducting this program proved to be a thorough education in real-life problem-solving. Every conceivable problem was encountered at least once. It was often more difficult and more frustrating to procure a particular size bolt than to analyze the stresses within that bolt.

True to the nature of real life, the results obtained in this work did not quite meet my expectations. Further improvements can be made in the system, but limited time for this study did not permit further efforts. I hope that this present work shows enough promise to encourage further efforts towards a solution.

I wish to express my gratitude to my thesis advisor, Dr. James E. Hitchcock, who introduced me to this challenging problem and provided invaluable insight and advice throughout this study. I am also grateful for the timely suggestions made by the other gentlemen on my thesis committee, Dr. Andrew Shine and Dr. Milton Franke.

I am especially grateful to Mr. Robert T. Mahone of the Optics Research Laboratory. His sponsorship and interest in my work, as well as his assistance and advice, are sincerely appreciated.

This report has been reviewed and is approved.

ALBERT W. BERG
Chief, Reconnaissance and Surveillance
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13. ABSTRACT

Thermal gradients within the lens cone of the KS-87B aerial camera cause focal length changes which degrade photographic quality. A thermal control system has been developed in an attempt to maintain isothermal conditions at 105°F within the lens cone. It consists of a thermal blanket, a heater film sandwiched between two layers of insulation, and thermostatic controls. The inner layer of blanket insulation serves as impedance to reduce the amplitude of temperature fluctuations at the inner surface, or lens cone. Testing was accomplished in natural indoor and outdoor environments, using thermistors to measure temperatures at 14 locations within the system. Tests revealed that temperature differences between different parts of the lens did not exceed 4°F in an environment of 33°F ambient temperature. Improved insulation should further reduce this difference. This thermal control system is simple, reliable, and relatively inexpensive.

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ABSTRACT

Thermal gradients within the lens cone of the KS-87B aerial camera cause focal length changes which degrade photographic quality. A thermal control system has been developed in an attempt to maintain isothermal conditions at 105°F within the lens cone. It consists of a thermal blanket, a heater film sandwiched between two layers of insulation, and thermostatic controls. The inner layer of blanket insulation serves as impedance to reduce the amplitude of temperature fluctuations at the inner surface, or lens cone. Testing was accomplished in natural indoor and outdoor environments, using thermistors to measure temperatures at 14 locations within the system. Tests revealed that temperature differences between different parts of the lens did not exceed 4°F in an environment of 33°F ambient temperature. Improved insulation should further reduce this difference. This thermal control system is simple, reliable, and relatively inexpensive.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTD)

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	Description
A	surface area
$\bar{A}$	cross-sectional area
b	thickness of insulation
c_p	specific heat at constant pressure
E	electrical potential difference
h	heat-transfer coefficient
I	electrical current
k	thermal conductivity
l	length of fin
L	length of cylinder
p	perimeter
P	power
q	rate of heat flux
Q	heat-transfer rate
r	radius
R	thermal resistance
t	temperature
T	absolute temperature
$\bar{T}$	average radiation temperature $(T_s + T_w)/2$
α	thermal diffusivity, $k/\rho c_p$
ε	emissivity
ρ	density
σ	Stefan-Boltzmann constant
τ	time

LIST OF SYMBOLS (CONTD)

Subscripts	Description
∞	free-stream
c	convection
H	heater
i	inner surface of annulus or enclosure
I	insulation
O	outer surface of annulus or enclosure
r	radiation
s	convective or radiating surface
w	camera compartment wall

SECTION I

INTRODUCTION

1. BACKGROUND

The KS-87B camera is an aerial reconnaissance framing camera (Figure 1). This camera is normally configured with an 18-inch focal length lens cone when used in the RF-4C aircraft for high-altitude day photography (Reference 1:p 4-29).

In August 1970 tests were conducted on the refaired nose of the RF-4C aircraft at Shaw AFB, South Carolina, to determine the quality of the 18-inch focal length lens used on the KS-87B camera. Temperature variations and pressure changes were discovered to have serious degrading effects on the photographic quality of the lens (Reference 2:1). As a result, further testing of this lens cone was performed by the manufacturer and by Aeronautical Systems Division (ASD), Wright-Patterson Air Force Base, Ohio. During one transit-temperature test, the lens was cold-soaked at 40°F and then exposed to a 90°F environment. During the first hour of testing, nonisothermal conditions within the lens resulted in focal length changes of as much as 0.020 inch, and resolution was reduced from 62 to 9 lines per millimeter. When the lens stabilized at a different isothermal condition, the focal length returned to its original value with a corresponding improvement in resolution (Reference 3). It was concluded that to obtain consistent and high-quality photography from this camera with a lens of fixed focal length, it must be operated at a stabilized temperature. In one test where temperatures were measured only on the exterior surfaces of the camera body and lens cone, the temperatures had to remain at a given value ±2°F for at least three hours before good resolution was obtained (Reference 2:15).

It was also observed during these tests that by refocusing the lens manually at any nonisothermal condition, a position of sharp focus could be attained with a resolution approximately the same as that of the stabilized lens (Reference 3). From this it was concluded that the focal

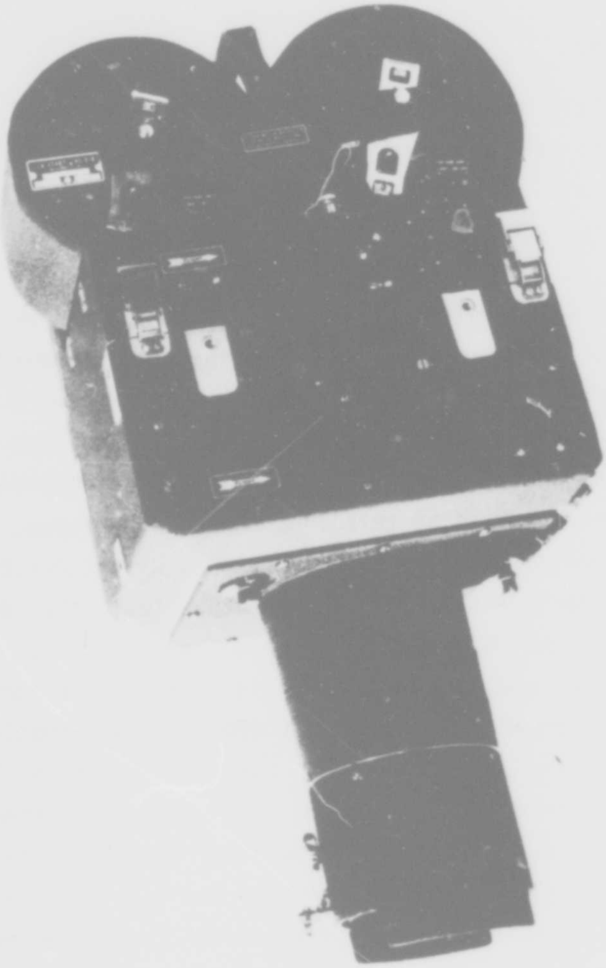


Figure 1. The KS-87B Camera With 18-inch Focal Length Lens Cone

shift produced during transit temperature conditions was caused by non-uniform thermal expansion along the aluminum lens barrel, and not by changes in radius of curvature of the surface of individual glass lens elements. Figure 2 illustrates the construction of the lens assembly.

As an interim measure, a note was added to the Flight Manual for the RF-4C aircraft, advising that some photographic resolution degradation may be experienced if the camera is operated when the 18-inch lens cone is not stabilized at the normal compartment operating temperature (Reference 1:p 4-30A).

In a previous effort to develop a thermal control system which would maintain isothermal conditions for another camera, the Deputy for Recon/Strike/Electronic Warfare, ASD, requested the assistance of Dr. James E. Hitchcock, Professor of Mechanical Engineering, Air Force Institute of Technology. Hitchcock suggested a temperature-regulated thermal blanket with fine temperature control, and he constructed and tested a sample blanket to demonstrate its capabilities (Reference 4).

2. THE PRESENT WORK

This study is a continuation of Hitchcock's work. Specifically, the objective is to design, construct, and test a simple, reliable, and relatively inexpensive thermal control system for the KS-87B camera with an 18-inch focal length lens cone. This system should be capable of preheating the lens to a stabilized temperature of 105°F within a reasonable time and maintaining that temperature within ±1°F during ground and flight operations.

The theory which supports this concept of a thermal blanket design is discussed in Section II. Also included is a description of the application of this theory to the design. The design considerations are examined in Section III. Design guidelines are enumerated, and the environment of the camera is described. Also included is a discussion of the assumptions made during this design. The equations used to analyze the system are

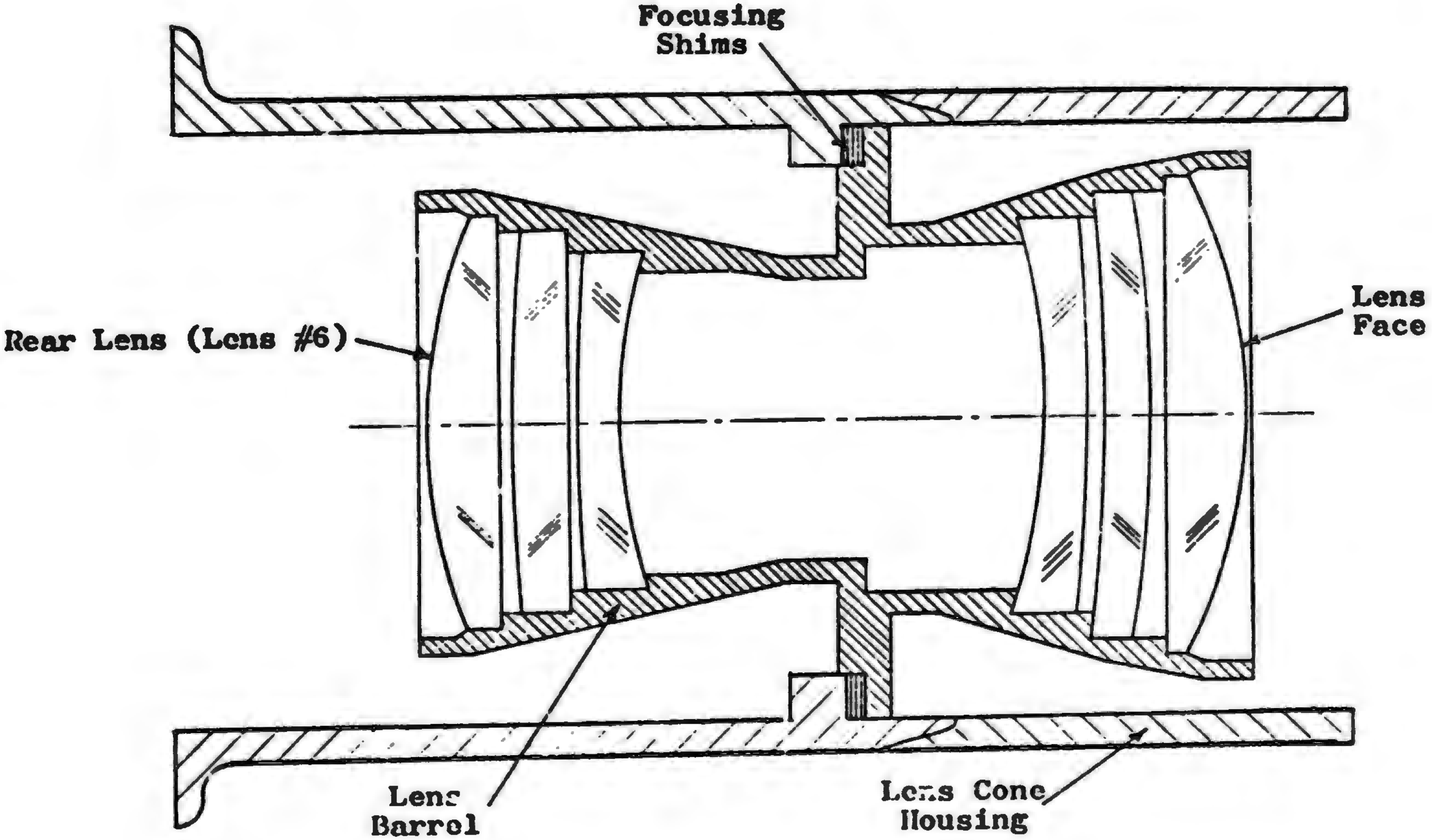


Figure 2. 18-inch Focal Length Lens Cone

included in Section IV, along with a discussion of the results of the analytical calculations.

Section V contains a general description of the KS-87B camera, the 18-inch focal length lens assembly, and the equipment and materials used in constructing and testing the thermal control system. Detailed descriptions and nomenclature are given in Appendix V.

The test procedures used to evaluate the performance of the model blanket and to simulate environmental conditions are outlined in Section VI. Results and conclusions are contained in Sections VII and VIII, respectively. Section IX contains recommendations concerning the feasibility of using such a system, as well as recommended improvements in materials and methods of construction.

SECTION II

THERMAL BLANKET CONCEPT OF THERMAL IMPEDANCE

1. CONCEPT

Preheating the lens cone and maintaining isothermal conditions within it require a heater and some type of insulated enclosure. A simple method of accomplishing this is to use an insulated thermal blanket. If costs are to be minimized, the thermostat is a reasonable choice for a temperature controller for the system.

Unfortunately, the thermostat operates in a cyclic manner, initiating heating at some preset temperature and ceasing it at some higher temperature which depends on the capabilities of the thermostat. This results in variations of temperature at the heater surface. These variations can be made periodic if heat losses are controlled such that the heater is on and off for equal periods of time.

Now the cyclic properties of the thermostat can be used to advantage, for if a layer of insulation is placed between the heater and the lens cone, as shown in Figure 3, this insulation will serve as impedance to dampen the amplitude of the temperature oscillations. With a proper choice of insulation material and thickness, the amplitude of the oscillations can be reduced sufficiently to effectively produce isothermal conditions at the outer surface of the lens cone housing.

2. THEORY

For heat conduction through a semi-infinite solid whose surface temperature varies periodically with time, the thermal state of the system is described by the equation (Reference 5:210)

$$t = t_{0M} \exp \left(-\sqrt{\pi/\alpha\tau_0}\; x\right) \cos \left[(2\pi\tau/\tau_0) - \sqrt{\pi/\alpha\tau_0}\; x\right] \tag{1}$$

where

x = penetration distance, measured normal to the surface ($x = 0$ at the surface)

t = temperature at position x

t_{OM} = maximum amplitude of the surface temperature oscillations

τ = time

τ_0 = period of the surface temperature oscillations

α = thermal diffusivity

For a particular value of x, if the values of time when the temperature maxima occur are computed for the depth x and the surface, it can be seen that the oscillations have the same period τ_0 at each depth, but the oscillations at depth x lag those on the surface by $1/2 \sqrt{\tau_0/\alpha\pi}\; x/$ Furthermore, the surface temperature amplitude, t_{OM}, is diminished at the depth x by the factor (Reference 5:211):

$$\exp\left(-\sqrt{\pi/\alpha\tau_0}\;\; x\right)$$

Thus, the periodic surface temperature variations produce a thermal wave which propagates through the solid with constant frequency and with diminishing amplitude. The higher the frequency, $1/\tau_0$, the more rapidly the amplitude of the wave is damped out (Reference 5:212-213). Figure 4 shows the characteristics of a temperature oscillation penetrating an infinitely thick wall.

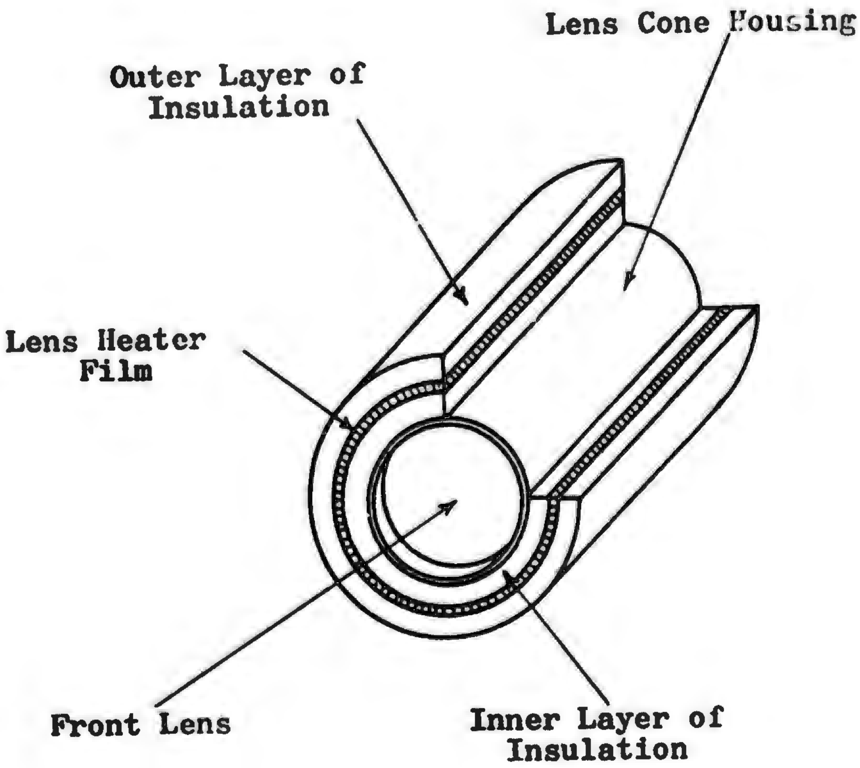


Figure 3. Cutaway View Showing Thermal Blanket Construction

3. APPLICATION TO A THERMAL BLANKET

The properties of heat conduction described above can be applied very effectively to the design of a thermal blanket. Consider a blanket which consists of a thermostatically controlled heater section sandwiched between two relatively thick layers of thermal insulation. Power to the heater section cycles on and off in response to commands from the thermostat. If the heat losses from the heater section are properly controlled, equal on and off times for the heater can be achieved, producing periodic variations in heater section temperature. The frequency of these variations can be increased by selecting a thermostat with a smaller on-off temperature differential.

The inner layer of insulation serves as an impedance to reduce the amplitude of temperature fluctuations at the inside surface of the blanket. With proper choices of insulating materials, dimensions, heater capacity, thermostats, and thermostat locations, the temperature fluctuations at the inner surface of the blanket adjacent to the lens cone can be effectively damped to a small fraction of the temperature fluctuations at the heater section (Reference 4:1).

The outer layer of thermal insulation serves two purposes: (1) it reduces the heat loss to the environment, thus reducing the power required to maintain a given temperature difference between the lens cone and the environment; (2) with sufficient thickness, it is the major resistance to external heat loss, so the blanket performance is only slightly sensitive to variations in the convective heat transfer resistance on the outside of the blanket, and impedes temperature changes at the heater which result from rapid changes in the environment temperature (Reference 4:1-2). With balanced selections of insulation thickness and heater capacity, heat losses from the heater section are controlled to provide equal heater on-off times.

Although the theory is based on heat conduction through a semi-infinite solid, it should apply equally well to a finite thickness wall, provided that the parameters involved produce sufficient damping to give relatively small temperature fluctuations at the inner surface of the wall.

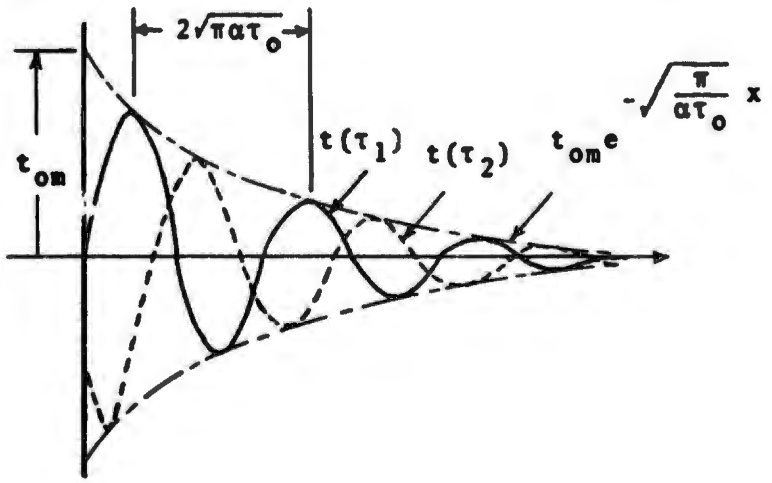


Figure 4. Thermal Wave Penetrating an Infinitely Thick Wall (from Reference 3).

SECTION III

DESIGN CONSIDERATIONS

The primary design objective was to design a thermal control system which is simple, reliable, effective, and relatively inexpensive.

1. GUIDELINES

Before analytical design efforts were begun, several guidelines and specifications were established, based on knowledge of the problem and on the results of tests described in Reference 4. These guidelines are:

a. The thermal blanket construction concept, which is outlined in Section II, will be used.

b. The thermal blanket will provide uniform heating to the entire exterior surface of the lens cone.

c. The heater section will be constructed with dual elements of equal electrical resistance, which can be connected either in series or in parallel. The parallel connection will provide a high-power capability for rapid preheating or for operation in extremely cold environments. The series connection will be used for maintenance of isothermal conditions with normal environments.

d. Electrical power for the heaters will be 115 volts, 400 cycles AC.

e. Control system power will be 28 volts DC. Relays will be used for controlling heater power and for automatic switching between low and high power operations. A separate thermostat, located between the inner layer of insulation and the lens cone, will sense temperature conditions which require high power.

f. Since the aircraft camera compartment ambient temperature is maintained at 95 ±5°F (Reference 11:p 5-1), design temperature for the lens cone will be 105°F to maintain a negative temperature gradient from the lens cone to the environment.

g. The aluminum bosses on the camera mounting frame will be replaced by phenolic bosses to reduce conduction heat losses from the camera body.

2. CAMERA ENVIRONMENT

The camera compartment of the RF-4C aircraft is located forward of the cockpit in the nose of the aircraft, and consists of three bays in tandem. The KS-87B camera with the 18-inch focal length lens cone is most frequently mounted in a vertical position in the aft bay, also referred to as the High Altitude Station (Reference 1:p 4-28).

The equipment air conditioning system of the RF-4C attempts to stabilize the camera compartment ambient air temperature. Cooling air to the camera compartment is regulated to maintain a compartment air discharge temperature of 95°F. However, climatic evaluation tests of the aircraft revealed that under arctic condtions for flight at 30,000 feet or above, the ambient air temperature in the aft bay varied between 49°F and 62°F (Reference 6:50). These tests also indicated that reduction of engine speed causes ambient temperature in the aft bay to decrease. This might be expected, since compartment cooling air is taken from the 17th stage of the engine compressor.

The camera window temperatures in the aft bay, during these arctic tests, varied between 5°F and 31°F for the same high altitude flight conditions (Reference 6:902-906). No sources of data could be found which gave fuselage surface temperatures or camera compartment wall temperatures.

3. ASSUMPTIONS

Available data on the camera environment, and the fact that results of arctic and tropic tests in Reference 6 represent extreme conditions were considered in selecting reasonable design parameters for the environmental conditions.

Ambient air temperature in the aft bay is assumed to be 60°F, and the window temperature is assumed to be 40°F. The average wall temperature within the aft bay is assumed to be 0°F, recognizing that interior bulkhead temperatures will most likely be higher while fuselage skin temperatures may approach the free air temperature of -69°F above 36,000 feet altitude.

Air flow within the aft bay is assumed to be of low velocity, such that natural convection and radiation are the heat transfer mechanisms for heat loss from the outer surface of the thermal blanket. Conduction heat transfer losses to the camera mount are assumed to be negligible, provided that thermally insulated bosses are used to secure the camera to its mount. Convection heat losses from the face of the lens are also considered negligible since the lens is recessed within the lens cone and faces downward when mounted in the aircraft.

SECTION IV

ANALYSIS

1. WORKING EQUATIONS

Heat losses by conduction through the layers of insulation are computed by using the Fourier-Biot law of one-dimensional heat conduction in finite-difference form:

$$Q_I = \frac{\Delta t_I}{R_I} \qquad (2)$$

and

$$R_I = \frac{b}{k_I A_I} \qquad (3)$$

where

Q_I = total rate of heat transfer by conduction through the insulation

Δt_I = temperature difference between surfaces of the insulation, $t_0 - t_I$

R_I = resistance to conduction heat transfer

b = thickness of insulation

k_I = thermal conductivity of insulation

A_I = mean area of insulation normal to the conduction path

Convection heat losses from both the lens cone and the camera body are found by using the empirical relation for film conductance with natural convection from a vertical cylinder to air at atmospheric pressure and under laminar flow conditions (Reference 7:199):

$$h_c = 0.29 \quad (\Delta t_c/L)^{1/4} \tag{4}$$

where

h_c = convection heat-transfer coefficient, BTU/hr - ft^2 - °F

t_c = convection temperature difference, $t_s - t_\infty$, °F

L = length of cylinder, ft

Newton's law of cooling, written in terms of a convective resistance, R_c, is (Reference 7:74-75):

$$Q_c = \frac{\Delta t_c}{R_c} \tag{5}$$

and

$$R_c = \frac{1}{h_c A_s} \tag{6}$$

where

A_s = convection surface area

Heat losses due to radiation are found in a similar manner by defining a radiation heat-transfer coefficient, h_R (Reference 7:264):

$$h_R = 4\epsilon\sigma(T)^3 \tag{7}$$

where

ϵ = emissivity of the radiating surface

σ = Stefan-Boltzmann constant

$\bar{T} = \frac{T_s + T_w}{2}$

This radiation heat-transfer coefficient can be used to find a radiation resistance, R_R:

$$R_R = \frac{1}{h_R A_s} \tag{8}$$

where

A_s = area of the radiating surface

which permits the solution of the following equation for radiation heat transfer:

$$Q_R = \frac{\Delta T_R}{R_R} \tag{9}$$

where

$\Delta T_R = T_s - T_w$

To determine the magnitude and significance of conduction heat losses from the lens cone to the camera body, the camera body is represented by a fin model. If the fin is of finite length and loses heat by convection from its end, assuming one-dimensional conduction along its length, the temperature distribution is given by (Reference 7:40):

$$\frac{t - t_\infty}{t_{I1} - t_\infty} = \frac{\cosh m(\ell-x) + (h_c/km) \sinh m(\ell-x)}{\cosh m\ell + (h_c/km) \sinh m\ell} \tag{10}$$

where

$m = \sqrt{h_c p/kA}$

A = cross-sectional area of the fin

p = perimeter of the fin

k = thermal conductivity of the fin

ℓ = length of the fin

t_{Ii} = temperature of the lens cone, which is the base of the fin

x = distance along the fin, measured from the base of the fin

Sample calculations are included in Appendix IV of this report.

2. RESULTS OF ANALYTICAL CALCULATIONS

a. Heat Losses

The insulating material, MIN-K, and the reasons for its selection, are described in Section V of this report. Using a thickness of 3/8-inch for each layer of insulation in the thermal blanket, lens cone temperature variations can be limited to within a 0.1°F range if the heater section temperature varies periodically with a maximum amplitude of 0.5°F and a period of 5.5 minutes. This amplitude value is well within the capabilities of temperature differentials for relatively inexpensive thermostats.

Solving for the radiation and convection losses from the outer surface of the thermal blanket, the thermal resistances are found to be approximately the same, due to temperature differences involved. Based on the assumed values of environment temperatures, the outer surface of the blanket loses 106 BTU/hr by radiation and receives 11 BTU/hr from the ambient air by convection, so the net heat loss from the blanket is 95 BTU/hr. The heat loss from the lens face, which is radiating to the 40°F surface of the window, is 13 BTU/hr.

Calculations of heat losses to the camera body, using the fin model, indicate an excellent conduction path. The temperature differential between the base of the fin and the tip is less than 1.5°F. If the camera body is neither insulated nor heated separately, large heat losses can be expected. However, the camera body contains several electric motors and power supply circuits. Whenever the camera system is in standby mode, these motors and circuits use 184 watts of electrical power, which is equivalent to 627 BTU/hr. When this amount of electrical power is converted to thermal energy within the camera body, it is sufficient to maintain the camera body temperature at 85°F in the design environment with no insulation applied. By using a thin layer of insulation around the camera body, its temperature can be maintained at 105°F, thus eliminating conduction heat losses from the lens cone to the camera body.

b. Heater Requirements

The heater film selected for use in the thermal blanket is described in Section V. The capacity of this heater film must be twice as large as the total rate of heat loss from the lens cone and lens face, since the heater is energized only one-half of the time to give periodic temperature variations. For a total heat loss of 108 BTU/hr, the heater film requires 63.3 watts of electrical power.

The camera body requires no additional heating to maintain a temperature of 105°F as long as the camera system is in standby mode. When the camera system is being used in one of several operating modes, larger amounts of power are supplied to it, resulting in additional heat generation. The time required to photograph a target is usually less than 5 minutes, however, so the effect of this increased heating should be negligible if the camera system remains in the standby mode throughout the remainder of the mission.

To preheat the lens cone and camera body before a mission while the camera system is off requires the use of an additional heater to supply an amount of heat equivalent to that which is generated with the camera system in standby. If the heater is allowed to cycle on and off with the heater film of the thermal blanket, it must supply twice the heat normally generated by the camera, 1254 BTU/hr or 368 watts.

SECTION V

TEST EQUIPMENT AND MATERIALS

1. DESCRIPTION OF CAMERA

The major components of the KS-87B camera, identified in Figure 5, include the lens cone, the camera body, the magazine, the cassettes, and a light sensor (Reference 8:p 1-4). The structural portions of the camera body, magazine, and lens cone are aluminum alloy castings (Reference 8:p 1-1-10). With the 18-inch lens cone installed, the camera is 32 inches in height and weighs 87 pounds, excluding film (Reference 8:p 1-1, 1-3).

Although four lens cones with different focal lengths are used with this camera, only the 18-inch focal length lens cone is considered in this study. This lens cone has the longest focal length and is the most sensitive to temperature-induced focal length changes (Reference 1:p 4-30, 4-30A).

The lens cone consists of a housing and a lens barrel containing six glass lenses, as shown in Figure 2. A cast flange around the center of the lens barrel is used to attach it to the lens cone housing. This provides a good path for heat conduction to the lens barrel. Lens focus is adjusted by inserting shims between the flange and the housing.

The lens cone housing is a two-piece cylindrical tube which shields and protects the lens barrel and suspends it at a precise, specified distance below the focal plane of the camera. The housing is bolted to the camera body and has an area of direct metal contact of approximately 18.5 square inches. This provides an excellent conduction path between the lens cone housing and the camera body.

The camera body is essentially a hollow, aluminum-alloy shell with an average wall thickness of approximately 1/4-inch. Several electrical circuit boards are attached to the inner wall of the shell. The top

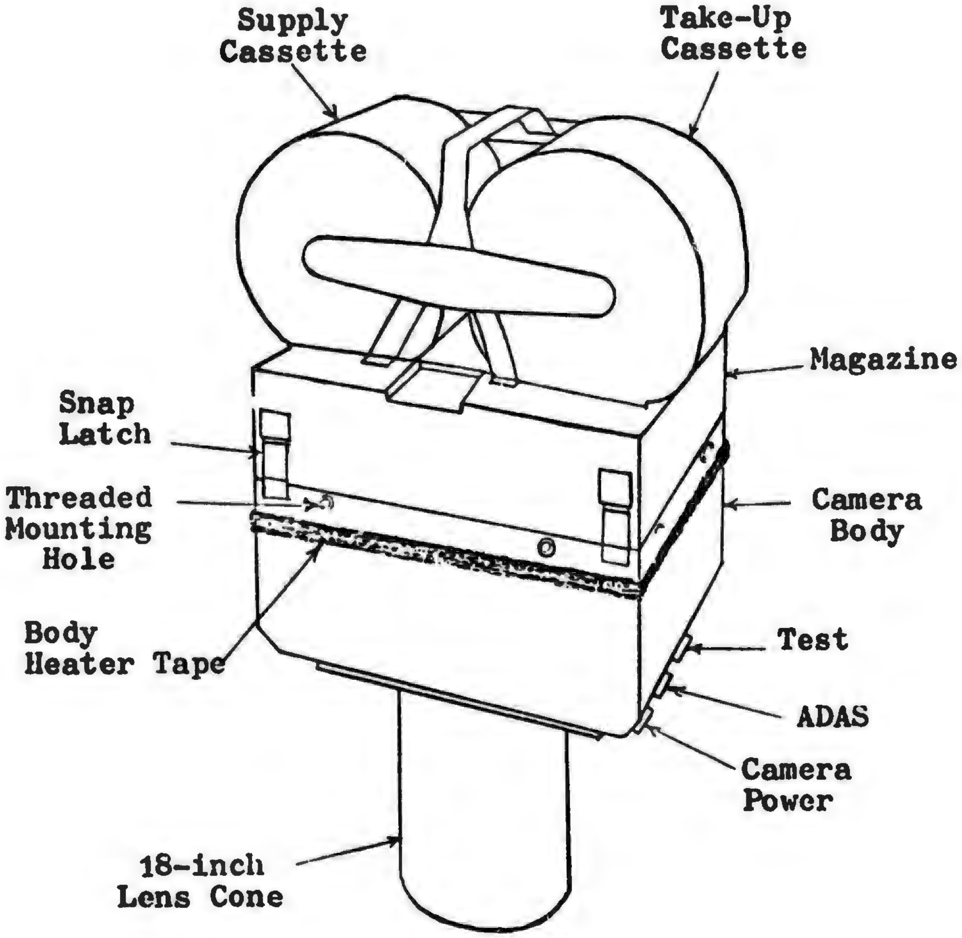


Figure 5. Major Components of the KS-87B Camera

surface of the enclosure contains the focal plane shutter curtain and shutter mechanism.

The magazine is mounted on top of the camera body, and contains gear trains and drive mechanisms for advancing the film through the magazine. Electronic subsystems are also included in the magazine. The two cassettes, used for film supply and take-up, are attached to the top of the magazine housing.

Four electric motors are located in the magazine, and they provide power for camera operation and subsequently generate heat. One of these, the recycle motor, operates continuously whenever the camera system is in standby or operating (Reference 8:p 4-7). The other three motors are used only during photographing operations. The electronic circuits in the magazine and the camera body produce the remainder of the total heat generated within the camera.

The light sensor is aligned parallel with the axis of the lens barrel, and its mounting bracket is bolted to the outer surface of the lens cone housing. The sensor and mounting bracket were removed for these tests.

The lens barrel used in these tests is the Pacific Optical 18-inch, f/4.0 lens assembly with a field of view of 20°. The barrel is a tubular casting of aluminum alloy, trade number 356-T7. The six glass lenses are mounted within the shell in such a manner that a portion of the edge of each lens makes direct contact with the metal barrel (Reference 9). A separate filter can be attached to the front end of the lens barrel by means of bayonet fasteners; however, the filter was not used during most of these tests.

2. THERMAL BLANKET MATERIALS

a. Heater Film

The heater film consists of a thin, flexible, rubberized sheet containing two equal-resistance heating elements. The film is 13.5 inches long and 25.6 inches wide, and is designed to cover the entire lower 13.5 inches of the lens cone. This provides a clearance of 0.6 inches between the top of the heater film and the film speed switch, permitting access to the switch. The heater elements are aligned in the heater film such that one element heats the lower end of the lens cone and the second element heats the upper end. The electrical resistance of each element is 105 ohms.

b. Insulation

The heater film is sandwiched between two layers of insulation, as shown in Figure 3. The insulation used is Johns-Manville Flexible Min-K, Standard Type. The insulation is 3/8-inch thick and is faced on both sides with a glass fabric stitched in a one-inch square pattern.

Min-K insulation was selected over several other materials because of its low thermal conductivity, low thermal diffusivity, and its ability to withstand temperatures greater than 200°F. Flexible Min-K is relatively easy to mold around cylindrical shapes, yet it does not compress or change thickness easily. The detailed properties of Flexible Min-K are provided in Appendix V.

During later tests, in an effort to reduce convective and radiation heat losses, the two layers of Flexible Min-K insulation were extended one inch beyond the top of the heater film. In addition, an annulus of polyethylene, two inches wide and having the same radial dimensions as the thermal blanket, was used to extend the blanket below the end of the lens cone.

c. Cover

After the two layers of insulation and the heater film are wrapped around the lens cone, they are held in place by a form-fitting cloth cover. This cover is made from green awning canvas, and it is secured by a zipper which opens along the length of the lens cone. The thermal blanket construction is shown in Figure 6.

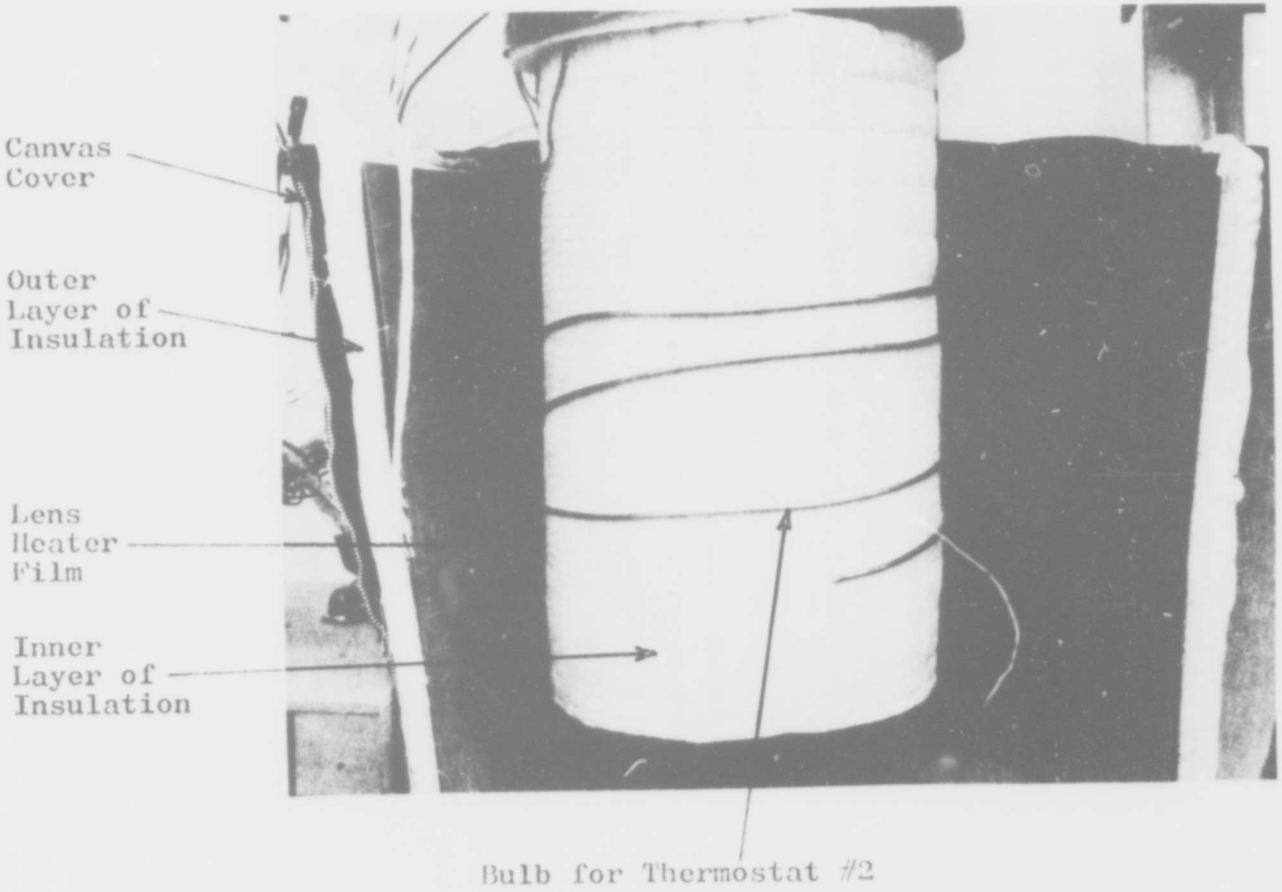


Figure 6. Thermal Blanket Construction

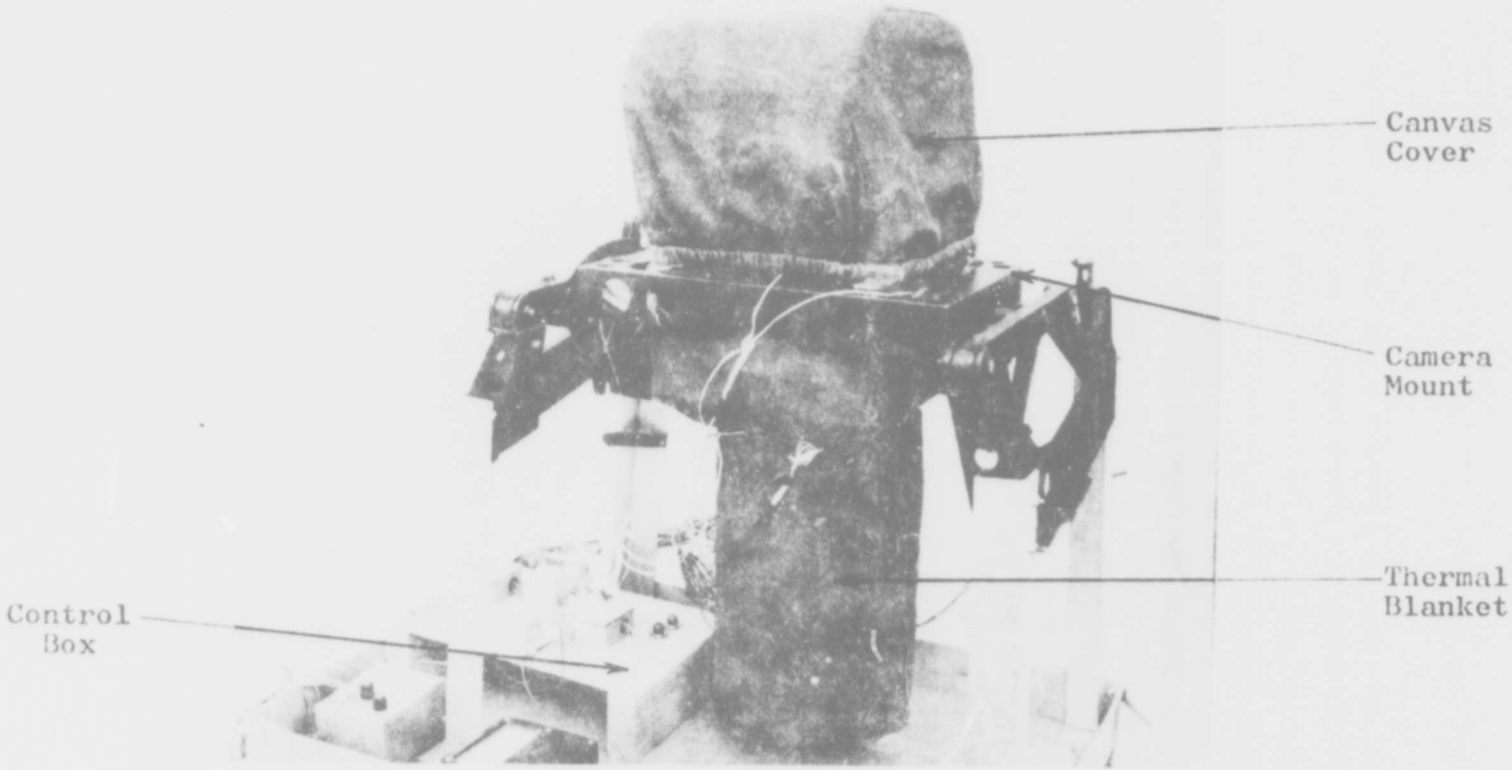


Figure 7. KS-87B Camera With Thermal Blanket and Cover Installed

3. BODY HEATER AND INSULATION

Excluding the lens cone, the remainder of the camera is enclosed by a two-piece cover consisting of a single layer of awning canvas, as shown in Figure 7. One portion of the cover surrounds the camera body and magazine. It is held in place by an elastic band around the top of the cover, as well as by the four bolts which connect the camera to the mount. The second portion of the cover encloses the cassettes. It has an elastic band around the bottom of the cover and it overlaps the lower cover by one inch.

Between the cassettes and the cover enclosing them, a layer of 3/8-inch Flexible Min-K insulation surrounds the cassettes on all four sides and on the top, as shown in Figure 8.

The body heater consists of 12 feet of "Heat-by-the-Yard" heating tape, which is made by Electrothermal Engineering Limited, London. Two 6-foot lengths of 1-inch-width tape can be connected in series or parallel to give low- or high-power heating. The electrical resistance of each element is 12.5 ohms at room temperature, but this value increases almost 50% when the tape is heating.

Approximately two-thirds of the heater tape is wrapped around the camera body, below the camera mount. The remainder of the tape is wrapped around the magazine, above the camera mount.

4. CONTROL SYSTEM

The control system senses temperature conditions at the lens cone and at the heater section of the thermal blanket, and directs heating as necessary. The control system consists of two thermostats, four relays, and associated wiring, fusing, and switching equipment. A schematic of the control system is given in Figure 9.

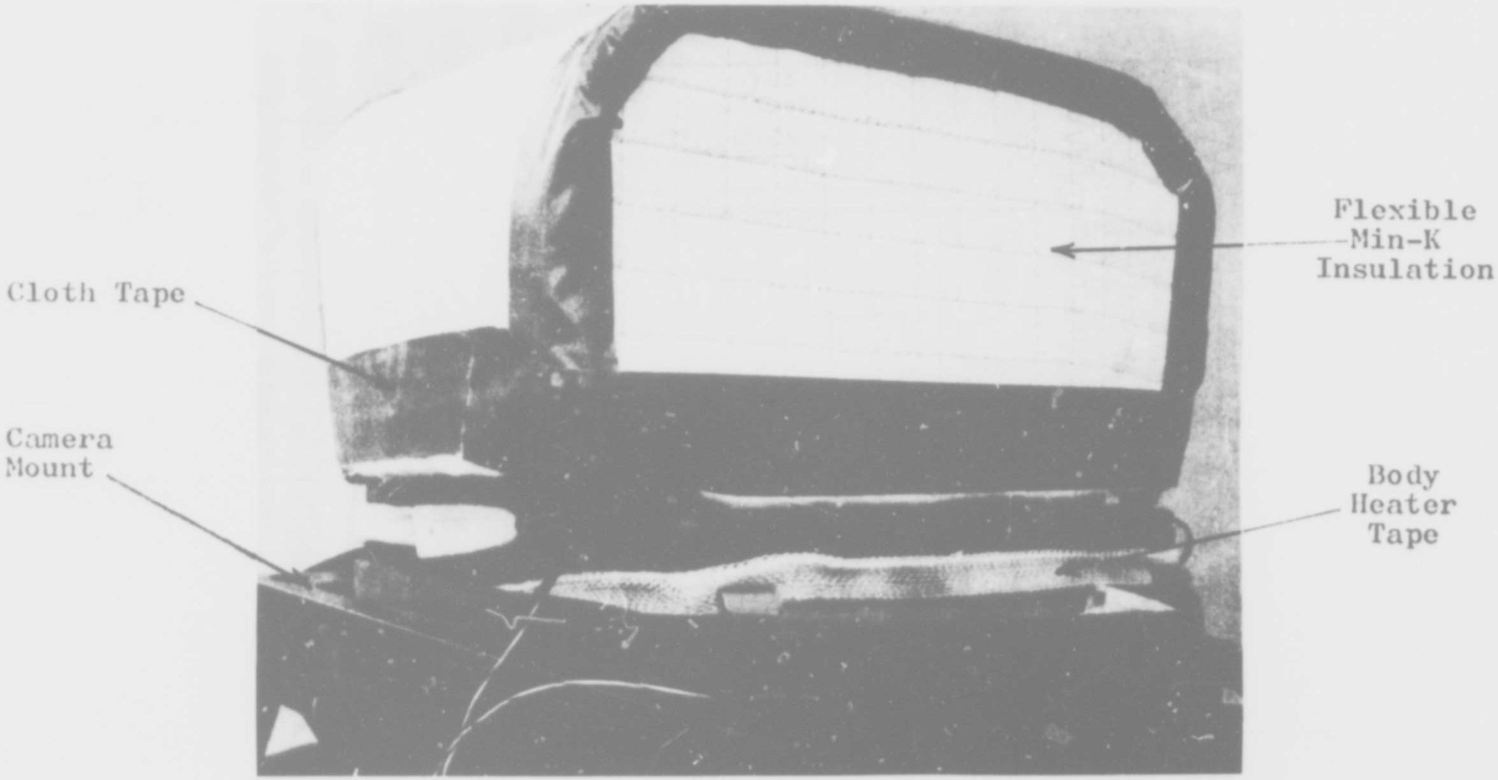


Figure 8. Insulation of Cassettes

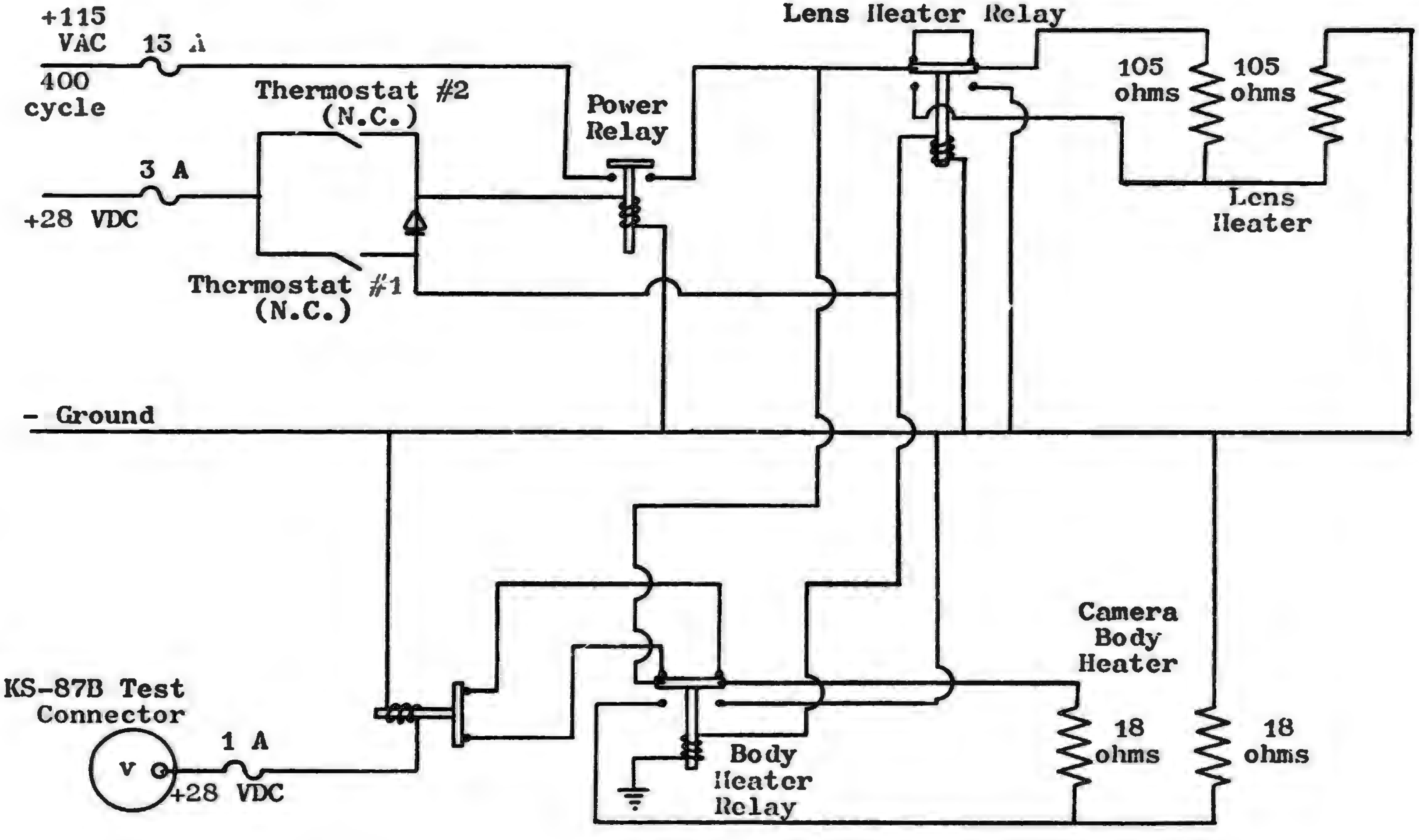


Figure 9. Schematic of the Control System

The thermostats are United Electric, model F7-8913, vapor-pressure-actuated thermal controls. They have a temperature-sensing range of 80° - 130°F. The thermostat sensing bulbs are each 100 inches long. One is wrapped directly around the metal lens cone housing. The other is located between the inner layer of insulation and the heater film, as shown in Figure 6.

Thermostat #1, which senses lens-cone temperature, is set at 100°F, and Thermostat #2, which senses heater temperature, is set at 105°F. During the preheating phase, the heaters remain on until the lens cone temperature reaches the cut-off temperature of Thermostat #1. Afterwards, the heating cycle is controlled by Thermostat #2, due to the difference in thermostat temperature settings.

Two DPDT relays are used to provide automatic switching between low- and high-power operations of the lens and body heaters. The relay coils are energized by 28 volt DC signals from Thermostat #1.

The power relay is a normally-open relay which controls the AC electrical power to the heaters. This relay can be closed by either of the thermostats. In the event of a 28 volt DC power failure, the power relay opens and prevents overheating within the system.

The fourth relay in the control system is used to disconnect the body heater circuitry when the camera system is operating and generating heat internally. When power is applied to the camera system, pin "V" of the KS-87B test connector is energized with 28 volt DC power. This pin can be connected to the coil of the normally-closed relay to interrupt the 115-volt AC power to the body heater.

For test purposes, three toggle switches are included in the control system circuitry: (1) an AC master power switch to interrupt the 115-volt AC line power; (2) a switch to replace the circuit from the test connector on the camera (since camera system power was not used, this switch permitted 28-volt DC line power to actuate the relay which disconnected the body heater circuitry); and (3) a switch in the circuit to connect

Thermostat #1 with the lens heater relay and the body heater relay and permit disabling the high-power capability and allow low-power preheating.

The 115-volt AC circuits are fused for 13 amps, and the 28-volt DC circuits for 3 amps. The wire sizes used in the AC and DC circuits are #18 and #20, respectively.

5. INSTRUMENTATION

The AC electrical current required by the entire thermal control system was measured by means of an ammeter installed in the 115-volt, 400 cycles-per-second line. AC and DC voltages were measured prior to each test by using a multimeter at the receptacles. Both AC and DC were regulated within the test facility, and practically no variation in voltage was noted.

Temperatures within the thermal blanket and lens cone, and those of the camera body, were measured by means of thermistors. The thermistors were cemented to the surfaces at 15 locations on the camera and blanket, as shown in Appendix II.

The thermistor used during these tests was the YSI 44030, which has a tolerance of ± 0.18°F throughout the temperature range experienced in the tests. The thermistor signals were interpreted by a Howell H-490 Data System, which provided both direct readings and printouts of the temperature values.

SECTION VI

TESTING PROCEDURES

The initial plan for testing the thermal control system included the use of an environmental chamber which would simulate inflight and ground environmental conditions. The chamber would also have a window through which the photographic quality of the lens could be examined during environmental condition changes. Chamber tests were to be followed by an actual in-flight test in the RF-4C aircraft.

However, a test chamber which could adequately simulate the design conditions was not immediately available at this facility. Also, there were no RF-4C aircraft available which had the capability of carrying this camera, due to modifications of the aircraft for special test projects.

1. TESTING ENVIRONMENT

Due to the lack of adequate chamber facilities, the thermal control system was tested in natural indoor and outdoor environments. For indoor testing, the ambient temperatures were 65° - 73°F. During outdoor testing, the ambient temperatures were in the range 14° - 47°F.

In order to correlate the test results with the design analysis, it was necessary to determine what value of equivalent temperature for this isothermal test environment would produce the same rate of heat loss from the model as it experiences under design environmental conditions. This equivalent temperature was calculated to be 33°F.

For outdoor testing, the entire model was enclosed by a loosely fitted plastic bag. Ventilation within the bag was adequate to prevent increased ambient temperatures, and the bag eliminated excessive convective losses caused by gusting winds.

2. TYPES OF TESTS PERFORMED

Tests were performed under five different operating conditions or environments to determine the performance characteristics of the thermal control system. These included:

a. Indoor preheating

b. Outdoor preheating

c. Indoor stabilized operation

d. Outdoor stabilized operation

e. Sudden and significant ambient temperature change

The last type of test was accomplished by letting the system temperatures stabilize with the thermal control system operating, and then moving the entire model from indoors to outdoors, or vice versa.

3. PROCEDURES

Prior to each test, the model was allowed to reach or closely approach thermal equilibrium with the test environment. For the outdoor preheating tests, the model was moved outdoors and allowed to cool to near-ambient temperature. More than three hours were required to achieve temperatures throughout the model that were within 5°F of the ambient temperature, when the initial temperature difference was 45°F.

Before applying power to the system, measurements were made of AC voltage, DC voltage, ambient temperature, and the temperature at each of the thermistor locations within the model. After power was applied, the amount of current to the complete system was measured immediately, and at increasing intervals of time thereafter. The amount of current decreased rapidly at first, but the rate of decrease slowed. This decrease was caused by the change of resistance of the body heater tape as it changed temperature.

Temperatures throughout the model were measured periodically, usually at 5 or 10 minute intervals. The times at which the heaters turned on and off were noted in order that cycle times might be determined.

In addition to these measurements, the temperatures are frequently noted for the lens heater, body heater, and lens cone at the instant at which the heaters turn on or off. These values indicate the temperature differential of the thermostats, the variance of lens cone temperature, and the change in thermostat temperature setting due to changes in ambient temperature.

SECTION VII

RESULTS

The thermal control system was subjected to 13 tests, many of which were combined tests which evaluated preheating, stabilized operation, and the effects of sudden ambient temperature change. During these tests, more than 23 modifications were made to the system, each of which had some influence on its performance. Consequently, it is difficult to correlate the results of the various tests. The results given here represent several phases of modification of the model.

In spite of this, many significant results were obtained, and a number of general trends were noted. Significant results were obtained only at low-power operation of the thermal control system. High-power operation was attempted during early tests, but excessive temperatures in the body heater tape caused scorching of both the wiring insulation and the canvas cover. Thereafter, only low-power operations were attempted.

The temperature at a particular location is considered stable if that temperature does not change by more than 0.1°F during a ten-minute period. A portion of the system, such as the lens barrel, is stabilized if the measured temperatures are stable, even though the part may not be isothermal.

1. PREHEATING

The preheating time is the time required for the temperature of the lens barrel and its interior to stabilize, after it had been cold-soaked to ambient temperature. For an ambient temperature of 35°F, the preheating time was 4 hours and 15 minutes. For an ambient temperature of 72°F, the preheating time was 3 hours and 45 minutes.

The maximum temperatures observed occur in the heater sections at the end of the first heating cycle. During indoor preheating tests, the maximum temperature at the body heater tape was 132.8°F. The maximum temperature observed at the lens heater film was 131.8°F. During outdoor preheating tests with an ambient temperature of 35°F, the maximum temperature at the body heater was 124.9°F and the maximum lens heater temperature was 131.8°F. Maximum body heater temperatures are lower during outdoor tests because the body heater is not as heavily insulated as the lens heater.

2. STABILIZED OPERATION

With the system fully stabilized for an ambient temperature of 73°F, the heaters cycled 23 seconds on and 122 seconds off. The temperature in the lens barrel was in the range 102.2° - 102.7°F, except at the lower end near the lens face, where the temperature was 101.2°F. The lens cone housing was isothermal with a temperature of 102.9°F. The lens heater cycled on and off when the heater section temperature reached 103.5°F and 104.5°F, respectively.

With a stabilized temperature spread of 1.5°F, the lens barrel never became truly isothermal, although this spread meets specification limits of ± 1°F. The desired mean temperature of 105°F was not achieved due to thermostat calibration and heat losses.

With the system stabilized for an ambient temperature of 40°F, the heaters cycled 35 seconds on and 70 seconds off, approaching periodic cycling as the ambient temperature approaches the design value. The temperatures throughout the lens barrel were within the range 98.1° - 99.0°F, except at the lower end of the lens barrel, where it was 96.0°F. The lens cone housing temperature was 99.3°F. The lens heater cycled on and off when the heater section temperature reached 103.2°F and 104.6°F, respectively.

Since the lens barrel temperatures were significantly lower during the outdoor test, additional insulation was installed around the camera body section. The following section examines the results of this and the effects of environmental changes.

The temperature of the outside surface of the front lens is strongly influenced by the use of a lens filter. For an ambient temperature of 35°F, the temperature of the lens surface was 89.9°F with the filter installed and 73.8°F without the filter.

3. EFFECTS OF ENVIRONMENTAL CHANGES

Moving the model outdoors caused a sudden change in ambient temperature, and the on and off times for the heating cycle changed. When the ambient temperature changed from 73°F to 42°F, the heater on-time increased, as expected, from 22 seconds to 35 seconds, while the off-time decreased from 123 seconds to 88 seconds.

Surface temperatures on the lens barrel reacted to the change quickly. The middle and upper ends of the barrel cooled at an initial rate of 1.8°F per hour, while the lower end cooled at an initial rate of 5.4°F per hour. The temperatures of the interior of the lens barrel remained constant for five minutes, and then began decreasing at a rate of 1.0°F per hour. The lens cone housing temperatures decreased at an initial rate of 3.0°F per hour.

The camera body also cooled rapidly following this change. The receptacle region cooled at an initial rate of 6.0°F per hour, while the cassettes cooled at a rate of 19.2°F per hour.

These different rates of cooling indicate that the lens barrel can be maintained at near-isothermal conditions for only a short period of time following an environmental change. Heat is lost more rapidly from the camera body, so the lens barrel could cool by conduction to the camera body.

After the lens barrel temperatures had stabilized, a layer of wool felt insulation, 1/2 inch thick and 3 inches wide, was wrapped around the perimeter of the camera body, directly over the heater tape region. This modification caused a significant increase in the temperatures of the lens barrel and lens cone. The temperature history before and after this modification is illustrated by the graph in Figure 10. The discontinuities in the curves after the modification are due to adjustments made to the model which increased convective heat losses. These adjustments consisted of partially removing the plastic cover so that the model was exposed to gusting winds.

The limited time remaining for the completion of this study prohibited reaccomplishing this test with the insulation installed during the ambient temperature change.

4. EXPERIMENT VS. THEORY

The theoretical model for the thermal blanket assumed one-dimensional heat conduction and resulted in a temperature at the inner surface of the blanket equal to the mean temperature of the heated surface. In the actual blanket, two-dimensional effects produce heat losses and cause the inner surface temperature to be somewhat lower than the heater temperature.

A temperature gradient necessarily exists along the length of the lens barrel, since the conduction path runs from the lens cone housing, through the flange at the center of the lens barrel, and then along the barrel toward either end. Thus, some temperature spread will persist within the barrel due to heat losses from the lower end.

5. COST OF MATERIALS

Many of the materials used in the construction of the thermal blanket and control system were scavenged or otherwise acquired at no cost. However, the best estimate for the cost of these materials is $350. Cost of individual items procured is included in Appendix I.

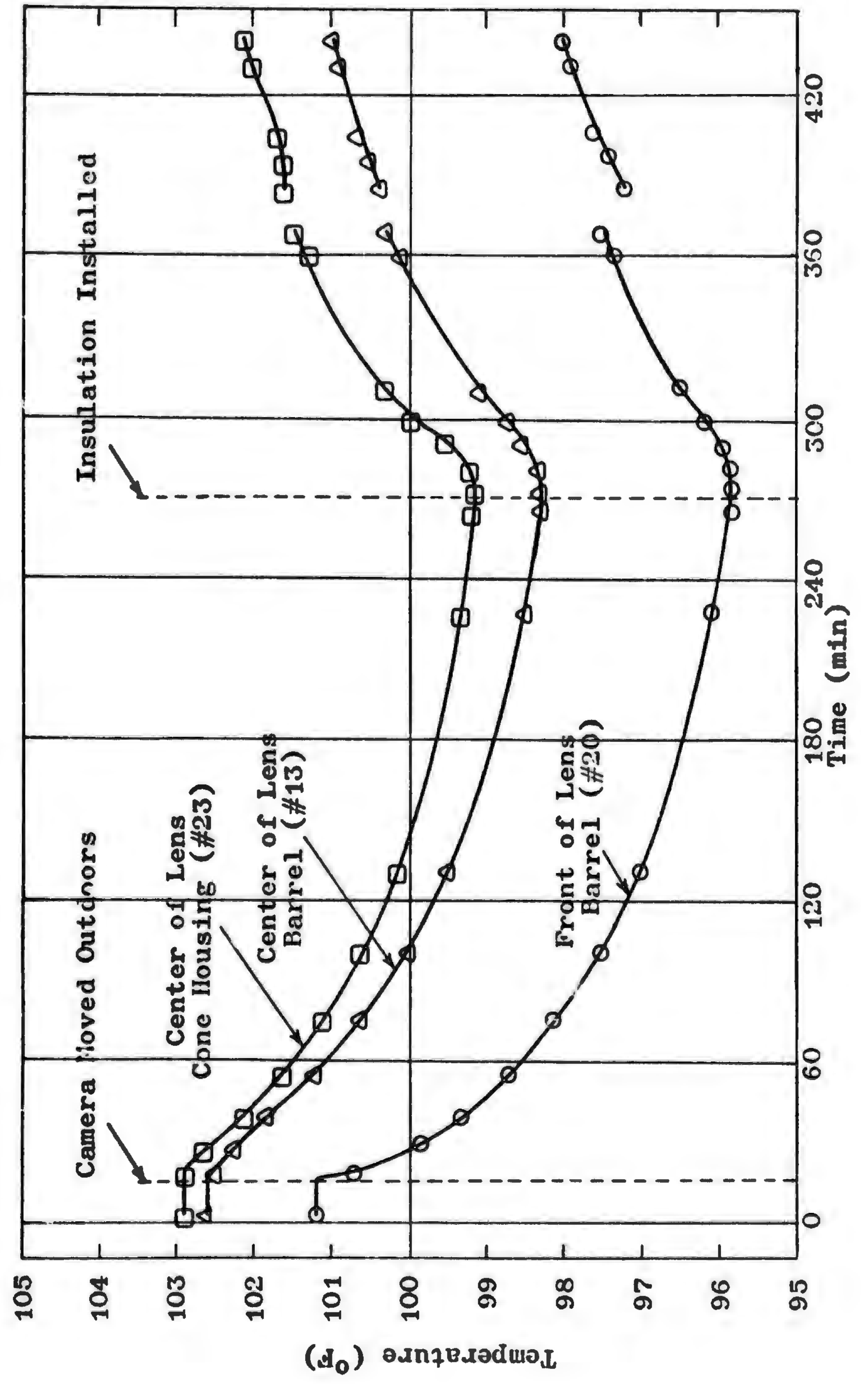


Figure 10. Effects of Environmental Temperature Change

SECTION VIII

CONCLUSIONS

The thermal control system developed in this study is a feasible solution to the thermal problems of the KS-87B camera. Even though test results were rather limited for the final configuration of the model, they indicate that near-isothermal conditions can be maintained within the lens barrel and that temperature changes due to changing environment are small. For a 30°F decrease in ambient temperature, temperatures within the lens barrel should not change by more than 3°F per hour, and these temperatures should all be within a 4°F range at design conditions.

The final test for the performance of this system must include measurements of the photographic qualities of the lens during changing environmental conditions. However, transit temperature testing of the lens barrel (Reference 10) has indicated that focal length changes are almost directly proportional to the maximum temperature differences within the lens barrel. With a 4°F temperature spread, focal length changes greater than 0.004 inches would not be expected.

Partial testing of the model with a layer of insulation installed over the body heater suggests that these values for temperature changes might be reduced. However, further testing is necessary to verify this hypothesis.

The assumptions made concerning ambient temperature and air flow within the camera compartment appear to be valid, based on data which was recently published (Reference 11:p 5-2, 5-42). However, the assumption that convective heat losses from the lens face are negligible failed to take into consideration the 0.6-inch long section of lens barrel which extends beyond the face of the front lens. Since the resistance to conduction of heat to this region is slight, the convective heat losses are significant. The large temperature difference within the lens barrel is due mainly to this lower end of the barrel being significantly cooler than the rest of the lens barrel.

This problem should be partially alleviated by the use of the lens filter. Temperatures of the lower-end of the lens barrel were not measured while the filter was installed, but the outer surface temperature for the front lens was significantly higher with the filter installed.

The materials used for the body heater and body cover are not suitable for full-range operations. During high-power operation of the system, the cover was scorched by the concentrated heat at the heater tape. A heater design which distributes the heat more evenly over the camera body is required.

The other materials used in the construction of the thermal control system functioned properly, although none of these materials has been certified for use in aircraft systems. This requirement may increase the costs of materials.

Compared with similar systems recently designed for other cameras, this thermal control system with a cost of less than $400 is a bargain, even if certification of materials does increase the cost. Thus, we believe the design objectives of simplicity, reliability, effectiveness, and low cost are attainable with only minor modifications to this model.

SECTION IX

RECOMMENDATIONS

Further testing should be accomplished before this design is accepted. With insulation installed around the camera body heater, tests should be performed to reevaluate performance of the system during preheating, stabilized operation, and changing environments. These tests should also measure the optical quality of the lens. During stabilized operation, electrical power should be applied to the camera system to verify the effects of heat generation within the camera.

Prior to testing this model in an aircraft, compliance with MIL-STD-810B is necessary to ensure compatibility with the aircraft environment.

Several changes in the present model design are recommended:

a. Replace the two layers of Flexible Min-K insulation in the thermal blanket with two cylindrical shells of Molded Min-K 503 insulation, which would be concentric and have adequate space between them for the heater film and thermostat bulb. The two shells should have the same dimensions as the present two layers of insulation, except the length should be 15.5 inches to allow for coverage of the entire length of the lens cone housing plus 1 inch.

b. Install layers of heat-resistant soft foam, approximately 1/4-inch thick, adjacent to each thermostat bulb. The foam would compress at the bulb, but remain expanded on either side of the bulb to fill the gap in the blanket.

c. Replace a cover material (awning canvas) with a durable, waterproof, flame-retardant cloth capable of withstanding temperatures of at least 200°F. The outer surface of the cloth should be black and nonreflective. The assembled thermal blanket will be completely covered with this cloth, both inside and outside, and sealed at the upper and lower ends. It will extend up and around the camera body and terminate at the lower edge of the mount. A separate cover of this cloth will enclose the cassettes and their insulation and extend down to the upper edge of the mount. The two separate covers will be connected with straps and snap fasteners.

d. Replace the body heater tape with two heater films like the one used in the thermal blanket. A 4-inch by 10-inch film would be installed on the back side of the magazine, directly behind the cassettes. A 3-inch by 46-inch film would be wrapped around the perimeter of the camera body, just below the mount. The 3-inch heater film would be covered by a 3/8-inch thickness of Flexible Min-K, measuring 3 by 46 inches. The present three pieces of insulation which cover the cassettes can be replaced by a molded shell of Min-K 530 with the same dimensions. This shell covers the 4-inch by 10-inch heater film.

APPENDIX I

COSTS OF MATERIALS

COSTS OF MATERIALS

The following list gives the costs of the separate materials used in the construction of the thermal control system. Those items which were on hand, rather than purchased, are denoted by (*) and their costs are estimated values.

Quantity	Item	Cost
1	Electrofilm heater film	$92.25
12 ft	"Heat-By-The-Yard" heater tape	15.00*
18 ft^2	Flexible Min-K insulation, 3/8-inch	99.00
2	United Electric thermostat, Type F7-8913	75.50
2	Allied Control relay, Type BOHR-6	22.00*
1	Kurman Electric relay, Type 26D2C	11.00*
1	Leach Corp. relay, Type 4466	11.00*
3	Toggle switches, SPST	10.00*
2	Fuse holders	3.00*
2	Fuses (1 - 15A., 1 - 3A.)	1.00*
2	Indicator lamps, 115 volts AC	4.00*
20 ft^2	Awning canvas	3.00
1	Zipper	0.60
30 ft	Wire, insulated, #18 and #20	3.00*
	Total Cost	$350.35

APPENDIX II

THERMISTOR IDENTIFICATION

THERMISTOR IDENTIFICATION

Channel	Location
09	Ambient air temperature
10	Airspace in center of lens barrel
11	Between lens elements #5 and #6
12	Outer surface of rear lens (#6)
13	Center of lens barrel outer surface
14	Rear of lens barrel outer surface
15	Front of lens cone housing
16	Middle of lens heater film
17	Camera body, beneath heater tape
18	Upper edge of magazine
19	Cassette
20	Front of lens barrel outer surface
21	Ambient surrounding surface temperature
22	Outer surface of front lens
23	Center of lens cone housing
24	Receptacle region of camera body

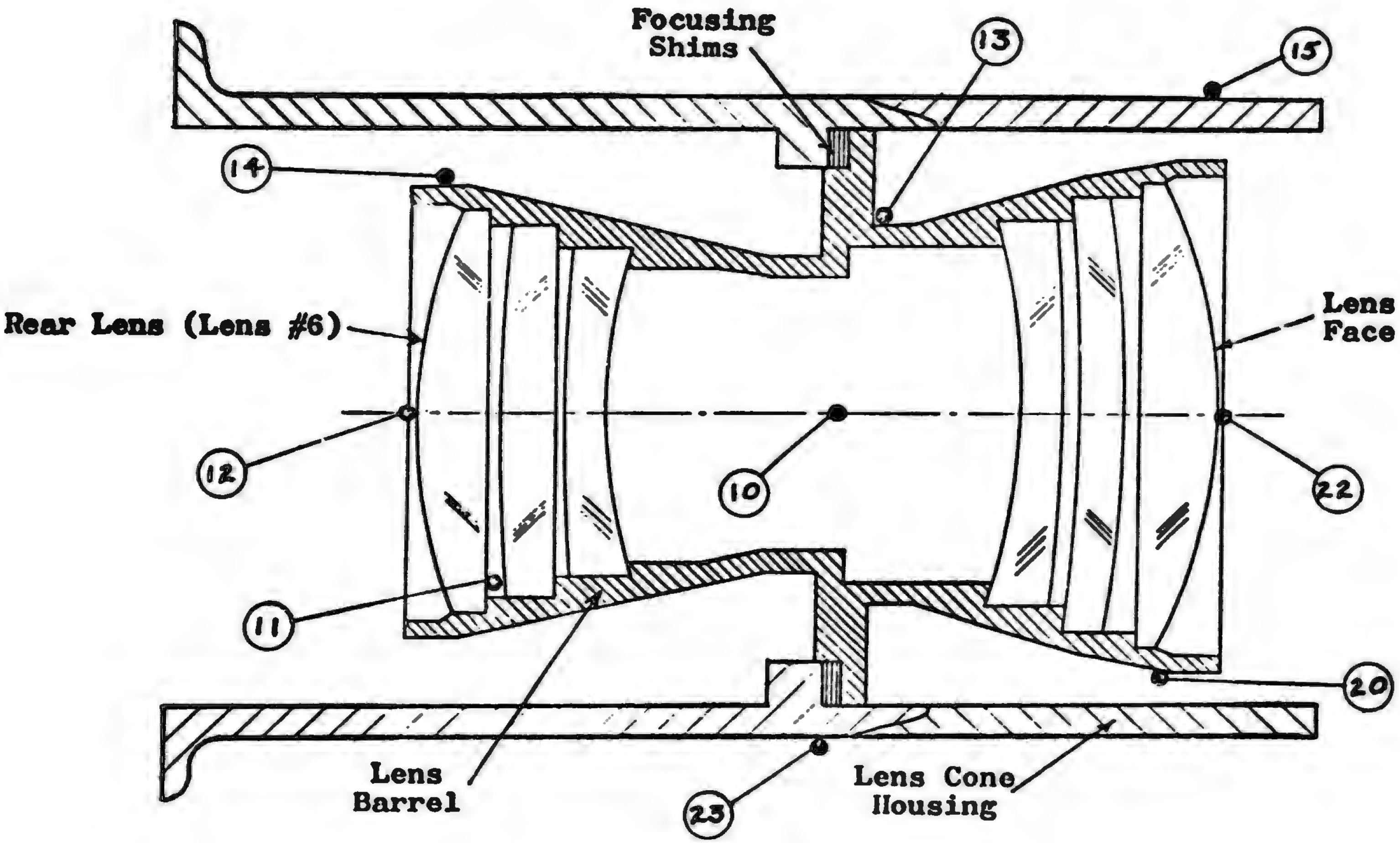


Figure 11. Thermistor Locations in the Lens Cone

APPENDIX III

TEST DATA

Table I

Outdoor Preheating Test

January 3, 1973

Average Ambient Temp. = 35°F

	Channels						
Time	10	11	12	13	14	15	16
1251	42.5	43.3	42.6	42.6	42.5	42.2	41.0
1253	Start of Test						
1300	42.5	43.0	43.6	42.8	42.8	44.8	83.5
1330	56.0	50.8	57.5	57.8	58.0	64.8	125.8
1359	69.5	63.3	71.2	72.9	72.6	78.2	129.9
1435	83.1	81.1	88.8	89.6	89.7	93.4	131.8
1503	95.6	92.2	96.9	94.0	96.9	96.6	119.3
1529	98.4	95.1	99.6	99.1	98.8	98.0	126.8
1603	100.0	100.8	101.6	100.9	100.6	98.7	115.4
1630	100.4	101.5	102.2	101.2	101.0	98.9	120.7
1710	100.9	102.2	102.4	101.6	101.3	99.1	115.6
1717	100.8	102.2	102.9	101.6	101.1	98.5	118.2

Table I (Continued)

Outdoor Preheating Test

January 3, 1973

Average Ambient Temp. = 35°F

Time	17	18	19	20	22	23	24
1251	41.8	42.7	43.1	42.1	39.8	42.3	41.3
1253	Start of Test						
1300	91.3	66.8	44.7	43.0	40.4	45.8	45.8
1330	121.1	98.6	65.3	57.3	43.8	66.8	76.9
1359	126.0	106.8	82.5	71.3	50.6	82.3	93.1
1435	129.9	124.9	98.5	85.2	60.4	98.0	104.7
1503	115.7	116.5	101.1	92.9	67.6	99.9	99.5
1529	127.9	123.9	101.2	95.0	70.0	102.8	103.5
1603	113.2	117.1	101.5	96.5	72.1	102.5	99.0
1630	120.0	120.9	101.2	97.1	71.3	103.1	99.9
1710	119.2	116.5	100.3	97.2	73.8	102.6	98.2
1717	122.1	118.8	99.9	97.0	74.0	102.8	98.4

Table II

Indoor Preheating Test

January 16, 1973

Average Ambient Temp. = 72°F

	Channels							
Time	09	10	11	12	13	14	15	16
0910	Start of Test - All Temperatures 71° ± 1°F							
1113	71.8	96.1	95.6	96.5	96.5	96.5	97.9	104.0
1200	72.5	97.2	97.3	97.7	97.6	97.5	98.7	105.6
1230	72.2	97.8	97.9	98.2	98.1	98.0	99.1	104.1
1300	72.3	98.2	98.4	98.6	98.4	98.4	99.3	104.3
1310	72.3	98.3	98.5	98.7	98.5	98.4	99.4	104.0
1415	72.5	98.6	99.0	99.1	98.9	98.8	99.7	104.0

	Channels							
Time	17	18	19	20	21	22	23	24
0910	Start of Test - All Temperatures 71° ± 1°F							
1113	106.1	103.8	95.7	95.1	73.2	86.0	97.6	96.7
1200	109.5	104.7	96.2	96.0	73.7	87.5	98.5	97.1
1230	105.2	104.0	96.5	96.5	73.7	88.2	98.9	97.3
1300	105.9	104.4	96.7	96.9	73.9	88.6	99.2	97.4
1310	105.4	104.3	96.8	97.1	73.9	88.8	99.2	97.5
1415	196.3	105.1	96.9	97.4	74.0	88.7	99.5	97.7

Table III

Stabilized and Changing Environments, Indoor and Outdoor Tests

January 19, 1973

Indoor Ambient Temp. = 73°F
Outdoor Ambient Temp. = 39°F

	Channels							
Time	09	10	11	12	13	14	15	16
0902	73.2	102.3	102.8	102.8	102.6	102.5	103.0	103.5
0918	51.6	102.3	102.8	102.8	102.5	102.4	102.8	105.2
0928	44.3	102.0	102.7	102.5	102.2	102.1	102.3	105.3
0930	42.8	101.5	102.5	102.2	101.8	101.6	101.9	104.1
0955	41.5	100.9	102.1	101.7	101.2	101.0	101.5	105.2
1015	40.5	100.3	101.5	101.1	100.6	100.4	101.1	104.7
1040	39.8	99.7	100.9	100.5	100.0	99.8	100.6	103.4
1110	41.5	99.2	100.2	100.0	99.5	99.3	100.2	104.1
1247	38.7	98.2	99.1	99.0	98.5	98.4	99.4	104.6
1324	37.6	98.0	98.9	98.8	98.3	98.2	99.2	104.5
1330	Insulation installed around heater tape area.							
1332	39.2	97.9	98.8	98.8	98.3	98.1	99.2	104.6

Table III (Continued)

Stabilized and Changing Environments, Indoor and Outdoor Tests

January 19, 1973

Indoor Ambient Temp. = 73°F
Outdoor Ambient Temp. = 39°F

	Channels							
Time	17	18	19	20	21	22	23	24
0902	109.2	105.4	99.0	101.2	73.8	97.4	102.9	101.0
0918	115.7	105.4	98.3	100.7	59.3	92.8	102.9	97.6
0928	118.5	105.4	95.1	99.8	46.6	89.7	102.5	96.6
0939	115.3	104.9	93.5	99.3	44.4	88.1	102.1	95.8
0955	120.4	105.1	92.4	98.7	43.2	86.4	101.6	95.8
1015	119.9	104.7	91.8	98.1	42.4	85.2	101.1	95.5
1010	114.9	103.8	91.1	97.5	42.1	83.8	100.6	95.3
1110	117.9	102.9	90.6	97.0	42.6	83.7	100.1	95.3
1247	118.5	103.8	89.7	96.1	41.4	82.2	99.3	94.6
1324	118.5	103.6	89.7	95.8	40.5	81.6	99.2	94.9
1330	Insulation installed around heater tape area.							
1332	120.6	104.1	89.5	95.8	40.8	81.6	99.1	94.9

Table III (Continued)

<u>Stabilized</u> <u>and</u> <u>Changing</u> <u>Environments</u>, <u>Indoor</u> <u>and</u> <u>Outdoor</u> <u>Tests</u>

January 19, 1973

Indoor Ambient Temp. = 73°F
Outdoor Ambient Temp. = 39°F

	Channels							
Time	09	10	11	12	13	14	15	16
1340	39.1	97.9	98.8	98.8	98.3	98.2	99.2	103.0
1349	39.1	98.1	98.8	99.0	98.5	98.4	99.4	104.4
1400	38.5	98.4	99.0	99.3	98.8	98.7	99.6	104.0
1410	37.5	98.6	99.2	99.6	99.1	99.0	100.0	103.9
1500	36.3	99.6	100.4	100.7	100.1	99.9	100.8	103.6
1508	36.5	99.8	100.5	100.9	100.3	100.1	101.0	103.4
1525	36.4	99.9	100.8	101.9	100.4	100.2	100.8	104.5
1535	36.5	100.0	101.0	101.2	100.5	100.3	101.0	103.1
1545	35.9	100.1	101.1	101.3	100.7	100.5	101.1	103.7
1610	35.8	100.4	101.4	101.6	100.9	100.8	101.4	104.9
1620	35.9	100.5	101.5	101.7	101.0	100.9	101.4	104.4

Table III (Continued)

Stabilized and Changing Environments, Indoor and Outdoor Tests

January 19, 1973

Indoor Ambient Temp. = 73°F
Outdoor Ambient Temp. = 39°F

	Channels							
Time	17	18	19	20	21	22	23	24
1340	118.6	104.2	89.6	95.8	40.8	81.7	99.2	95.4
1349	122.2	105.1	89.7	95.9	40.4	81.6	99.5	96.2
1400	122.2	105.3	90.1	96.2	40.3	81.6	100.0	96.8
1410	122.1	105.8	90.3	96.5	39.7	81.6	100.3	97.6
1500	121.9	196.5	90.6	97.3	38.3	81.4	101.3	97.9
1508	121.5	196.6	90.9	97.5	38.7	81.7	101.5	98.1
1525	123.4	105.9	91.2	97.2	38.5	81.0	101.6	98.8
1535	121.6	196.3	91.3	97.4	37.2	80.5	101.6	98.6
1545	122.4	196.6	91.3	97.6	36.8	80.9	101.7	98.0
1610	121.9	107.0	91.6	97.9	36.8	81.4	102.0	98.4
1620	122.7	107.3	91.7	98.0	36.7	81.5	102.1	98.3

APPENDIX IV

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

1. THERMAL WAVE PROPERTIES

Inner layer of insulation: $\rho = 17.3 \text{ lb/ft}^3$

$k = 0.018 \text{ BTU/hr-ft-°F}$

$c = 0.20 \text{ BTU/lb-°F}$

$b = 0.031 \text{ ft}$

$$\alpha = \frac{k}{\rho c} = \frac{0.018}{(17.3)(0.20)} = 0.0052 \text{ ft}^2\text{/hr}$$

$$= 1.4 \times 10^{-6} \text{ ft}^2\text{/sec}$$

For an on-off differential of 1.0°F,

$t_{OM} = 0.5°\text{F}$. From Fig. 4-29, Ref 5:

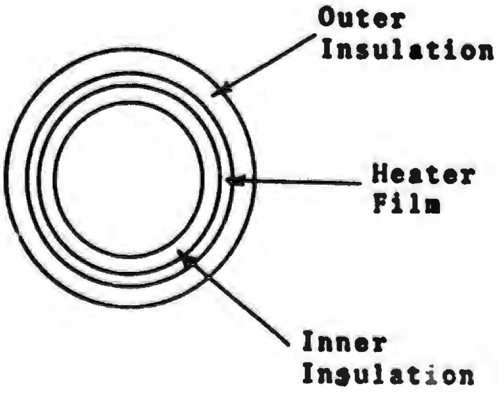
$$\text{for } \frac{t}{t_{OM}} = 0.1,$$

$$\frac{x}{2\sqrt{\pi\alpha\tau_0}} = 0.4$$

$$\tau_0 = \frac{1}{\pi\alpha}\left[\frac{x}{2(0.4)}\right]^2 = 0.0919 \text{ hr}$$

$$= 5.51 \text{ min}$$

2. HEAT LOSSES IN LENS



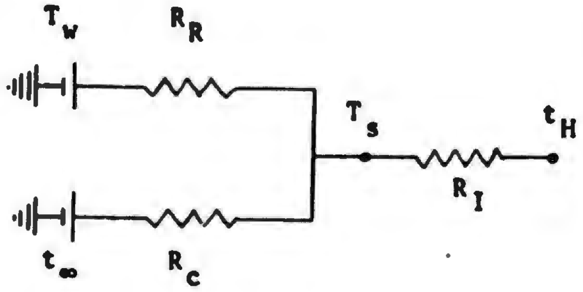
Radii:

Inner layer, inner surf. = 3.594 in.

Inner layer, outer surf. = 3.969 in.

Outer layer, inner surf. = 4.219 in.

Outer layer, outer surf. = 4.594 in.



Electrical Analogy of Lens Heat Losses

$$A_I = 2\pi\left(\frac{r_0 + r_i}{2}\right) L = 2.8078 \text{ ft}^2$$

$$R_I = \frac{b}{k_I A_I} = \frac{.03125}{(0.02)(2.8078)} = 0.5565 \ \frac{H_R - {}^\circ F}{BTU}$$

$$A_s = 2\pi r_0 L = 2.9315 \text{ ft}^2$$

For $t_H = 105^\circ F$, $t_\infty = 60^\circ F$, $t_w = 0^\circ F$

Assume: $t_s = 52^\circ F$, $\varepsilon = 0.9$

$$\bar{T} = \frac{512 + 460}{2} = 486^\circ R$$

$$h_c = 0.29\left(\frac{\Delta t_c}{L}\right)^{1/4} = 0.29\left(\frac{60 - 52}{1.2188}\right)^{1/4}$$

$$= 0.4640$$

$$R_c = \frac{1}{h_c A_s} = \frac{1}{(.4640)(2.9315)} = 0.7352$$

$$h_R = 4\varepsilon\sigma\bar{T}^3$$

$$= 4(0.9)(0.1714 \times 10^{-8})(486)^3 = 0.7083$$

$$R_R = \frac{1}{h_R A_s} = \frac{1}{(0.7083)(2.9315)} = 0.4816$$

Since heat is added to blanket by convection,

$$Q_I + Q_c = Q_R$$

$$\frac{\Delta t_I}{R_I} + \frac{\Delta t_c}{R_c} = \frac{\Delta T_R}{R_R}$$

Solving for t_s:

$$\frac{105 - t_s}{0.5565} + \frac{60 - t_s}{0.7352} = \frac{t_s - 0}{0.4816}$$

$$t_s = \frac{270.2896}{5.2335} = 51.65$$

$$\therefore \quad Q_I = \frac{\Delta t_I}{R_I} = \frac{105 - 52}{0.5565} = 95.24 \text{ BTU/hr}$$

3. RADIATION LOSSES FROM LENS FACE

$$A = \pi r^2 = (3.1416)(3.060)^2 = 29.417 \text{ in}^2$$

$$= 0.2043 \text{ ft}^2$$

Assume: $\varepsilon = 0.94$, $t_s = 105°F$, $t_w = 40°F$

$$\bar{T} = \frac{500 + 565}{2} = 533°R$$

$$h_R = 4\varepsilon\sigma\bar{T}^3 = 0.9758$$

$$R_R = \frac{1}{h_R A} = \frac{1}{(0.9758)(0.2043)} = 5.0161$$

$$Q_{lens} = \frac{\Delta t}{R_R} = \frac{105 - 40}{5.0161} = 12.96 \text{ BTU/hr}$$

4. CONDUCTION HEAT LOSSES TO BODY (FIN MODEL)

Assume: $A = 0.940\ \text{ft}^2$

$A_s = 4.915\ \text{ft}^2$

$L = 1.2786\ \text{ft}$

$p = 3.8438\ \text{ft}$

$t_\infty = 60°\text{F}$

$t_0 = 105°\text{F}$

$k = 90\ \frac{\text{BTU}}{\text{hr-ft-°F}}$

$d = 0.9609\ \text{ft}$

$\Delta t = \frac{105 - 60}{2} = 23°$

$$h = 0.27\left(\frac{\Delta t}{d}\right)^{1/4} = 0.27\left(\frac{23}{.9609}\right)^{1/4} = 0.597$$

$$m^2 = \frac{hp}{kA} = \frac{0.597(3.8438)}{90(0.940)} = 0.027\ 1/\text{ft}^2$$

$$m = 0.1645/\text{ft}$$

$$\frac{t-t_\infty}{t_0-t_\infty} = \frac{\cosh[0.1645(1.2786-x)]+(0.0401)\sinh[0.1645(1.2786-x)]}{\cosh[(.1645)(1.2786)]+(0.0401)\sinh[(.1645)(1.2786)]}$$

Solving this for Selected Values of x:

$\frac{x}{L}$	$\frac{t-t_\infty}{t_0-t_\infty}$	t
1	0.9702	103.7
0.782	0.9730	103.8

5. TEMPERATURE OF THE CAMERA BODY

The temperature of the insulated camera body was computed by using the same equations used for lens heat losses. The values used were:

Q_I = 627 BTU/hr (generated internally)

$A_s = 7.68$ ft^2

$\epsilon = 0.9$

$k_I = 0.2$ BTU/ft^2-°F

$b = 0.05$ ft

APPENDIX V

DETAILED DESCRIPTION OF EQUIPMENT

DETAILED DESCRIPTION OF EQUIPMENT

This appendix contains pertinent specifications for the KS-87B camera and for the materials which were specically selected and purchased for this model. The items acquired at no cost are adequately described in the text of this report, since their specifications are not critical to this design.

1. KS-87B CAMERA

Part number: 7320-1000-2
Manufactured by: Chicago Aerial Industries, Inc.
Barrington, Illinois

Overall Dimensions (with 18-inch lens cone installed):
Height.............31.937 inches
Width..............10.320 inches
Length.............15.875 inches
Weight.............87.15 pounds

Power Requirements (Standby Mode):
AC - 115 volts rms, 400 ± 20 Hz, three phase
Phase A: P.F. = 0.490
VA = 71.3
Watts = 35

Phase B: P.F. = 0.284
VA = 42.2
Watts = 12

Phase C: P.F. = 0.800
VA = 46
Watts = 36

DC - 28 volts, 3.6 amperes.

2. HEATER FILM

Part number 113-147
Manufactured by: Electrofilm Inc.
7116 Laurel Canyon Blvd.
North Hollywood, California 91605
213-875-1000

Dimensions:
Length.............13.50 inches
Width..............25.60 inches

Power Requirements (each element):
Voltage............57.5 volts AC
Resistance.........104.5 ohms
Power..............31.65 watts

Heating Capacity (half-time operation):
Low-power..........108 BTU/hr
High-power.........432 BTU/hr

3. THERMOSTATS

Type F7-8913
Manufactured by: United Electric Controls Co.
85 School Street
Watertown, Massachusetts 02172
617-926-1000

Specifications:
Range..............80°-130°F
Bulb Style.........C
Bulb length........100 inches
Bulb material......copper

4. INSULATION

Flexible Min-K, Standard Type SS
Manufactured by: Johns-Manville
8741 Americana Blvd.
Indianapolis, Indiana 46268
317-297-2230

Construction: Special flexible Min-K (F 182) core faced on both sides with No. 116 glass fabric stitched in one-inch square pattern

Dimensions: 36 x 36 x 3/8 inches
Weight: 0.54 psf
Thermal Conductivity: 0.018 BTU/hr-ft-°F
Max. Service Temperature: 1800°F
Specific Heat: 0.20 BTU/lb-°F

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