

A DATA REDUCTION PROGRAM FOR
A ROCKETSONDE TEMPERATURE SENSOR

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CASE FILE
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University of Utah
Electrical Engineering Department

Warren W. Lacey
Forrest L. Staffanson

Forrest L. Staffanson
Principal Investigator

ABSTRACT

A mathematical model for obtaining *air temperature* from a standard ARCASONDE bead, wire, film temperature sensor and its radar track is developed in this thesis. In addition, *pressure* and *density* of the atmosphere, and *horizontal winds* are computed. While this model has an unrestricted altitude range, the rocketsonde flights used generally vary from 20 to 90 kilometers. The temperature errors encountered in these flights become large at high altitudes, with aerodynamic heating and thermal conduction being the largest. Aerodynamic heating is due mainly to the high speed of the rocket and the initial altitudes. The thermal conduction model describes a bead and film, which respond with a dynamic lag to temperature changes, connected by a wire which responds instantaneously. The temperature corrections due to radiation and electrical heating are relatively small at altitudes below 50 kilometers. Approximate values of radiation heating in the sensor can be computed from Lambert's Cosine Law. The large uncertainties associated with the radiation inputs to the sensor are due mainly to the large uncertainties in the absorptivity of the sensor.

A computer program is developed for the UNIVAC 1108 to take rocketsonde data and produce air temperature, pressure, density, and horizontal winds. A real rocketsonde flight at Wallop's Island, Virginia on September 5, 1967 at 1516 Z with an altitude range of 25 to 50 kilometers serves as an illustration of this program.

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GLOSSARY

A	total or surface area of sensor - m^2
a	albedo of the earth-atmosphere system
C	specific heat of the sensor - $J/(kg^\circ K)$
C_p	specific heat of the atmosphere at constant pressure
C_s	speed of sound - m/s
DF	drag force - N
D	diameter or thickness of the sensor - m
ϵ	emissivity
F	long wave radiation flux density - W/m^2
f	ratio of cross section to total surface area
g	gravity - m/s^2
h	convection coefficient - $W/(m^2 \cdot K)$
I	short wave radiation flux density
I_0	solar constant
J	radiation intensity - $W/(m^2 \text{ sr})$
i	angle of incident radiation
δ	angle of emitting radiation
k	thermal conductivity - $W/(m^\circ K)$
L	Mean free path - m
ζ	station latitude
l	length of sensor component - m
p	pressure - N/m^2
Q	heat flux into the sensor - W/m^2

R	distance between the sensor and radiation source - m
R_D	gas constant for dry air - J/(kg°K)
R_e	mean radius of the earth - m
r	recovery factor
S	distance along a sensor component - m
T	temperature - °K
t	time - s
τ	time constant - s
V	air speed of the sensor - m/s
v	volume - m ³
W	electric heating referred to thermistor surface area - W/m ²
W_x	east wind - m/s
W_y	south wind - m/s
Ω	angular velocity of the earth
x	east horizontal direction - m
y	south horizontal direction - m
z	altitude - m
ρ	density - kg/m ³
σ	Stefan-Boltzmann constant - W/(m ² °K ⁴)
α	absorptivity
λ	decay length - m
μ	viscosity - kg/(m s)

Subscripts:

a	average
Ag	silver film
Ag-My	silver-mylar laminar film
b	thermistor bead
c	conduction
e	equilibrium or steady-state condition
f	film
i	incident
ℓ	long wave radiation
My	mylar
r	total radiation
s	short wave radiation
w	wire
1	earth and atmosphere
2	instrument package

I. INTRODUCTION AND STATEMENT OF THE PROBLEM

The purpose of this paper is to develop a mathematical model which will calculate atmospheric temperatures, pressures, densities and horizontal wind distributions of the upper atmosphere from rocketsonde measurements. Data from the rocketsonde flight at Wallop's Island, Virginia on September 5, 1967 at 1516 Z provides the basis for the discussion of the results. The measuring instrument used is the standard ARCASONDE 1A temperature sensor carried by the ARCAS rocket to altitudes of fifty to seventy kilometers. The sensor temperature and radar track are recorded digitally on magnetic computer tapes as the rocketsonde descends by parachute back to earth. A computer program has been developed which will calculate atmospheric parameters from the rocketsonde data.

The ARCASONDE 1A temperature sensor consists of an aluminum coated metallic oxide thermistor bead attached by two platinum-iridium wires to a silver film deposited on a mylar substrate. The mathematical model adopted to describe this sensor uses the bead, wire, and film as integral components. A schematic representation of this sensor is shown in the following figure.

In the process of measuring the air temperature, the sensor is subject to heat transfer with the environment. These heat inputs are radiation from the sun, the earth-atmosphere system, and the instrument package, as well as aerodynamic, electrical, and radiofrequency heating. Sensor lag and thermal conduction due to heat exchange with the wires

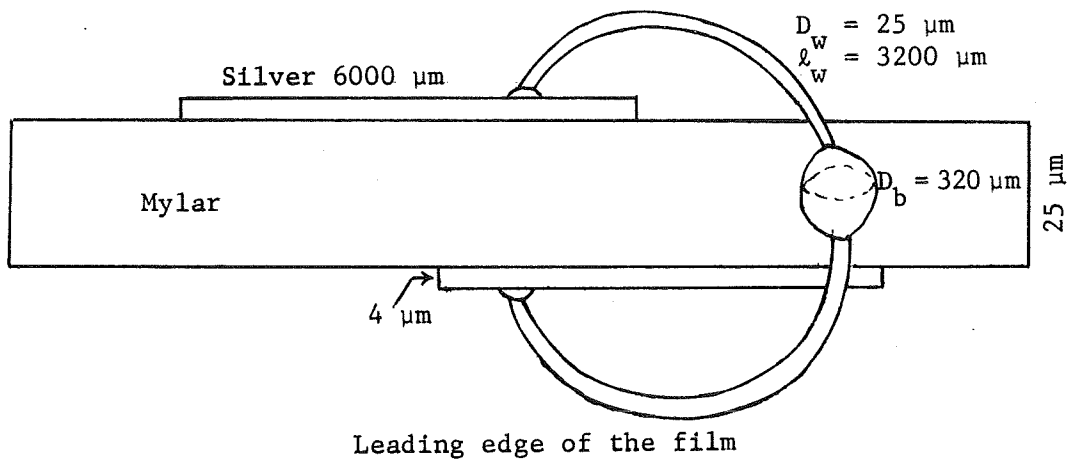
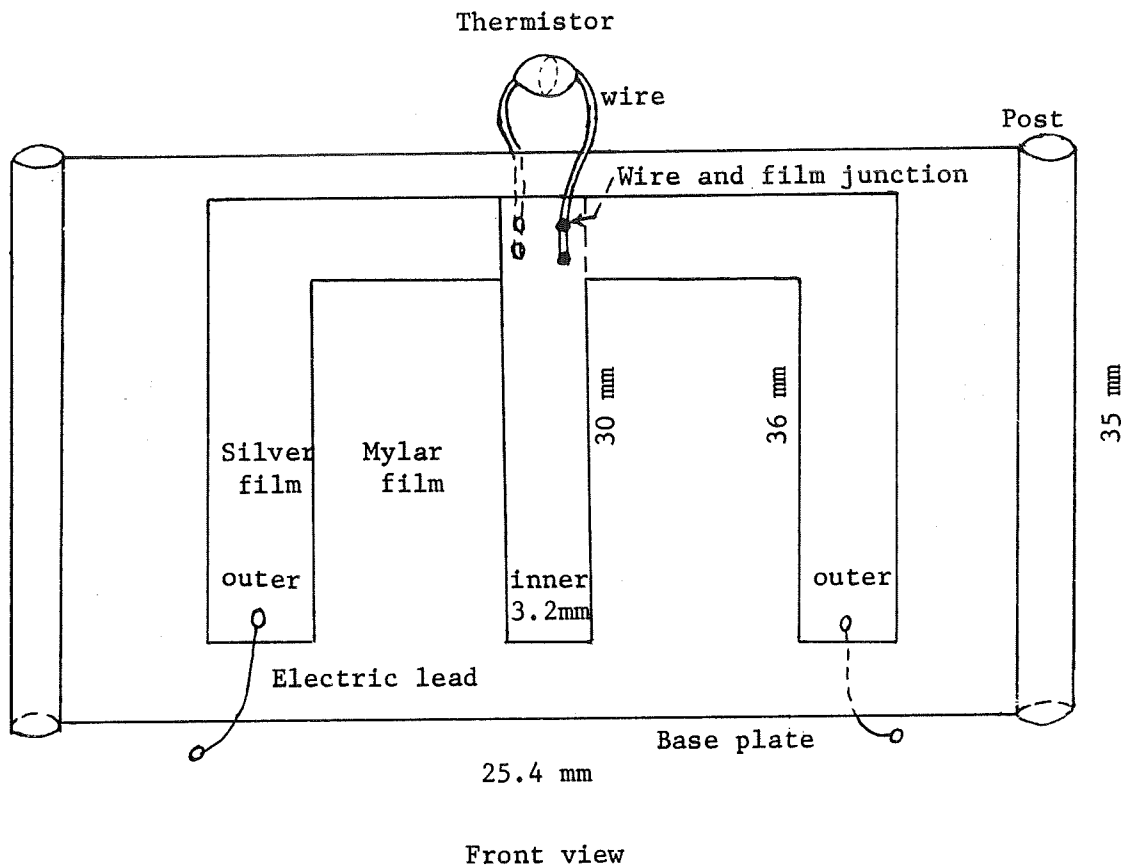


Fig. 1. ARCASONDE bead-wire-film sensor.

and film are additional sources of complication.

In regard to application, rocketsonde data can be used to measure atmospheric parameters from 20 to 90 kilometers in a region where satellite data and radiosonde information are not available on a routine basis. If the rocketsonde stations are sufficiently dense and soundings are made often enough, synoptic charts can be made to supplement existing radiosonde charts. These charts would contain geostrophic and thermal winds as well as diurnal and seasonal variations of the atmosphere.

II. PHYSICAL FACTORS AFFECTING ROCKETSONDE MEASUREMENTS

1. Convection and Aerodynamic Heating

The heat flux between a stationary sensor and the surrounding air is related to the difference between the air and sensor temperatures by the first law of thermodynamics, i.e.,

$$\rho c \frac{V}{A} \cdot \frac{\partial T}{\partial t} = h(T_{\text{air}} - T) [W/m^2] \quad (1)$$

Because the sensor is moving relative to the air at speed V , air is compressed and heated at the sensor. The resulting increase in the sensor temperature due to this aerodynamic heating is

$$\Delta T = \frac{rV^2}{2C_p} [^\circ K] \quad (2)$$

The recovery factor, r , corrects for nonadiabatic friction and kinetic effects of the surrounding air.²¹

By combining the effect of aerodynamic heating (Eq. 2 with Eq. 1), the convective heat transfer equation follows:

$$\rho c \frac{V}{A} \frac{\partial T}{\partial t} = h \left(T_{\text{air}} + \frac{rV^2}{2C_p} - T \right) \quad (3)$$

The form of the equation for the convection coefficient, h , and recovery factor, r , depends on the altitude, air speed, and character-

istic length of the sensor component. Assuming the sensor is in steady state ($\partial T / \partial t = 0$), the sensor temperature can be calculated from Eq. 3 to give

$$T_r = T_{air} + \frac{rV^2}{2C_p} \quad (4)$$

The recovery temperature, T_r , is the equilibrium temperature of an isolated object moving with air speed, V , assuming no radiation inputs.

2. Radiation

Radiation heating of the ARCASONDE sensor is inherent in the measurement of air temperature using rocketsonde data. The sources of radiation and approximate calculations of the heating effect will be considered in this section. The total radiation received by the spherical thermistor in the ARCASONDE sensor is due to the following sources:

1. Direct (parallel) sunlight: I_1
2. Reflected (diffuse) solar energy from the earth and atmosphere: I_2
3. Reflected shortwave radiation from the earth and atmosphere which is reflected from the instrument package: I_3
4. Direct long wave radiation from the earth and atmosphere: F_1
5. Long wave radiation from the instrument package: F_2
6. Long wave radiation from the earth and atmosphere reflected by the instrument package: F_3

Disregarding multiple reflections between the earth, thermistor, and instrument package, the total radiation input is given as the sum of the individual components.

$$Q = (I_1 + I_2 + I_3) \alpha_S + (F_1 + F_2 + F_3) \alpha_L \left[\text{W/m}^2 \right] \quad (5)$$

In reality, the absorptivity (α) and reflectivity ($1 - \alpha$) are not known exactly, but are assumed to be spectrally averaged quantities in the long wave region ($\alpha_L, 1 - \alpha_L$) and short wave region ($\alpha_S, 1 - \alpha_S$).

The basic radiation laws for a spherical receiver realized by the thermistor bead in the case of long wave radiation will be derived next. Here we work with a black thermistor where the absorption is taken into account in Eq. 5.

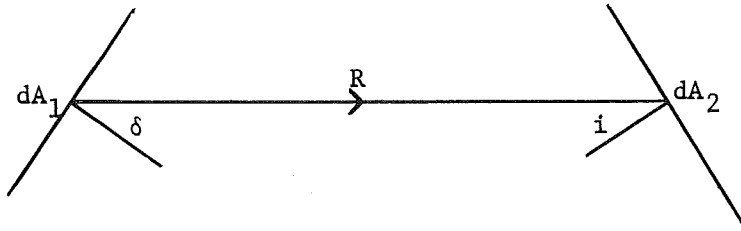


Fig. 2. Geometrical configuration of receiving and emitting surfaces.

According to Lambert's Cosine Law of Photometry, the radiation energy due to an elemental surface dA_1 emitted at an angle δ and received by another elemental surface dA_2 at an incidence angle i is

$$dQ = J \frac{dA_1 \cos \delta dA_2 \cos i}{R^2} \text{ [Watt]} \quad (6)$$

assuming R is much larger than the dimensions of the elemental areas.

The important geometrical quantities involved in Eq. 6 are

1. the solid angle subtended by the emitting surface, dA_1 , as viewed by dA_2 :

$$\frac{dA_1 \cos \delta}{R^2} \text{ [sr]}$$

2. the apparent radiation receiving surface:

$$dA_2 \cos i$$

3. the intensity of the emitted radiation:

$$J \left[\text{W}/(\text{m}^2 \text{ sr}) \right]$$

Since the receiving element (thermistor) is a spherical surface, $dA_2 \cos i$ can be replaced by its cross sectional area, $\pi D_b^2/4$. The ratio

of the cross section to the total surface area of the thermistor is $f = 1/4$. Equation 6 can be written as an average flux density for the thermistor as follows:

$$\frac{dQ}{\pi D_b^2} = J \cdot f \, dA_1 \frac{\cos \delta}{R^2} \left[\frac{W}{m^2} \right] \quad (7)$$

This equation can be used to calculate radiative flux densities received by the thermistor from the earth and instrument package as illustrated in Fig. 3. Consider radiation from a small black element of the earth's surface, which can be considered as an infinitely far extended horizontal plane of temperature T_1 . In the absence of the atmosphere, the flux density intercepted by the spherical thermistor and distributed over its total surface area is obtained from Eq. 7.

$$dF_1 = \frac{dQ_1}{\pi D_b^2} = \frac{\sigma T_1^4}{\pi} f \frac{x \, dx \, d\phi}{R^2} \cos \delta \quad (8)$$

Simplifying Eq. 8 and taking into account the geometry of Fig. 3, one obtains for flux density from the earth's surface

$$F_1 = \frac{\sigma T_1^4}{2} \int_0^{\pi/2} \sin \delta \, d\delta \quad (9)$$

Taking into account the earth's atmosphere, and denoting by J_λ the

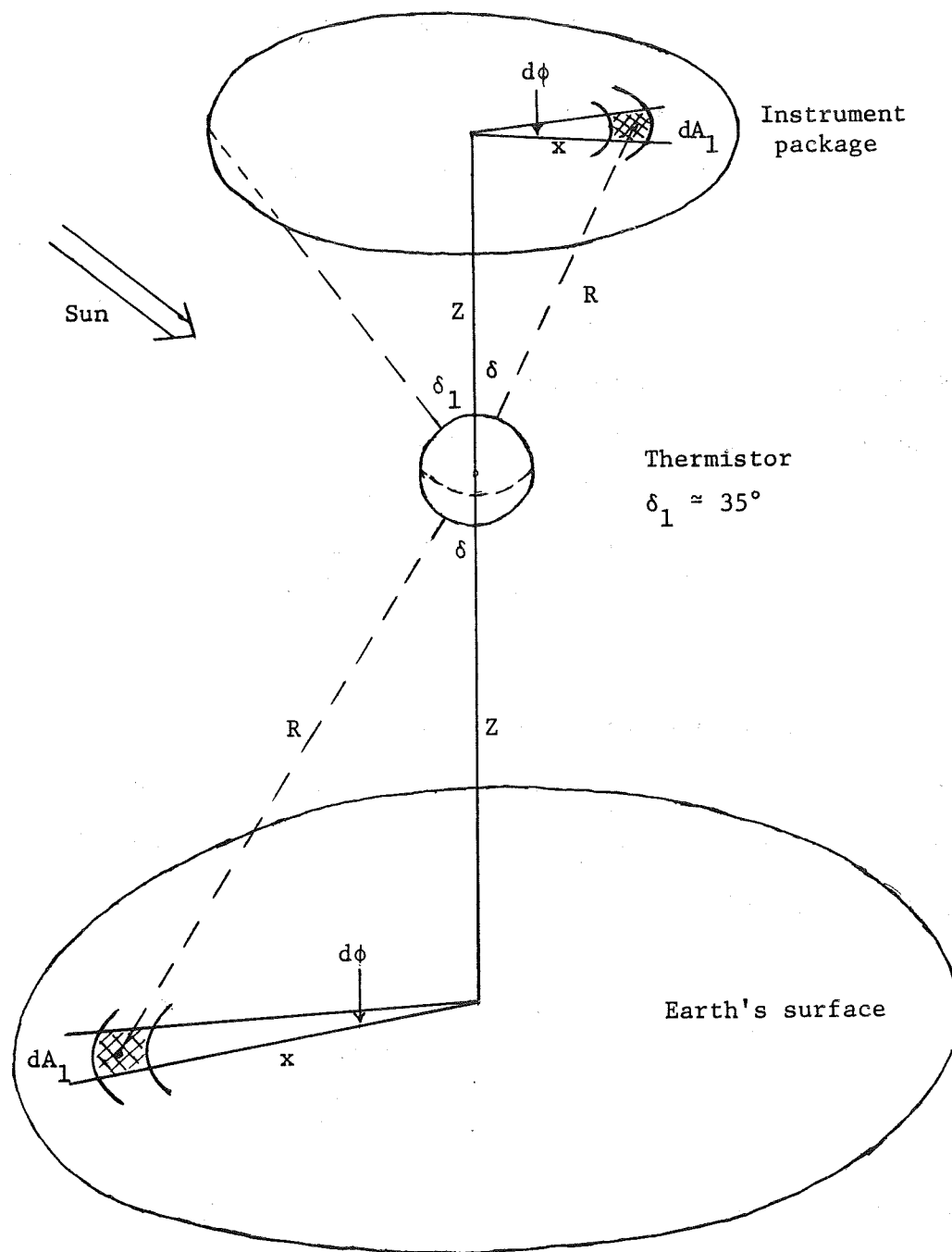


Fig. 3. Earth and instrument package as radiation sources.

monochromatic intensity received at the spherical thermistor, the radiant flux density (Eq. 9) can be written more generally as

$$F_1 = \frac{\pi}{2} \int_0^{\infty} d\lambda \int_0^{\pi/2} J_{\lambda}(\delta) \sin \delta d\delta \quad (10)$$

Radiation flux from the instrument package with a temperature T_2 and absorptivity α_{L2} can be obtained from Eq. 9 due to the similar geometrical relationship (see Fig. 3) as the function

$$F_2 = \frac{\sigma \alpha_{L2} T_2^4}{2} (1 - \cos \delta_1) \quad (11)$$

The instrument package also receives long wave radiation from the earth and it's atmosphere. The flux density incident on the base plate of the instrument package, assuming it is oriented essentially parallel to the earth's surface, is

$$F_i = 2\pi \int_0^{\infty} d\lambda \int_0^{\pi/2} J_{\lambda}(\delta) \cos \delta \sin \delta d\delta \quad (12)$$

Based on the assumption of diffuse reflection of the instrument package, the long wave illumination of the thermistor due to this reflected energy is

$$F_3 = \frac{F_1}{2} (1 - \cos \delta_1) (1 - \alpha_{L2}) \quad (13)$$

Thus, from this analysis one is able to obtain approximate values for the long wave component of radiation flux density onto the thermistor.

Basic formulas for short wave radiation received by the thermistor will be obtained next. For this particular rocketsonde flight, the zenith angle of the sun (dependent on latitude, time, and date) is about 51 degrees;¹⁸ therefore, direct solar energy is not screened off from the thermistor by the instrument package and parachute. The direct short wave flux density can be written in terms of the solar constant, I_0 , as follows:

$$I_1 = I_0 \cos \phi \quad (14)$$

where ϕ is the angle between the sun and the vertical to the sensor component. For the case of the thermistor, ϕ is equal to zero. It is assumed that reflected sunlight from the earth and atmosphere does not depend on any geometrical relationships, i.e., it is uniformly reflected. At rocketsonde altitudes, the assumed uniformly reflected sunlight occurs above most of the atmosphere and clouds. Thus, the reflected shortwave radiative intensity is $I_0 a/\pi$, where a stands for the total albedo of the earth-atmosphere system. The short wave radiation flux density received directly by the thermistor from the earth-atmosphere system is given by

$$I_2 = I_0 a/2 \quad (15)$$

The short wave flux density reflected from the earth and atmosphere and received by the base plate of the instrument package is obtained using Eq. 12.

$$I_i = I_0 a \quad (16)$$

This short wave energy uniformly reflected from the instrument package and received by the thermistor is

$$I_3 = \frac{I_0 a}{2} (1 - \alpha_{S2}) (1 - \cos \delta_1) \quad (17)$$

Equation 5 for total flux density received by the thermistor can now be written as follows:

$$Q = \frac{I_0}{2} \left[\frac{1}{2} + a + (1 - \alpha_{S2}) (1 - \cos \delta_1) a \right] \alpha_S + \left[F_1 + \left(\frac{\sigma \alpha_{L2} T_2^4}{2} + (1 - \alpha_{L2}) F_1 \right) (1 - \cos \delta_1) \right] \alpha_L \quad (18)$$

Some of the parameters used in calculating the radiation flux density are

1. solar constant I_0 : the average value is 1396 W/m^2 , with major changes due to seasonal variations (± 3.4 percent)

$$I_0 = 1396 \pm 47.5 \text{ W/m}^2$$

as taken from the Handbook of Geophysics and Space Environments.¹³

2. earth-atmosphere albedo a : the average albedo can be determined by using Angstrom's formula⁹ and estimating the amount and type of cloud cover.

$$a = .17 + .34 C, C = \text{tenths of cloud cover}$$

Estimating a 75 percent cirrostratus cloud cover, based on a surface synoptic map published by the U. S. Weather Bureau on September 5, 1967 at 1:00 a.m. EST for the area surrounding the rocketsonde station, the albedo according to Angstrom's formula is

$$a \approx .43 \pm .09$$

A 20 percent variation in albedo is assumed²⁰ due to uncertainties in the amount and type of cloud cover.

3. sensor absorptivities: values of the absorptivities of the sensor components (see Appendix C) along with estimated uncertainties which are used in the flux calculations are

listed below.

	Thermistor ¹⁷	Wire ¹⁷	Ag-My Film (Appendix C)	Instrument Package ¹
Short Wave	.16 ± .06	.19 ± .08	.05 ± .02	.80 ± .10
Long Wave	.10 ± .01	.10 ± .01	.51 ± .20	.80 ± .10

The variable condition of the surface of the sensor components contributes to large uncertainties in the above absorptivities.²³

4. An assumed temperature of the instrument package is $T_1 \approx 280^\circ\text{K}$ which is above ambient air temperature due to aerodynamic heating of the high speed rocket.

Values of long wave radiation from the earth-atmosphere system, F_i , arriving at a flat plate parallel to the earth's surface have been estimated by Zdunkowski.²⁹ The computations are based on the following radiation sources:

1. the cirrostratus cloud (at a temperature $T_1 = 243^\circ\text{K}$ and altitude of about 10 kilometers based on radiosonde data) is a black body,
2. water vapor, carbon dioxide, and ozone gases in the atmosphere.

A value of F_i for partial cloudiness is estimated from this data by using

the linear interpolation formula

$$F_i = (1 - C)F_{\text{clear}} + C F_{\text{cloud}} \quad (19)$$

where F_{clear} and F_{cloud} are the flux densities for a clear and overcast sky, respectively. Based on radiosonde data at the time of the rocketsonde flight

$$F_{\text{clear}} = 270 \text{ W/m}^2, \quad F_{\text{cloud}} = 170 \text{ W/m}^2$$

Since the radiation flux intercepted by a spherical thermistor and distributed over its entire surface area is one half of that intercepted by a unit area of flat plate parallel to the earth's surface (see Eqs. 10 and 12).

$$F_1(\text{thermistor}) = \frac{F_i(\text{flat plate})}{2} \quad (20)$$

Radiation received by an element oriented vertically to the earth's surface for the case of a wire cylinder and a flat plate can be obtained in a similar fashion. In the absence of the atmosphere, for example, the long wave radiation received by such an element (as shown by Moller)¹⁵ is one half of the radiation received by a flat plate parallel to the earth's surface, i.e.,

$$F_1(\text{vertical element}) = \frac{F_1(\text{flat plate})}{2} \quad (21)$$

In general, these results hold for radiation emitted from the earth-atmosphere system and received by the vertical element.

The radiation flux densities obtained from the analysis in this section are contained in the following table:

TABLE I
Radiation Flux Densities Onto the Bead, Wire, and Film

$$\left[\frac{W}{m^2} \right]$$

	$I_1^{\alpha_S}$	$I_2^{\alpha_S}$	$I_3^{\alpha_S}$	$F_1^{\alpha_L}$	$F_2^{\alpha_L}$	$F_3^{\alpha_L}$	Total Radiation
Thermistor	55.7 ± 22.9	48.0 ± 29.7	1.8 ± 1.9	9.8 ± 1.9	2.6 ± 2.4	1.8 ± 1.1	119.7 ± 59.9
Wire	65.5 ± 29.8	67.0 ± 38.0	1.0 ± 1.0	9.8 ± 1.9	1.3 ± 1.2	$.2 \pm .2$	144.8 ± 72.1
Ag-My film	27.1 ± 11.8	15.0 ± 9.6	$.2 \pm .3$	49.7 ± 19.5	6.6 ± 5.3	$.9 \pm .8$	99.5 ± 47.3

The radiation input to a conductively isolated thermistor due to the above radiation sources is approximately

$$Q = 120 \pm 60 \text{ W/m}^2$$

Assuming the thermistor is a grey body of constant emissivity, ϵ_b , the long wave radiation emitted from a unit area of the thermistor is

$$\sigma \epsilon_b T_b^4$$

The total radiation input to the bead can now be written as

$$Q = \sigma \epsilon_b T_b^4 \quad (22)$$

Using the condition of radiative equilibrium, i.e., the radiation input to the thermistor is equal to the radiation emitted

$$Q = \sigma \epsilon_b T_b^4 ,$$

the thermistor temperature is computed.

$$T_b = \sqrt[4]{\frac{Q}{\sigma \epsilon_b}} = 378 \pm 50^\circ\text{K} \quad (23)$$

This temperature is only realized by a steady-state sensor at high altitudes where radiation is the only significant heat source.

3. Thermal Conduction

Heat transfer into the thermistor by thermal conduction from the wires and film will be discussed next. In general, the heat flux

through a plane surface is proportional to the cross sectional area, A , and the temperature gradient, $\partial T/\partial S$.

$$Q_c(S, t) = k A \frac{\partial T(S, t)}{\partial S} [W] \quad (24)$$

The thermal conduction coefficient, k , is assumed to be an absolute constant, i.e., it doesn't depend on time, t , or distance, S . The particular bead-wire-film system used in the ARCASONDE sensor is illustrated in Fig. 4.

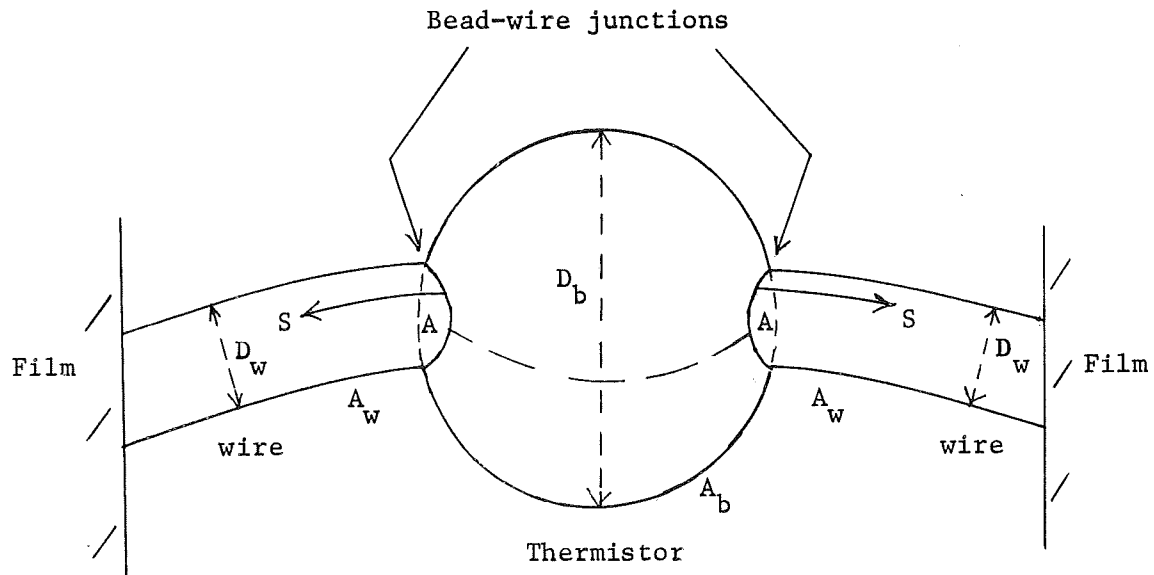


Fig. 4. Bead-wire-film system in the ARCASONDE sensor.

At the bead-wire junction, the net thermal flux has to vanish, since a planar surface has no heat capacity. Therefore, at the bead-wire junction, the heat flux out of the two wires is equal to the heat flux into the thermistor.

$$Q_c(\text{thermistor}) = 2 Q_c(\text{wire}) \quad (25)$$

Heat conducted into the thermistor and referred to the entire surface area, A_b , can be obtained from Eqs. 24 and 25.

$$\frac{Q_c(0, t)}{A_b} = \frac{k_w D_w^2}{2D_b^2} \frac{\partial T_w(0, t)}{\partial S} \quad (26)$$

In order to evaluate the wire temperature gradient at the junction (Eq. 26), the temperature distribution in the wire must be obtained. This can be done by considering the heat fluxes along the wire, which are

$$1. \text{ Convective heat transfer: } h_w(T_r - T_w) \quad (3)$$

$$2. \text{ Radiation: } Q_{rw} - \sigma \epsilon_w T_w^4 \quad (22)$$

$$3. \text{ Thermal conduction: } Q_{cw}(S, t) = k_w V_w/A_w \partial^2 T_w(S, t)/\partial S^2 \quad (27)$$

The temperature change in the wire can be related to the sum of the above heat fluxes by the first law of thermodynamics, yielding the following heat transfer equation for the wire.

$$\rho_w \frac{C_w V_w}{A_w} \frac{\partial T_w}{\partial t} = h_w \left(T_{air} + \frac{r_w V_w^2}{2C_p} - T_w \right) + Q_{rw} - \sigma \epsilon_w T_w^4 + k_w \frac{V_w}{A_w} \frac{\partial^2 T_w}{\partial S^2} \quad (28)$$

Equation 28 can be linearized by expanding the radiation term, $-\sigma\epsilon_w T_w^4$, in a Taylor's series about the average wire temperature, T_{aw} .

$$-\sigma\epsilon_w T_w^4 = 3\sigma\epsilon_w T_{aw}^4 - 4\sigma\epsilon_w T_{aw}^3 T_w \quad (29)$$

A solution to Eq. 28 can now be obtained by using the linearization (Eq. 24) and assuming

1. The wire temperature is steady state ($\partial T_w / \partial t = 0$)
2. The bead and film temperatures are used as boundary conditions
3. An exponential solution: $T_w(S) = A e^{-s\lambda_w} + B e^{s\lambda_w}$
 - a. λ_w^{-1} is the decay length of the wire temperature distribution.

The resulting solution, as obtained by Staffanson,¹⁷ is

$$\frac{\partial T_w(0)}{\partial S} = \lambda_w \left[\frac{T_f}{\sinh\left(\lambda_w \ell_w\right)} + T_{ew} \tanh\left(\frac{\lambda_w \ell_w}{2}\right) - T_b \coth\left(\lambda_w \ell_w\right) \right] \quad (30)$$

where

$$\lambda_w = \sqrt{\frac{h_w + 4\sigma\epsilon_w T_{aw}^3}{k_w v_w / A_w}} \quad (31)$$

and

$$T_{ew} = \frac{h_w T_r + Q_{rw} + 3\sigma\epsilon_w T_{aw}^4}{h_w + 4\sigma\epsilon_w T_{aw}^3} \quad (32)$$

T_{ew} = the steady-state temperature of a conductively isolated wire.
Thermal conduction into the thermistor can be written as a linear function of air temperature by using Eqs. 26 and 30.

$$\begin{aligned} \frac{Q_{cb}}{A_b} = & \frac{k D_w^2 \lambda_w}{2D_b^2} \coth(\lambda_w \ell_w) \left[\frac{h_w (1 - \operatorname{sech}(\lambda_w \ell_w))}{h_w + 4\sigma\epsilon_w T_{aw}^3} T_{air} \right. \\ & + (1 - \operatorname{sech}(\lambda_w \ell_w)) \left(h_w \frac{r_w V^2}{2C_p} + Q_{rw} + 3\sigma\epsilon_w T_{aw}^4 \right) / (h_w + 4\sigma\epsilon_w T_{aw}^3) \\ & \left. + T_f \operatorname{sech}(\lambda_w \ell_w) - T_b \right] \quad (33) \end{aligned}$$

This equation can be abbreviated as follows:

$$\frac{Q_c}{A_b} = HK (K_1 T_{air} + K_2 - T_b) \quad (34)$$

where

$$HK = \frac{k D_w^2}{2D_b^2} \lambda_w \coth(\lambda_w \ell_w) \quad (35)$$

$$K_1 = \frac{h_w (1 - \text{sech}(\lambda_w \ell_w))}{h_w + 4\sigma \epsilon_w T_{aw}^3} \quad (36)$$

$$K_2 = (1 - \text{sech}(\lambda_w \ell_w)) \left(h_w \frac{r_w V^2}{2C_p} + Q_{rw} + 3\sigma \epsilon_w T_{aw}^4 \right) / (h_w + 4\sigma \epsilon_w T_{aw}^3) \quad (37)$$

$$+ T_f \text{sech}(\lambda_w \ell_w)$$

All quantities in the thermal conduction Eq. 33 are known except the film temperature. This quantity will be evaluated next.

The film temperature can be obtained from the heat transfer Eq. 28 for the case of a film. It is necessary for computational purposes to approximate 28 as an ordinary differential equation by neglecting thermal conduction in the film. Mathematical simulation of the ARCAS 1A film mount in which the time dependent, two-dimensional temperature distribution is computed,¹⁶ demonstrates that the wire-film junction temperature, T_f , is independent of heat transfer with the wire, and the film temperature is essentially uniform within three decay lengths of the junction. Heat transfer in the film can now be written as the following ordinary differential equation

$$\rho_f \frac{C_f V_f}{A_f} \frac{dT_f}{dt} = h_f \left(T_{air} + \frac{r_f V^2}{2C_p} - T_f \right) + Q_{rf} - \sigma \epsilon_f T_f^4 \quad (38)$$

where T_f is a function of time. This equation can be approximated by the one-step finite difference equation

$$T_{fi+1} = T_{fi} + \frac{A_f \Delta t}{\rho_f C_f V_f} \left[h_{fi} \left(T_{air_i} + \frac{r_{fi} V^2}{2C_p} - T_{fi} \right) + Q_{rf} - \sigma \epsilon_f T_{fi}^4 \right] \quad (39)$$

for a time interval, Δt , of about 0.5 seconds. The air temperature, T_{air} , in this equation is initially set equal to the standard air temperature, and thereafter, T_{air} is set equal to the previously calculated air temperature.

After four film temperatures are calculated, the multistep Adams-Bashforth quadrature is used to complete the integration.

$$T_{fi+4} = T_{fi+3} + \frac{\Delta t}{24} \left[55 \frac{\partial T_{fi+3}}{\partial t} - 59 \frac{\partial T_{fi+2}}{\partial t} + 37 \frac{\partial T_{fi+1}}{\partial t} - 9 \frac{\partial T_{fi}}{\partial t} \right] \quad (40)$$

These integrated values of film temperature are now used in Eq. 33 to evaluate thermal conduction into the thermistor. Heat transfer by thermal conduction is one of the major sources of temperature error in the thermistor (Fig. 6e).

4. Time Constants and Decay Lengths of the Sensor

The purpose of this section is to obtain expressions for the time constant and decay length of the sensor components. These quanti-

ties have the following significance in relation to the sensor temperature.

1. The time constant, τ , is a measure of the response speed, in seconds, to a change in the sensor temperature.
2. The decay length, λ^{-1} , is a measure of distance along the sensor component through which heat transfer occurs by thermal conduction.

The expression for the time constant of the sensor can be obtained from the heat transfer equation for the thermistor bead as given in Eq. 50. An abbreviated form of this equation is

$$\tau \frac{\partial T_b}{\partial t} + T_b = T_{eb} \quad (41)$$

where the time constant is

$$\tau = \frac{\rho_b C_b V_b / A_b}{h_b + 4\sigma\epsilon_b T_{ab}^3 + HK} \quad (42)$$

and the steady-state temperature is

$$T_{eb} = \frac{h_b \left(T_{air} + \frac{r_b V^2}{2C_p} \right) + Q_{rb} + 3\sigma\epsilon_b T_{ab}^4 + W/A_b}{h_b + 4\sigma\epsilon_b T_{ab}^3 + HK} \quad (43)$$

Time constants for the wire, film, and isolated bead can also be obtained from Eq. 42 with the exception that HK is equal to zero. In

order to determine the effect of the time constant, τ , on the sensor temperature, a solution of Eq. 41 for T_b is obtained by assuming

1. the time constant and steady-state temperature are approximately constant in time,
2. an assumed solution is $T_b = Be^{-t/\tau} + T_{eb}$ where B is determined from the initial sensor temperature, T_{ob} .

Based on these assumptions, the time dependent solution of the sensor temperature is

$$T_b = T_{eb} + (T_{ob} - T_{eb}) e^{-t/\tau} \quad (44)$$

Thus, the time required for the sensor to obtain 95 percent of the steady-state temperature, T_{eb} , is about three time constants. During this time, the sonde has fallen through a vertical distance

$$\Delta Z = 3\tau \cdot \frac{dz}{dt} \quad (45)$$

which is the altitude resolution in measuring air temperature due to dynamic lag of the sensor temperature. If no corrections are made for dynamic lag of the sensor temperature, this altitude resolution would correspond to an error in the sensor temperature. Time constants of the bead, wire, film, and sensor, and altitude resolution are contained in the following table.

TABLE II

Time Constants and Altitude Resolution of the Sensor

Altitude (km)	Fall Speed (m/sec)	τ_b (sec)	τ_w (sec)	τ_f (sec)	τ_{sensor} (sec)	Altitude Resolution(m)
50	136.0	1.55	.02	1.89	.77	313.5
45	95.4	1.07	.01	1.84	.56	160.2
40	66.0	.79	.006	1.71	.41	81.3
35	40.2	.65	.003	1.72	.32	38.7
30	26.8	.55	.002	1.67	.27	21.6
25	16.8	.48	.001	1.51	.23	11.7

The decay length of the sensor component can be obtained from the steady-state heat transfer Eq. 28. An abbreviated form of this equation is

$$\frac{\partial^2 T}{\partial S^2} = \lambda^2 (T - T_e) \quad (46)$$

where the decay length

$$\lambda^{-1} = \sqrt{\frac{kV/A}{h + 4\sigma\epsilon T_a^3}} \quad (47)$$

and the equilibrium temperature

$$T_e = \frac{h \left(T_{\text{air}} + \frac{rV^2}{2C_p} \right) + Q_r + 3\sigma\epsilon T_a^4}{h + 4\sigma\epsilon T_a^3} \quad (48)$$

In order to determine the effect of the decay length on the temperature of the sensor component, a solution of Eq. 46 is obtained by assuming

1. the decay length and equilibrium temperature are approximately constant in S
2. a solution is $T(S) = Be^{-S\lambda} + T_e$ where B is determined from the boundary condition.

Based on these assumptions, the distribution of the sensor temperature is

$$T(S) = T_e + (T_o - T_e)e^{-S\lambda} \quad (49)$$

where T_o = the sensor temperature at $S = 0$. The decay length, λ^{-1} , is a measure of the effective conduction length of the sensor component, in particular, a point ten decay lengths or greater away from a source is insulated from that source. Therefore, if both the thermistor and film are separated by ten lengths of wire, the thermistor is assumed to be insulated from the film. Film properties within about three decay lengths of the wire-film junction, except for strong sources, essentially determine the temperature of the junction. Thus, the convection coefficient, h, based on three decay lengths of film represents the

the effective h for the wire-film junction near the leading edge of the film.

Based on rocketsonde data, the thermistor remains decreasingly influenced by the film down to 25 kilometers, but becomes strongly dependent on the film above 45 kilometers. A list of decay lengths for the wire and film along with the wire length in terms of its decay lengths is given in the following table.

TABLE III

Decay Lengths of the Wire and Film (mm)

Altitude (km)	λ^{-1}		ℓ_w/λ^{-1} Wire
	Wire	Film	
50	1.4	9.3	2.3
45	1.1	8.3	2.9
40	.8	8.1	4.0
35	.6	8.0	5.3
30	.5	7.8	6.4
25	.4	7.5	8.0

Above 25 kilometers, the thermistor and film are well within three decay lengths of the wire. Above 45 kilometers, the decay length of the wire temperature is less than the characteristic length of the wire, which implies very strong thermal conduction between the thermistor and film.

III. RESULTS OF ROCKETSONDE MEASUREMENTS

1. Air Temperature

The major objective of this chapter is to present results of applying the program to obtain the air temperature from the sensor temperature. The temperature of the sensor is determined from the following heat sources into the thermistor:

1. Thermal conduction $HK(T_k - T_b)$ where $T_k \equiv$ conduction temperature of the atmosphere.
2. Convection heat exchange $h_b(T_r - T_b)$ where $T_r =$ recovery temperature.
3. Radiation heating $Q_{rb} - \sigma \epsilon_b T_b^4$, $Q_{rb} =$ radiation input to the thermistor.
4. Electric heating $= W/A_b$ which is assumed to be equal to about 20 W/m^2 .

Relating the change in thermistor temperature to the sum of the above heat sources yields the following heat transfer equation:

$$\frac{(\rho C v)_b}{A_b} \frac{\partial T_b}{\partial t} = h_b(T_r - T_b) + HK(T_k - T_b) + Q_{rb} - \sigma \epsilon_b T_b^4 + \frac{W}{A_b} \left[\text{W/m}^2 \right] \quad (50)$$

The solution of Eq. 50 for air temperature can be written as a sum of the sensor temperature plus terms corresponding to heat sources to the thermistor bead.

$$T_{\text{air}} = T_b$$

sensor temperature

$$+ \left(HK(1 - K_1)T_b - K_2 \right) / (h_b + HK \cdot K_1) \quad \text{conduction temperature correction}$$

$$- \frac{h_b r_b V^2}{2C_p} / (h_b + HK \cdot K_1) \quad \text{aerodynamic temperature correction}$$

(51)

$$+ \frac{(\rho C_v)_b}{A_b} \frac{\partial T_b}{\partial t} / (h_b + HK \cdot K_1) \quad \text{dynamic lag temperature correction}$$

$$+ \left(\sigma \epsilon_b T_b^4 - Q_{rb} \right) / (h_b + HK \cdot K_1) \quad \text{radiation temperature correction}$$

$$- \frac{W}{A_b} / (h_b + HK \cdot K_1) \quad \text{electric temperature correction}$$

Although these terms are so named, each is influenced by all the heat sources. A graph of the air temperature as a function of altitude along with the sensor and standard air temperature is contained in Fig. 5. The air temperature, as contained in Fig. 5, deviates by more than one degree Kelvin from the sensor temperature above 40 kilometers. Note also that the external heat sources (discussed previously in this paper) have increased the sensor temperature beyond that of the air and standard temperatures. Thus, the sensor temperature must be corrected for these heat sources in order to yield the correct air temperature. Small fluctuations of the calculated air temperature below 30

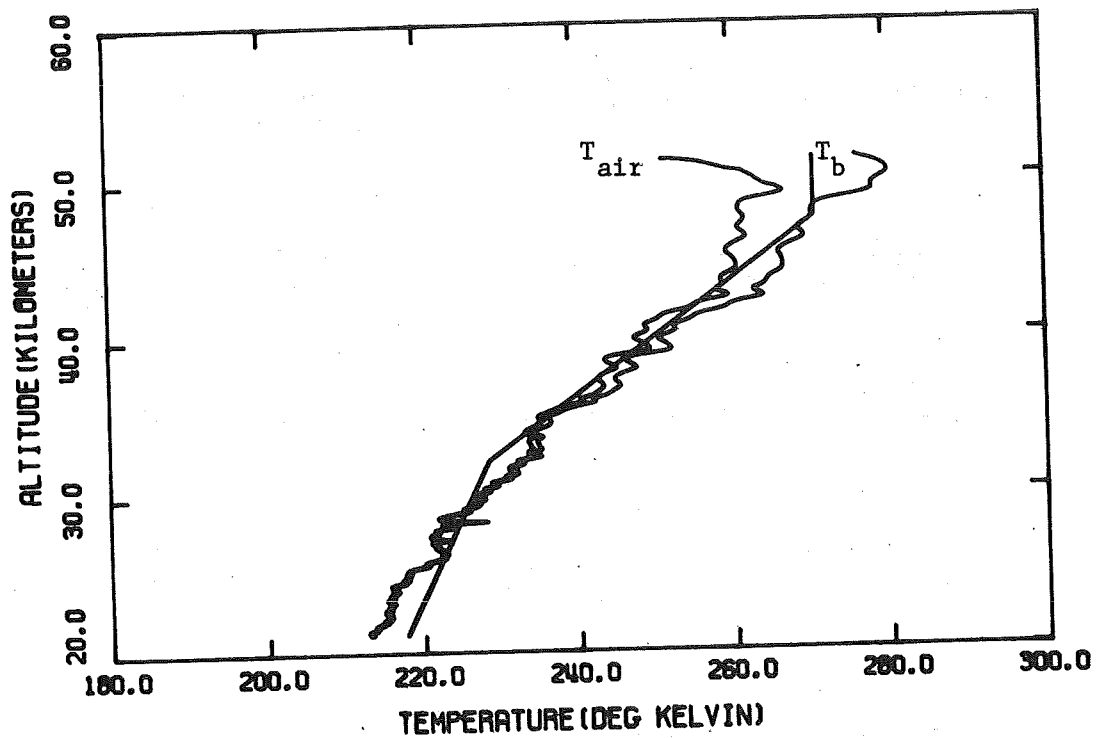
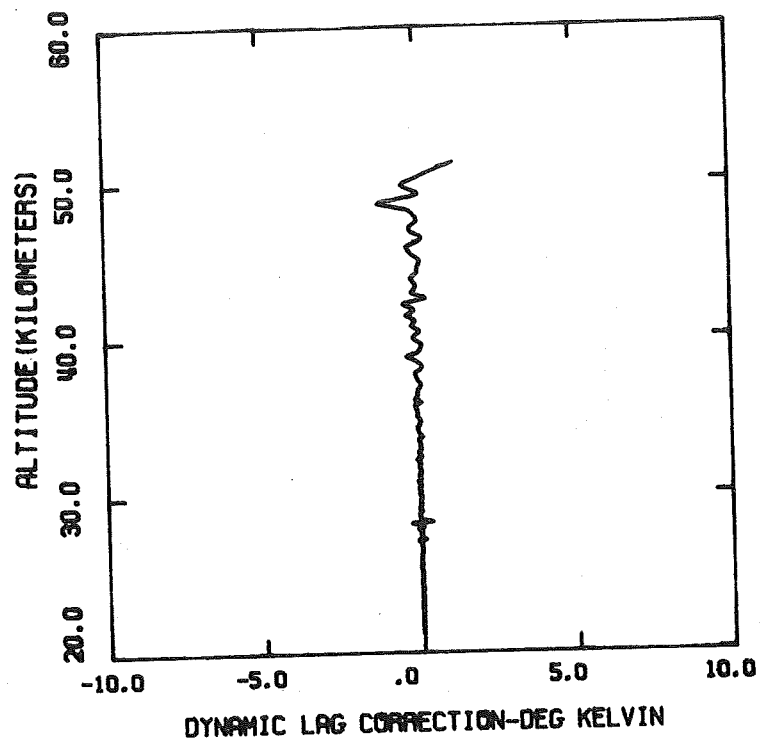
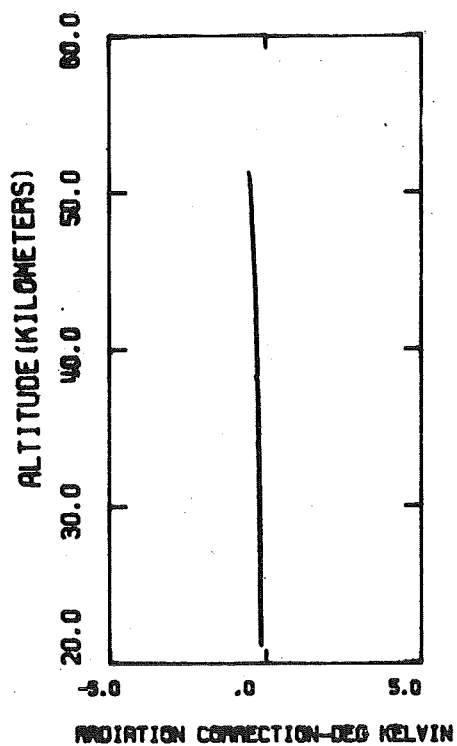


Fig. 5. Standard, sensor, and air temperature profiles.

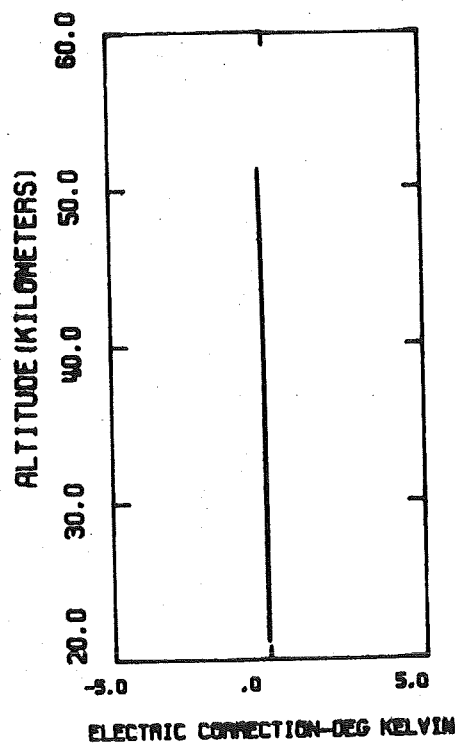
kilometers, where temperature corrections are negligible, must be the result of the atmosphere if telemetry errors have been corrected. Thus, the detailed air temperature fluctuations above 30 kilometers, where sensor temperature corrections are larger, must also be due to the atmosphere. The air temperature lapse rate below 50 kilometers is less than about 8°K/km .



(a)

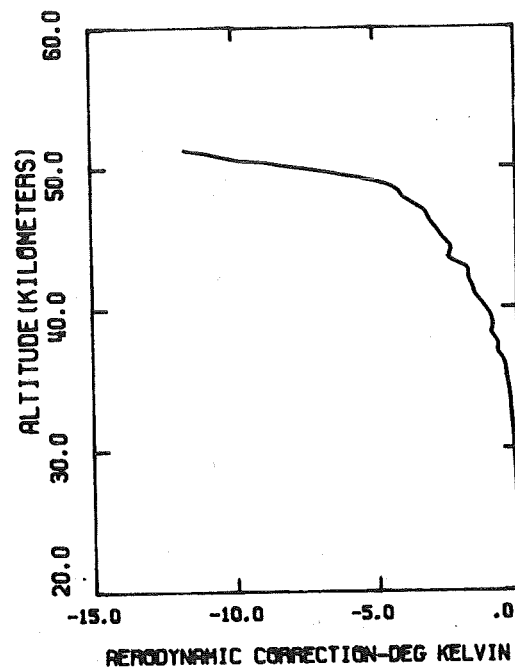


(b)

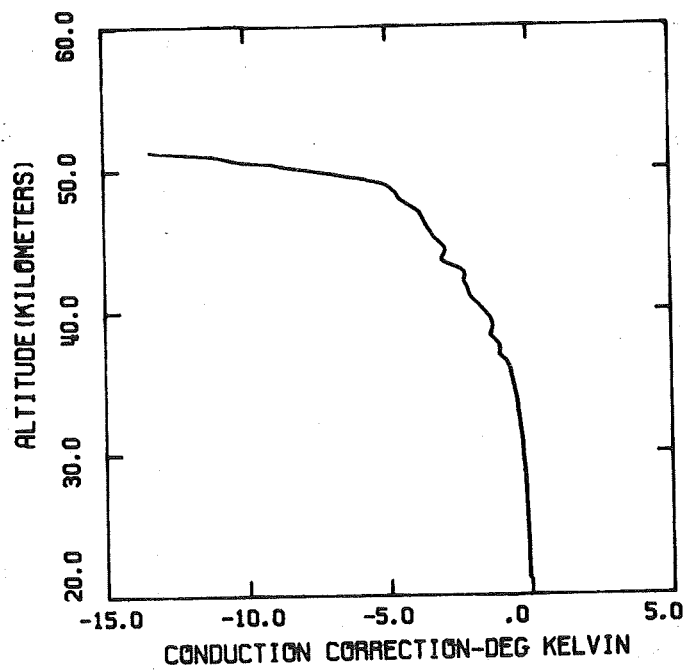


(c)

Fig. 6. Temperature corrections.



(d)



(e)

Fig. 6 (continued). Temperature corrections.

Graphs of the sensor temperature corrections as a function of altitude are contained in Figs. 6a to 6e. As shown in Figs. 6a to 6e, the temperature corrections due to radiation and electrical heating are negligible at altitudes below 50 kilometers. The temperature errors due to thermal conduction and aerodynamic heating are significantly large above 30 kilometers. For example, at 50 kilometers, these heat sources result in an increase in the sensor temperature of about 20°K. Note also that both of these curves have the same shape as the fall speed of the rocketsonde. Thus, a decrease in the air speed of the rocketsonde (particularly at high altitudes) by using a disk-gap-band parachute (as compared to a hemispherical parachute) would reduce errors due to thermal conduction and aerodynamic heating.

2. Horizontal Winds

The horizontal winds for a rocketsonde flight can be obtained from radar data and the equation of motion for the rocketsonde-parachute system. The forces acting on the falling system are assumed to be gravity and drag. The resultant force yields the following acceleration:

$$\frac{d^2\vec{r}}{dt^2} = -g(z)\vec{k} + \vec{DF} \left[\text{m/sec}^2 \right] \quad (52)$$

Gravity can be expressed as a function of altitude by the formula

$$g(z) = g(o) \left[1 - \frac{2z}{R_e} + \frac{3z^2}{R_e^2} \right] \quad (53)$$

where R_e is the mean radius of the earth. The drag force per unit mass obtained from dimensional analysis is

$$\vec{DF} = \frac{\rho v}{2m} C_D A |\vec{V}_R| \vec{V}_R \quad (54)$$

where

C_D = nondimensional drag coefficient

A = parachute

V_R = air speed of the sonde

The position of the sonde with respect to the ground station is shown in the following figure.

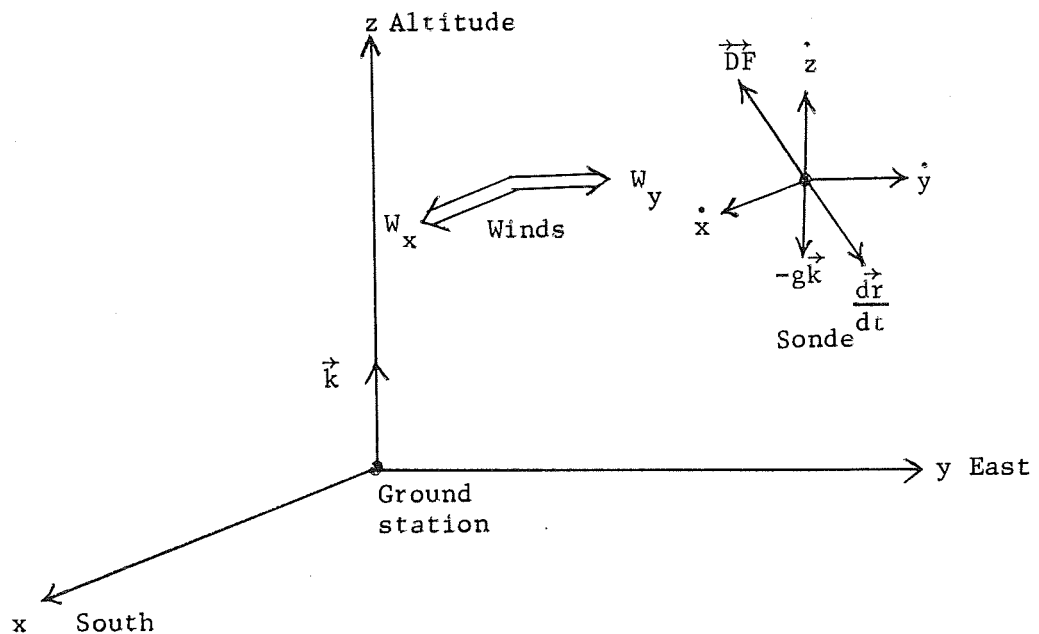


Fig. 7. Forces acting on a descending rocketsonde.

Neglecting earth rotation, the equation of motion for the sonde-parachute system can be written as

$$\text{East component:} \quad d^2y/dt^2 = +K \left(\frac{dy}{dt} - W_y \right) \quad (55.a)$$

$$\text{South component:} \quad d^2x/dt^2 = +K \left(\frac{dx}{dt} - W_x \right) \quad (55.b)$$

$$\text{Vertical component:} \quad d^2z/dt^2 = -g + K \left(\frac{dz}{dt} - W_z \right) \quad (55.c)$$

where K is defined as $\frac{\rho V}{2m} C_D A |V_R|$. These three equations can be solved for the horizontal winds (W_x , W_y), and K , assuming the vertical wind, W_z , is zero.

$$K = + \left(d^2z/dt^2 + g \right) / dz/dt \quad (56.a)$$

$$W_x = - \left(d^2x/dt^2 \right) / K + dx/dt \quad (56.b)$$

$$W_y = - \left(d^2y/dt^2 \right) / K + dy/dt \quad (56.c)$$

Values of the first and second derivatives of position with respect to time can be evaluated and are obtained from the subroutine DIRSIT using radar data. Substituting Eq. 56 into the equation for air speed yields

$$|V_R| = \sqrt{\left(\frac{dx}{dt} - w_x\right)^2 + \left(\frac{dy}{dt} - w_y\right)^2 + \left(\frac{dz}{dt}\right)^2} \quad (57)$$

and the total drag force on the parachute

$$DF = K|V_R| \quad (58)$$

A graph of the horizontal winds as a function of altitude is contained in Fig. 8.

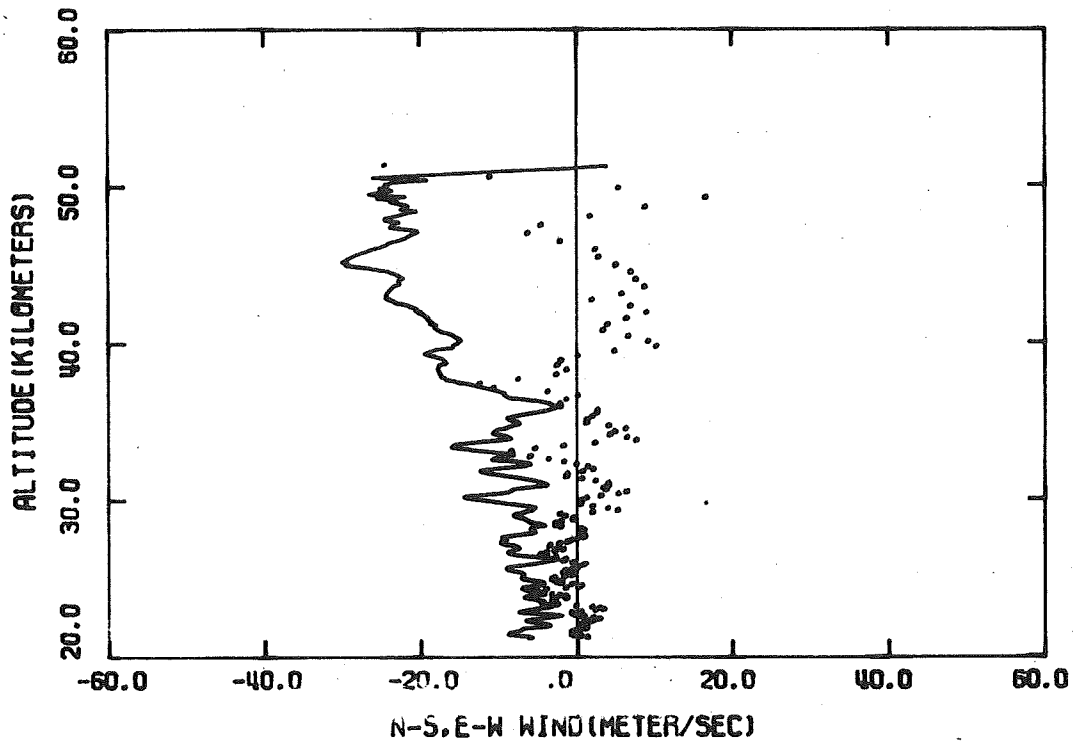


Fig. 8. Horizontal winds.

As seen from Fig. 8, the solid curve representing the eastward zonal wind is much larger than the meridional south wind. A maximum wind speed of about 30 m/s occurs in the region of 45 kilometers, suggesting the existence of a stratopause jet stream at this altitude.¹¹ Since the wind is approximately geostrophic at rocketsonde altitudes, the horizontal pressure gradient, ∇_{HP} , can be determined from the geostrophic wind equation¹⁰

$$W \approx \frac{1}{(2\Omega \cos \zeta) \rho} \nabla_{HP} \quad (59)$$

As an example, at 45 kilometers and 40 degrees latitude

$$\rho(\text{air}) \approx .2 \cdot 10^{-2} \text{ kg/m}^3$$

$$W(\text{horizontal wind}) \approx 30 \text{ m/sec}$$

$$2\Omega \cos \zeta \approx .5 \cdot 10^{-4} \text{ rad/s}$$

Thus, the geostrophic approximation of the horizontal pressure gradient at 45 kilometers is

$$\nabla_{HP} \approx 3 \cdot 10^{-6} \text{ N/m}^3$$

3. Pressure and Density Calculations

Atmospheric pressure and density can be calculated as a function of altitude from the air temperature profile, as contained in Eq. 51, and a reference value obtained from radiosonde data. Pressure at an altitude Z_{i+1} is obtained by using the hydrostatic equation and the ideal gas law and integrating over an altitude interval from Z_i to Z_{i+1} .

$$p_{i+1} = p_i \text{ EXP } \left\{ - \frac{1}{R_D} \int_{Z_i}^{Z_{i+1}} \frac{g(z)}{T_{\text{air}}} dz \right\} \left[\frac{N}{m^2} \right] \quad (60)$$

where

$$R_D = \text{gas constant for dry air } \left[\frac{\text{J}}{\text{kg}^\circ\text{K}} \right]$$

The first pressure in this integration is obtained by linearly interpolating into the radiosonde data at the lowest rocketsonde altitude, since radiosonde data is more reliable at the lower altitudes. Additional pressures are obtained from the following numerical scheme:

1. Two Lagrange polynomials are fitted to the function g/T_{air} (using rocketsonde data) at the altitudes Z_{i-1} , Z_i , Z_{i+1} and Z_i , Z_{i+1} , Z_{i+2} .
 - a. The coefficients of these polynomials are a_i , b_i , c_i .
2. These two polynomials are averaged together and integrated upward between the altitudes Z_i and Z_{i+1} yielding the following pressure, p_{i+1} :

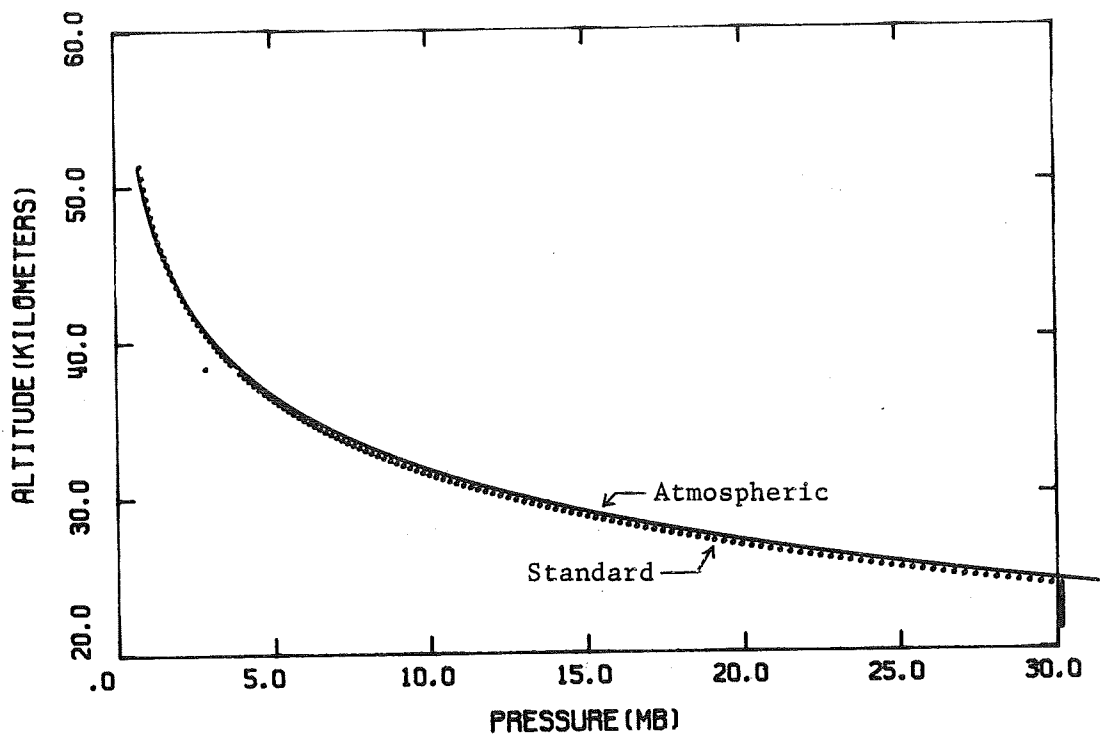


Fig. 9. Atmospheric and standard pressure profile.

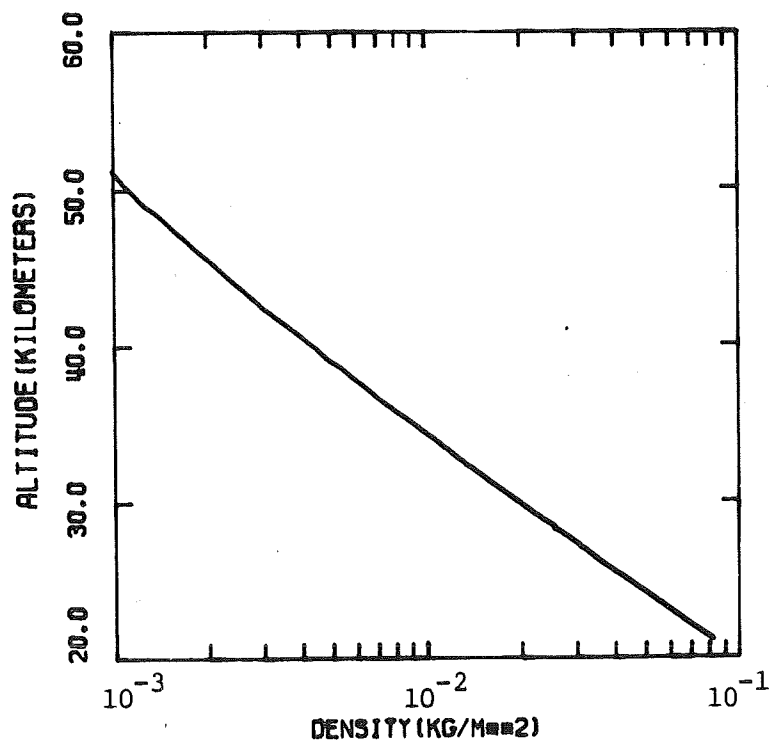


Fig. 10. Atmospheric density.

$$\begin{aligned}
 p_{i+1} = p_i \text{ EXP} & \left[- \frac{1}{R_D} \left\{ \frac{a_i + a_{i+1}}{2} \cdot \frac{z_{i+1}^3 - z_i^3}{3} \right. \right. \\
 & \left. \left. + \frac{b_i + b_{i+1}}{2} \cdot \frac{z_{i+1}^2 - z_i^2}{2} + \frac{c_i + c_{i+1}}{2} \cdot (z_{i+1} - z_i) \right\} \right]
 \end{aligned}
 \tag{61}$$

The air density can be obtained from the pressure (Eq. 61) and air temperature as follows:

$$\rho_i = \frac{p_i}{R_D T_{\text{air}_i}}
 \tag{62}$$

Figures 9 and 10 illustrate the results of calculating the air pressure and density based on atmospheric temperature. Note that the computed values of the atmospheric pressure and density are greater than the standard atmosphere values as given in the U.S. Standard Atmosphere Tables, 1962²⁴ and Fig. 8. Knowing the temperature, pressure, and density of the air, one can compute the following atmospheric parameters:

1. thermal conductivity J/(ms°K)
2. viscosity m²/s
3. mean free path m
4. speed of sound m/s

Formulas for the above quantities are contained in the U.S. Standard Atmosphere, 1962.²⁴

$$k = \frac{6.325 \cdot 10^{-7} T_{\text{air}}^{3/2}}{\left(T_{\text{air}} + 245.4 \cdot 10^{-12/T_{\text{air}}}\right) 4186.0465} \quad (63)$$

$$\mu = \frac{1.458 \cdot 10^{-6} T_{\text{air}}^{3/2}}{T_{\text{air}} + 110.4} \quad (64)$$

$$L = \frac{R_D T_{\text{air}} \cdot 10^{+3}}{\sqrt{2} \pi 6.02257 \cdot 10^{26} \left(3.65 \cdot 10^{-10}\right)^2 p} \quad (65)$$

$$C_S = \sqrt{1.4 R_D T_{\text{air}}} \quad (66)$$

These parameters can be used to calculate the convection coefficients and recovery factors of the bead-wire-film temperature sensor. Computational results for the mean free path and speed of sound are contained in Table IV.

4. Conclusions and Summary

The complete problem of obtaining temperature, pressure, and density of the atmosphere and horizontal winds from a rocketsonde flight is described in the flow chart of Fig. 11. The subject of this paper has been concerned only with describing the mathematical model for the data reduction problem enclosed by the dashed line. The most important assumptions which have been made to obtain this mathematical model are the following:

1. The bead, wire, and film are the components of the ARCASONDE temperature sensor.
2. There is no thermal conduction in the film.
3. Heat flux from the wires does not effect the film temperature distribution.
4. The temperature of the wire-film junction is equal to the uniform film temperature distribution.
5. The wire responds instantaneously to temperature changes.
6. Temperature errors in the thermistor are due to
 - a. thermal conduction
 - b. aerodynamic heating
 - c. dynamic lag
 - d. electric and radio frequency heating
 - e. radiation.
7. Nominal values for the physical sensor parameters can be obtained from references (Appendix C).
8. The ideal gas law and the hydrostatic equation are valid.

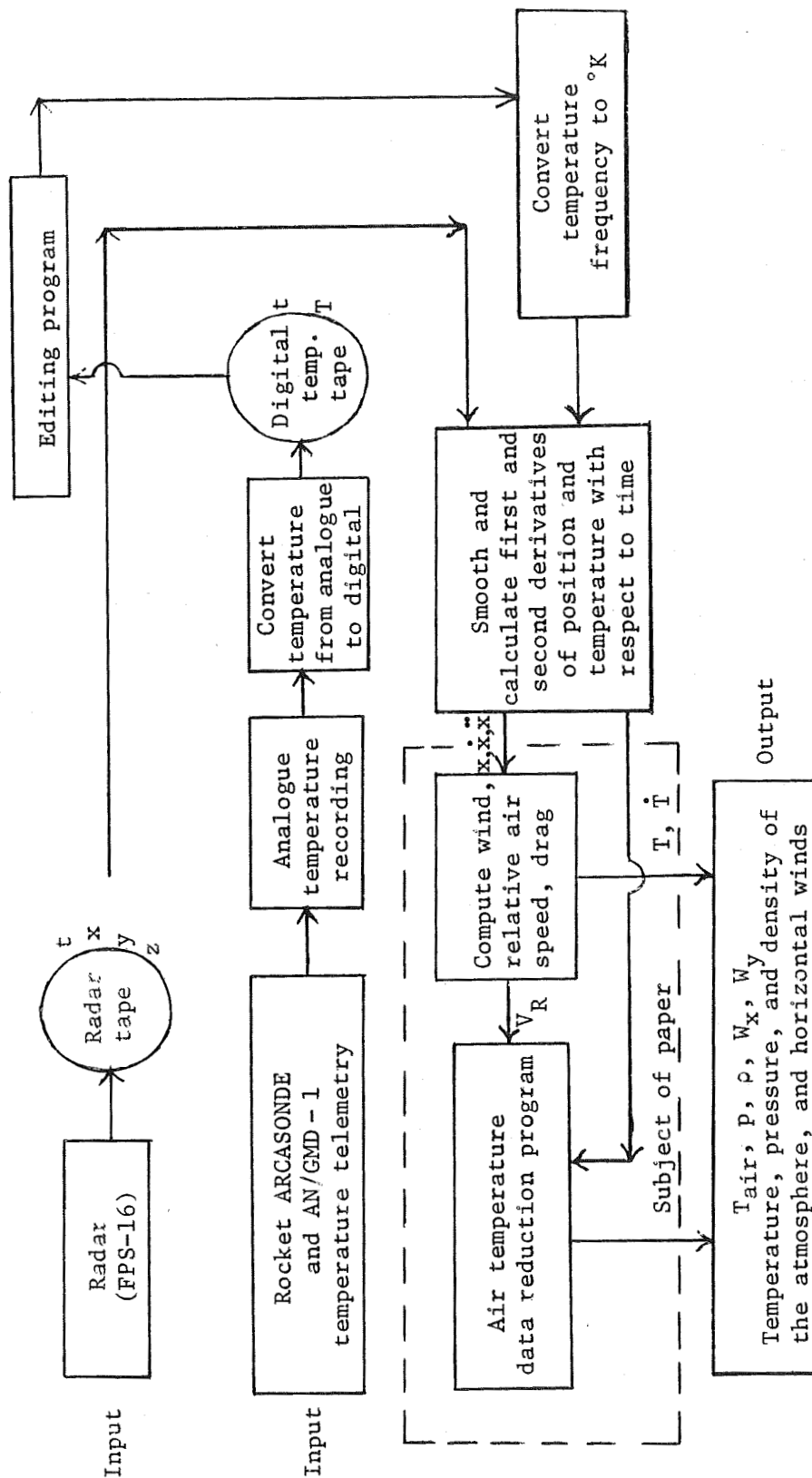


Fig. 11. System flow chart for rocketsonde measurements.

The results of the formulas developed in this chapter for calculating atmospheric parameters are listed in Table IV at 1000 meter intervals. In addition, radiosonde information from the Meteorological Rocket Network publication is included for comparison with the overlapping rocketsonde data. The following comparisons can be made between the radiosonde and rocketsonde data (in the overlapping region):

1. Air pressure is essentially the same in both cases.
2. The radiosonde temperature is higher than the rocketsonde temperature.
3. The wind in both cases follow the same pattern. The variance may be due to an averaging process applied to the radiosonde data which was not applied to rocketsonde data.

Note that the difference between the calculated air and the rocketsonde temperatures are large at high altitudes where the air speed is high. In addition, the mean free path of the atmosphere, L , is larger than the characteristic length of the wire above 42 kilometers, while this is never true for the thermistor and film.

A flow chart of the air temperature data reduction program, which has been the major emphasis of this paper, is illustrated in Fig. 12. Note that the quantities which directly determine the sensor temperature corrections are

1. the convection coefficient and recovery factor of the thermistor: h_b, r_b
2. thermal conduction parameters: HK, K_1, K_2
3. radiation and electric heating of the thermistor: W, Q_{rb}

TABLE IV
ROCKETSONDE AND RADIOSONDE DATA

Rocketsonde data							Radiosonde data							
dz/dt m/s	Z kilo- meter	W _x m/s	W _y m/s	P mb	$\rho \cdot 10^{-2}$ kg/m ³	C _S m/s	L · 10 ⁻⁴ m	T _b °K	T _{air} °K	Z km	T _{air} °K	W _x m/s	W _y m/s	P mb
-152.0	51	-20.93	4.67	.74	.101	320.8	.80	277.7	255.2					
-136.0	50	1.03	-24.96	.84	.112	325.1	.72	280.0	262.8					
-118.06	49	11.63	-23.72	.96	.125	327.2	.64	277.8	266.5					
-114.10	48	1.25	-23.50	1.08	.145	323.8	.56	270.6	260.9					
-105.23	47	-6.27	-20.21	1.23	.164	324.0	.49	269.5	261.3					
-100.62	46	1.47	-25.81	1.41	.187	324.2	.43	269.1	261.6					
-95.31	45	4.20	-29.19	1.60	.214	323.0	.38	266.1	259.6					
-91.27	44	7.15	-22.65	1.82	.243	323.4	.33	266.4	260.2					
-83.08	43	4.00	-24.31	2.07	.279	322.3	.29	263.7	258.5					
-78.89	42	8.17	-19.84	2.37	.322	320.4	.25	260.4	255.5					
-75.20	41	3.01	-18.10	2.70	.376	317.1	.22	254.6	250.3					
-65.68	40	9.09	-15.19	3.09	.434	315.7	.19	251.3	247.9					
-58.96	39	-1.15	-17.21	3.53	.494	316.3	.16	251.8	249.0					
-58.53	38	-2.64	-17.37	4.06	.578	313.8	.14	247.6	245.1					
-53.65	37	-9.81	-10.71	4.65	.667	312.6	.12	245.2	243.1					
-43.43	36	-2.84	-2.87	5.36	.777	310.8	.10	242.0	240.4					
-40.14	35	.66	-7.85	6.18	.915	307.6	.089	236.9	235.4					
-36.38	34	5.11	-8.80	7.13	1.065	306.2	.076	234.6	233.4					
-34.25	33	-9.45	-9.93	8.25	1.229	306.6	.066	235.1	234.0					
-31.49	32	1.44	-10.03	9.51	1.428	305.5	.057	233.1	232.2	32	234.6	1.	-9.	9.5
-28.43	31	3.56	-4.08	10.99	1.661	304.4	.049	231.4	230.6					
-26.80	30	.45	-12.97	12.76	1.958	302.0	.041	227.8	227.0	30	231.0	1.	-7.	12.7
-24.07	29	-2.63	-8.16	14.83	2.294	300.8	.035	225.8	225.1					
-21.80	28	.39	-5.35	17.23	2.695	299.3	.030	223.4	222.9	28	227.1	0.	-6.	17.0
-20.47	27	-4.16	-7.85	20.03	3.150	298.3	.026	222.1	221.5					
-19.17	26	-1.61	-4.45	23.37	3.662	298.9	.022	222.8	222.3	26	223.1	-1.	-9.	23.0
-16.76	25	-3.17	-7.07	27.23	4.355	295.9	.019	218.4	217.9					
-15.41	24	-4.61	-4.10	31.86	5.142	294.5	.016	216.3	215.9	24	219.2	-2.	-6.	31.2
-13.95	23	2.76	-5.64	37.26	6.025	294.2	.013	215.8	215.4					
-13.51	22	.21	-3.57	43.63	7.075	293.8	.011	215.2	214.8	22	216.7	-1.	-3.	42.5
										20	215.2	0.	2.	58.0

4. physical parameters of the thermistor (Appendix C)
5. sensor temperature and its first derivative with respect to time: T_b , dT_b/dt
6. the relative air speed of the rocketsonde: V_R

Properties of the wire and film are used to compute the thermal conduction parameters which directly influence the sensor temperature corrections. The characteristic length of the film, CLF, is computed to be within 10^{-3} meters of three decay lengths of the film.

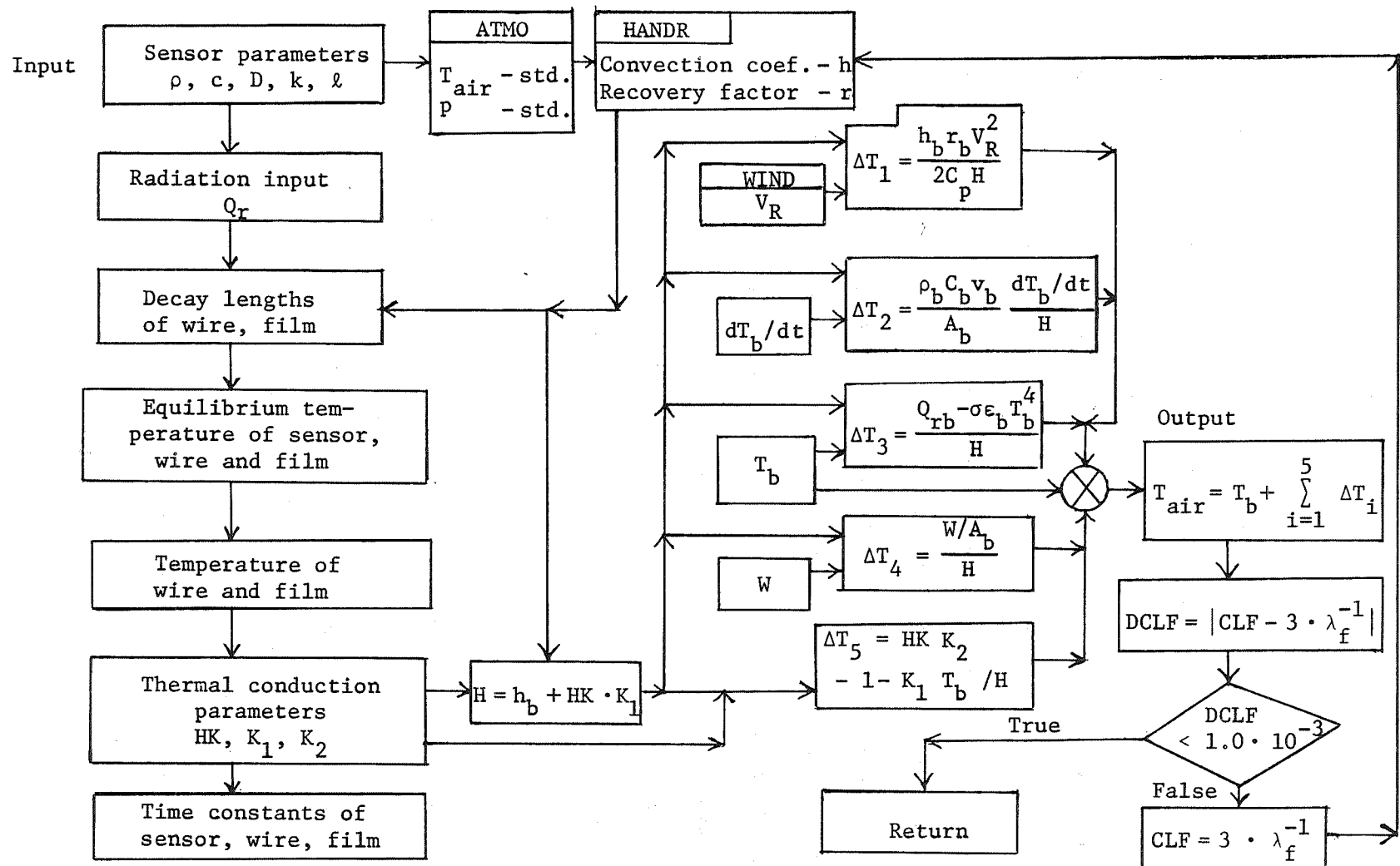


Fig. 12. Air temperature reduction flow chart.

APPENDIX A

COMPUTER PROGRAM

A computer program written in FORTRAN IV has been designed for the UNIVAC 1108 to compute temperature, density, and pressure of the atmosphere and horizontal winds from the ARCASONDE temperature sensor and its radar track. This program uses digital radar and temperature tapes from rocketsonde measurements as input. Initially, records of the radar and temperature tape are skipped in order to establish an approximate coinciding point in time for both sonde position and sensor temperature. Then, all the reference frequency and a beginning portion of the frequency data for the sensor are read. A least squares fit is applied to the reference frequency. One record of radar tape is read and groups of five points are averaged together. The third point is taken as the time for the averaged group. If the radar time is out of range of the temperature data, another record of the temperature tape is read. This time is linearly interpolated into the frequency data. The resulting frequency value is divided by the corresponding reference frequency to obtain the frequency ratio of the rocketsonde. The frequency ratio is then linearly interpolated into the calibration curve to obtain sensor temperature in degrees Kelvin.

At this point, the program is ready to accept time, sensor temperature, and radar data to compute air temperature, pressure, density, and horizontal winds. The complete data reduction program consists of twelve subroutines. The main data correction subroutine, FSCINV, applies

corrections to the sensor temperature to obtain air temperature. A statement description of the asterisked subroutines is included in this appendix. The other subroutines, such as HANDR, will be included in future reports. The amount of core storage, in octal notation, is also estimated for each subroutine.

<u>Subroutine</u>	<u>Core Storage Length (octal)</u>
* MAIN	12244
* DRIVER	47013
* GRAF	1005
ATAIAT	711
* RATIO	2114
* ATMO	1375
* FSCINV	2262
* WIND	304
INITAL	1012
DIRSIT	2205
HANDR	2172
* INTEG	431
Total	77537

The purpose of each subroutine and its relationship to the other subroutines is illustrated by the flow chart in Fig. 13.

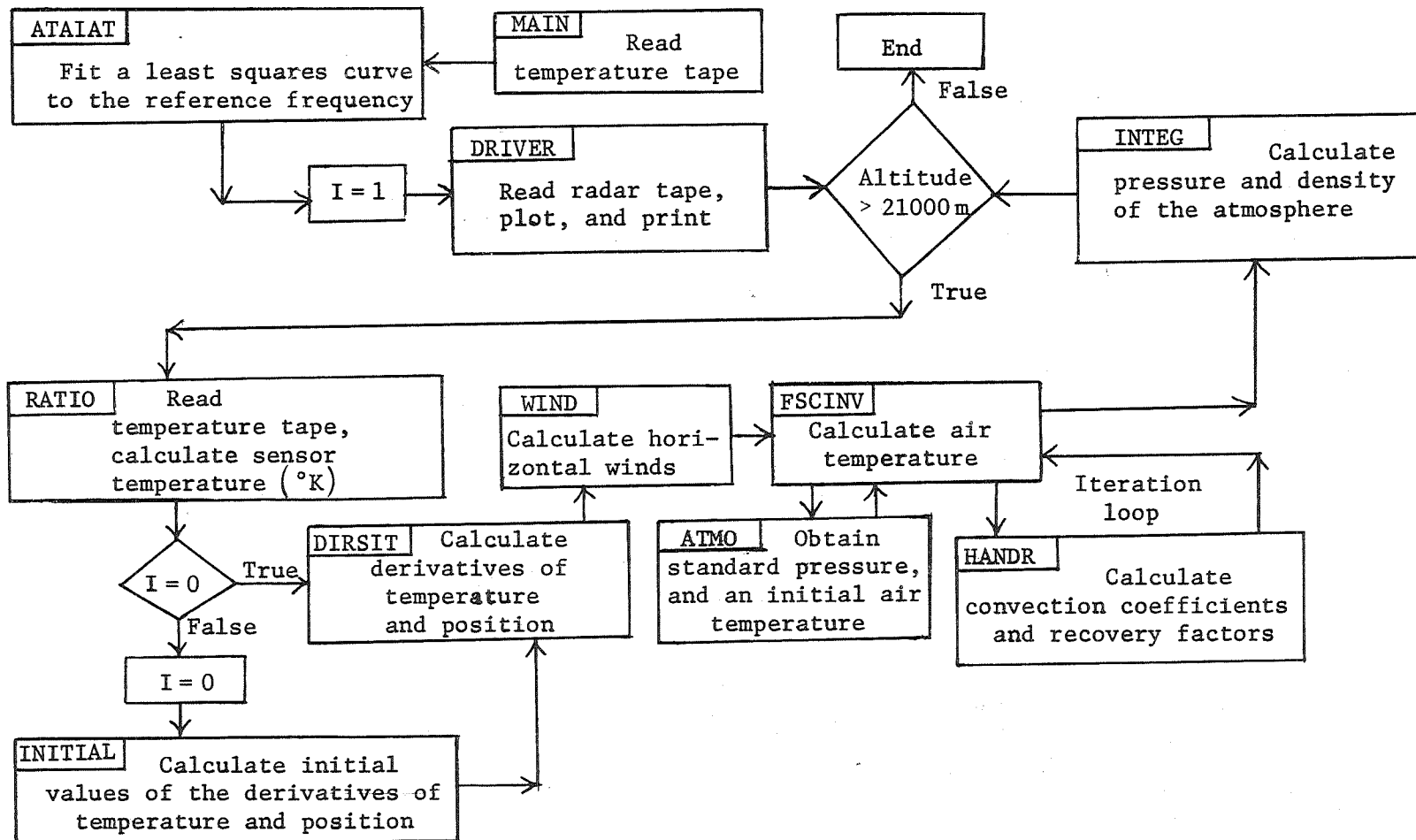


Fig. 13. Flow chart of the computer program.

MAIN PROGRAM

The main program reads in all of the reference temperature and a beginning portion of the sensor temperature.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
1	S	Storage array for one record of temperature tape.
2	WA, WP	Radiosonde altitude and pressure.
3	Y, X	Sensor temperature and time.
4	YL, XL	Reference temperature and time.
7	FRT, TMP	Calibration frequency ratio and sensor temperature (°C).
	FMRK1, FMRK2	Minimum and maximum calibration frequency ratio.
8	BS, CS	Coefficients of the linear equation for standard temperature.
	PO, AS	Standard pressure versus altitude.
9	XLAT, XLONG	Latitude and longitude of the station.

<u>Statement</u>	<u>Description</u>
11	Skip two records or 72 seconds of temperature tape.
12	Skip 15 records or 240 seconds of radar tape.
14-21	Read on punched cards: a. standard atmospheric pressure b. calibration curve c. standard temperature coefficients d. latitude and longitude e. radiosonde pressure

<u>Statement</u>	<u>Description</u>
36	Read in one record of temperature tape.
38	If the frequency is less than 10.0 ignore.
39	If IR = 0, store time in QZ.
40	If the frequency is greater than 165.0, go to statement 45.
41	Subtract 12 seconds from the time and store in X.
42	Store sensor frequency in Y.
43	II = number of sensor frequencies.
47	Store the sum of reference frequencies in SUM.
48	If the time increment is greater than 0.5 seconds, continue.
49	If there are less than 40 reference frequencies, ignore.
50	NP = number of reference frequencies.
53	YL = average reference frequency.
54	XL = average of the first and last reference time.
63	Print out reference frequency and time.
65	Call ATAIAT to fit a least squares curve to the reference frequency.
66	Call DRIVER subroutine.
70	END

DRIVER SUBROUTINE

The DRIVER subroutine handles the mechanics of data reduction in the following order:

- a. sensor parameters and radiation inputs are read in

- b. the radar tape is read
- c. five positions from the radar tape are averaged together
- d. the data reductions subroutines are called
- e. variables are stored and plotted in blocks of 500 words.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
2	Z	Storage array for one record of radar tape.
3-6	HEAD1-HEAD18	Storage arrays for plotting annotation.
7-8		Storage arrays for plotting.
9	Z1, Z2	Pressure and density of the atmosphere.
11	P	Standard air pressure.
12	STAIR	Standard air temperature.
13	T	Time - s.
	X	Position - m.
	XBAR	Average position - m.
	XDOT	First derivative of position - m/s.
	XDDOT	Second derivative of position - m/s ² .
14		Indexes used in DIRSIT.
15	TEMT	Sensor temperature - °K.
	TEDOT	First derivative of sensor temperature with respect to time - °K/s.
	ZMARK	5000 meter printout index.
	DTIME	Time increment for integration in the FSCINV subroutine.
	LRUN	Index for label printout in DRIVER.
16		Standard atmosphere temperature and pressure.
18-19	TOO	Time - s.
	XR, YR, ZR	Raw position - m.
	XS, YX, ZS	Smooth position - m.
	XD, YD, ZD	First derivative of the smooth position - m/s.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
	XDD, YDD, ZDD	Second derivative of the smooth position - m/s^2 .
	TE	Sensor temperature - $^{\circ}\text{K}$.
	TD	First derivative of sensor temperature - $^{\circ}\text{K/s}$.
	TDD	Second derivative of sensor temperature - $^{\circ}\text{K/s}^2$.
21	CLB	Characteristic length of the thermistor bead - m.
	CLW	Characteristic length of the wire - m.
	CLF	Characteristic length of the film - m.
	CLFILM	Length of film along the air flow - m.
23	ZOT	Altitude - m.
	RHO	Atmospheric density - kg/m^3 .
	VS	Speed of sound - m/s .
	AMU	Atmospheric viscosity - kg/(m s) .
	AK	Thermal conductivity of the atmosphere - $\text{W/(m}^{\circ}\text{K)}$.
	AMFP	Mean free path of the atmosphere - m.
	RTV	Relative air speed of the sensor - m/s .
	TPINF	Air temperature - $^{\circ}\text{K}$.
24	TOTRAD	Total radiation flux density.
25	EPS	Emissivity of the sensor.
	RHOC	Density - kg/m^3 times the specific heat - $\text{J/(kg}^{\circ}\text{K)}$ of the sensor.
	D	Diameter of the sensor component - m.
	W	Electric heating of the thermistor - W/m^2 .
	ZKD	Conductivity - $\text{W/(m}^{\circ}\text{K)}$ times the diameter - m of the sensor component.
26	S	Width of the film strip - m.
	SMB	Length of the inner film strip - m.
	ZLL	Length of the outer film strip - m.
	ZL	Length of the wire - m.
	XEDGE	Length of the leading edge of the film strip - m.

<u>Statement</u>	<u>Description</u>
27-31	Format statements for reading.
35-46	Read in the sensor parameters and radiation inputs.

<u>Statement</u>	<u>Description</u>
35-46	Read in the label annotation for plotting.
67-100	Print out sensor parameters and radiation input.
102	AMASS = mass of rocket-parachute system.
103	AREA = cross sectional area of parachute.
113	Set the characteristic length of the film equal to CLFILM.
118	Read one record of radar tape.
119	Begin the DO loop for the radar data.
122-124	Summing variables.
127	Begin DO loop to average five radar positions together.
129	Average time is at the third position.
132	Using the average time, TIM, call RATIO to obtain the sensor temperature, TEMPT.
134-136	Add the five radar positions together.
138-140	Calculate the following average positions: X(I, 1) South X(I, 2) East X(I, 3) Altitude.
143-145	Calculate ZMARK, the 5000 m. interval printout index.
150	Call INITAL subroutine to obtain initial values of the first and second derivatives of temperature and position.
156	Set the maximum plot size.
161	Begin the data reduction cycle.
163	Read one record of radar tape.
164	If there is no radar data, go to statement 393 and rewind the tapes.
171	Call DIRSIT to obtain first and second derivatives.

<u>Statement</u>	<u>Description</u>
175	Calculate the time increment, DTIME.
177-179	Heading print out.
182	Call WIND subroutine to obtain horizontal winds, relative air speed, gravity, and drag.
184	Call FSCINV to obtain air temperature and corrections.
186	Print out the results.
192-214	Store variables to be plotted.
218-236	Same as statements 122-140.
237	If the altitude is less than 21000 m, finish plotting at statement 240.
238	If 500 variables are stored, begin plotting at statement 240.
240	Begin plotting the following seven graphs as a function of altitude or time.
242	rocket position - m
259-275	rocket speed - m/s
276-294	horizontal winds - m/s
296-306	air and sensor temperature - °K
308-317	sensor frequency
319-349	air temperature corrections - °K
352-359	standard air pressure - mb.
360	End of the plotting loop.
361-369	Redefine the plotting indexes to minimize pen movement.
370-382	Establish plot continuity.
384	If altitude is less than 21000 m, rewind the tapes.
385	Print a heading for each page of printout.
391	Go back to the beginning of the cycle (statement 161) and read in another radar record.
393-394	Rewind radar tape A, and temperature tape B.

<u>Statement</u>	<u>Description</u>
397	Call INTEG subroutine to obtain atmospheric pressure and density.
398-399	Store pressure in Z1 and density in Z2.
	The following six plots are of the atmospheric parameters as a function of altitude.
400-406	pressure
408-417	density
418-428	viscosity
429-439	speed of sound
440-450	thermal conductivity
451-462	mean free path
464	End of plotting.
465	Return to the MAIN program.
466-474	Format statements for heading printout.
475	End of DRIVER subroutine.

ATMO SUBROUTINE

The purpose of this subroutine is to calculate the standard atmosphere values of pressure and temperature.

<u>Statement</u>	<u>Description</u>
7	Dummy storage arrays for inverting the standard altitude and pressure.
8	If LLL = 1, go to statement 20.
9-12	Scale the standard temperature coefficients.
13-16	Invert the standard atmospheric pressure versus altitude and store in SAM and SIT.
17-19	Store the inverted standard atmosphere back into the original arrays.

<u>Statement</u>	<u>Description</u>
20-23	Search altitude for the corresponding standard temperature coefficients.
24-31	Evaluate the standard temperature and store in TAIR and STAIR.
32-36	Search altitude to find the standard pressure.
37	Linear interpolate to calculate the standard pressure, p.
38	Return to DRIVER subroutine.
39	End of ATMO subroutine.

WIND SUBROUTINE

The purpose of the subroutine WIND is to calculate gravity, horizontal winds, and drag on the parachute. Inputs to this subroutine are the first and second derivatives of position with respect to time.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
8		If LLL = 1, go to statement 17.
10	GRAV	Gravity at the rocketsonde station = 9.79976.
13	RADUS	Radius of the earth at the rocketsonde station.
17	G ZOT	Gravity as a function of altitude, ZOT. Altitude
19	XD YD ZD VEL	dx/dt dy/dt dz/dt Air speed of the rocketsonde.
20	ZDD	d^2z/dt^2
21	XDD WX	d^2x/dt^2 South wind.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
22	YDD WY	d^2y/dt^2 North wind.
23	RXV	Relative air speed in the south direction.
24	RYV	Relative air speed in the east direction.
26	RTV	Relative air speed of the rocketsonde.
28	DRAG	Drag force on the rocketsonde.
29		Return to DRIVER subroutine.
30		End of WIND subroutine.

INTEG SUBROUTINE

The purpose of subroutine INTEG is used to obtain atmospheric pressure and density given altitude, air temperature, gravity, and an initial pressure from radiosonde data.

<u>Statement</u>	<u>Description</u>
4	ATD = altitude BTMP = air temperature CGR = gravity
5	A, B = radiosonde altitude and pressure.
6	XO = molecular weight of the atmosphere.
7	R = universal gas constant.
8	After the first altitude, go to statement 17.
10-13	If the altitude, ATD, is between A_{i+1} and A_i , go to statement 14.
14	Calculate pressure by linearly interpolating into the radiosonde pressure.

<u>Statement</u>	<u>Description</u>
15	Calculate air density, DEN.
16	Return to DRIVER subroutine.
22-23	If the altitude, ATD, is equal to the first or last altitude of the flight, go to statement 33.
24-32	Fit two Lagrange polynomials to $CGR \cdot XO / (R \cdot BTMP)$ at the altitudes ATD_{j-1} , ATD_j , ATD_{j+1} . The coefficients of the polynomial are C, D, E.
34-41	At the first and last altitude of flight, set the polynomials equal by equating their coefficients.
42-44	Integrate the average of the polynomials, XINT, and evaluate the air pressure, PRESS, (see Chapter III, Eq. 53).
45	Compute air density, DEN.
46	Return to DRIVER subroutine.
47	End of INTEG subroutine.

GRAF SUBROUTINE

The GRAF subroutine is used to plot a rectangular grid, tick marks, and annotation. The following scale, in inches, is used for tickmarks and annotation:

tick marks: $(\text{length of axis}/12.0)^{1/4}/8.0$

annotation: $(\text{length of axis}/12.0)^{1/4}/7.0$

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
1-2	HEAD1	Annotation for the X-axis.
	HEAD2	Annotation for the Y-axis.
	NC1	Number of characters in the X-axis annotation.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
	NC2	Number of characters in the Y-axis annotation.
	XST	Starting X value.
	XEND	Ending X value.
	YST	Starting Y value.
	YEND	Ending Y value.
	XDIV	X value per division.
	YDIV	Y value per division.
	XLT	Length of the X-axis in inches.
	YLT	Length of the Y-axis in inches.
	MM	Abscissa of the graph origin in inches.
	NN	Ordinate of the graph origin in inches.
	N	Number of digits to the right of the decimal place for number annotation.
5-6		YZ1, XZ2 are scale factors for tick marks in the Y and X directions.
7-8		Z3, Z4 are scale factors for annotation in the Y and X direction.
9		Begin DO loop for plotting the four sides of a grid.
10-13		Plot the left most Y-axis and number annotation. MA = number of divisions on the axis. YNUM = value of Y at the tick mark.
24-34		Plot the top X-axis.
35-45		Plot the right most Y-axis.
46-59		Plot the bottom X-axis and number annotation. XNUM = value of X at the tick mark.
61-66		Plot the label on the lower X-axis and the right most Y-axis.
67		Return to DRIVER subroutine.
68		End of GRAF subroutine.

RATIO SUBROUTINE

Subroutine RATIO takes a given time from the averaged radar data and finds the corresponding temperature frequency and reference frequency from the temperature data. Using the sensor calibration curve and linear interpolation, a sensor temperature in degrees Kelvin corresponding to the ratio of these two frequencies is obtained. In addition, the temperature tape is read if the averaged radar time exceeds that of the temperature data.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
3		Calibration curve.
	FR	Frequency ratio.
	TEP	Temperature (°C).
	FMRK1	Minimum frequency ratio.
	FMRK2	Maximum frequency ratio.
4	S	Storage array for the temperature tape.
5	X	Time.
	Y	Sensor frequency.
6	C	Coefficients of the quadratic fit to the reference frequency.
9	C1	Reference frequency.
10-13		Search for time in the temperature data corresponding to the radar time, TIM.
15		If TIM is greater than the temperature data, go to statement 43 and read another record from the temperature tape.
16-17	C2	Linear interpolate to find the temperature frequency.
19	RATIO	Compute the frequency ratio.

<u>Statement</u>	<u>Variable</u>	<u>Description</u>
20-21		If RATIO is outside of the calibration curve, go to the error statement 53.
22-29		Search the calibration curve for a corresponding frequency ration.
32-34		Linear interpolate to obtain the sensor temperature, TEMP (°K).
35		Return to DRIVER subroutine.
36-39		Establish sensor frequency continuity.
43		Read one record of the temperature tape.
45-46		If the sensor frequency is less than 10.0 and greater than 165.0, ignore.
48-49		Store time and sensor frequency in the X and Y arrays.
51		If no frequencies were read in, go to statement 43 and read in a temperature record.
52		Go back to statement 10 and continue the temperature interpolation.
53-58		Error statements.
59		Return to the DRIVER subroutine.
60		End of RATIO subroutine.

FSCINV SUBROUTINE

The purpose of the subroutine FSCINV is to obtain the air temperature given the sensor temperature and air speed. The temperature corrections due to the following heat sources are also computed:

1. thermal conduction, DTCOND
2. aerodynamic heating, DTAERO

3. dynamic lag, DTDYN
4. electric heating, DTELEC
5. radiation, DTRAD

<u>Statement</u>	<u>Description</u>
7	Convection coefficient, CONV. Recovery factor, RECF.
16	CP $\left(C_p \right)$, specific heat of the air at constant pressure. PI $\left(\pi \right)$ SIGMA $\left(\sigma \right)$, Stefan-Boltzmann constant.
18	Call the subroutine ATMO to obtain standard air pressure and an initial air temperature.
19	Store the sensor temperature in TEMP(1).
20-24	At the initial altitude set the temperature of the bead, wire, and film equal to the sensor temperature.
25-31	Compute the convection coefficient, HO, and recovery factor, RF, for the leading edge of the film.
32-35	Compute the convection coefficients and recovery factors for the bead, wire, and film strip along the air flow.
36-37	Calculate an average convection coefficient and recovery factor for the film weighted with the length of the leading edge and the length of the film strip along the air flow.
39	$CAPH = h + 4\sigma\epsilon T^3$
40-42	$\lambda = \sqrt{\frac{h + 4\sigma\epsilon T^3}{kV/A}}$, λ = the inverse decay length cm^{-1}
49-50	Three times the decay length for the wire and inner film strip are DEC2(wire), DECAY (inner film strip).
51-52	If DECAY is greater than the length of the film strip (CLFILM), then set DECAY = CLFILM.
54	$TEA = 3\sigma\epsilon T^4$
55	$AERO = rv^2/2C_p$

<u>Statement</u>	<u>Description</u>
56-60	The equilibrium temperature for the bead, wire, and film, TE, are calculated as a linear function of the air temperature. $TE = AK * T_{air} + BK$
62-63	The change in the film temperature, DTFILM, is calculated as a finite difference solution of the heat transfer equation for the film. Change in film temperature during a .5 sec time interval is $T_{fi+1} - T_{fi} = DTFILM$.
65-66	The average wire temperature is obtained by integrating the temperature distribution over the wire length.
67	Store the average wire temperature in TEMP(2).
69-72	The heat conduction coefficients HK, K_1 , and K_2 are calculated.
73	The ratio of convection to conduction coefficients is $SAM = h / (HK * K_1)$
75-78	The time constants of the bead, wire, film $\tau = \frac{\rho Cv / A}{h + 4\sigma\epsilon T^3}$ and sensor are $\tau(\text{sensor}) = \frac{\rho Cv / A}{h + 4\sigma\epsilon T^3 + HK}$
79-80	The steady state temperature of the sensor is $TE = \left[(h + HK * K_1) * T_{air} + h * AERO + TOTRAD + TEA + ELECT + HK * K_2 \right] / (h + 4\sigma\epsilon T^3 + HK) .$
81-87	Calculate the air temperature corrections due to extraneous heat sources and time lag.

<u>Statement</u>	<u>Description</u>
89	The air temperature is equal to the sensor temperature plus the sum of the temperature corrections.
91-94	If the difference between the characteristic length of the film (CLF) and three times the decay length of the film (DECAY) is greater than 10^{-3} , set CLF = DECAY and go to statement 31 to recompute h and r for the film.
95	If ALTITD is greater than ZMARK (print out index), go to statement 180.
99-168	Print out block.
180	Increment the film temperature. $T_{fi+1} = T_{fi} + DTFILM$
181	Return to DRIVER subroutine.
182	End of FSCINV subroutine.

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1*   DIMENSION S(800)
2*   COMMON /STD/ WA(50), WP(50)
3*   COMMON /TEMP/ X(800), Y(800)
4*   COMMON /DATAIA/ XL(80), YL(50)
5*   COMMON /NIT/ II
6*   COMMON /XXX/ LLL
7*   COMMON /INTP/ FRT(900), THP(900), FMRK1, FMRK2
8*   COMMON /VAB/ BS(10), CS(10), AS(300), PO(300), AAS(10)
9*   COMMON /CAT/ XLAT, XLONG
10*  CALL SKPFLS (1MB,0,2)
11*  CALL SKPFLS (1MA,0,15)
12*  READ 251, (AS(I), PO(I), I = 1,272)
13*  READ 1, (FRT(I), THP(I), I = 1,801)
14* 251 FORMAT(8F10.5)
15*  READ 150, (AAS(I), I = 1,6)
16*  READ 151, (BS(I), I = 1,5)
17*  READ 151, (CS(I), I = 1,5)
18*  READ 157, XLAT, XLONG
19*  READ 157, (WP(I), WA(I), I = 1,23)
20*  FMRK1 = FRT(1)
21*  FMRK2 = FRT(800)
22* 151 FORMAT(5F10.4)
23* 150 FORMAT(6F10.1)
24* 157 FORMAT(2F10.5)
25*  LLL = 0
26*  X(1) = 0.0
27*  SUM = 0.0
28*  NP = 0
29*  IR = 0
30*  N = 0
31*  II = 1
32* 8 CONTINUE
33*  CALL VABIN (NW,1MB,S,800)
34*  DO 2 JJ = 1,NW,2
35*  IF(S(JJ+1) .LT. 10.0) GO TO 2
36*  IF(IR .EQ. 0) OZ = S(JJ)
37*  IF(S(JJ+1) .GT. 165.0) GO TO 4
38*  X(II) = S(JJ) - 12.0
39*  Y(II) = S(JJ+1)
40*  IF(IR .EQ. 1) GO TO 6
41*  II = II + 1
42*  GO TO 2
43* 4 N = N + 1
44*  IR = 1
45*  SUM = SUM + S(JJ+1)
46*  IF(S(J) - S(J-2) .LT. 0.5) GO TO 2
47* 6 IF(N.LT.40) GO TO 7
48*  NP = NP + 1
49*  DIV = N
50*  YL(NP) = SUM / DIV
51*  XL(NP) = (OZ + S(JJ))*0.5
52* 7 CONTINUE
53*  N = 0
54*  SUM = 0
55*  IR = 0
56* 2 CONTINUE
57*  IF(II .EQ. 1) GO TO 8
58*  PRINT 10, II
59* 10 FORMAT(1X, I6)
60*  PRINT 104, (XL(J), YL(J), JJ, NP)
61*  C.....ATAIAT FITS A LEAST SQUARES CURVE TO THE REFERENCE TEMPERATURE
62*  CALL ATAIAT(NP)
63*  CALL DRIVER
64* 1 FORMAT(6F10.3)
65* 104 FORMAT(1X, 2F20.10)
66*  STOP
67*  END

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1*   SUBROUTINE DRIVER
2*   DIMENSION Z(800)
3*   DIMENSION HEAD1(6), HEAD2(6), HEAD3(6), HEAD4(6), HEAD5(6), HEAD6(6),
4*   HEAD7(6), HEAD8(6), HEAD9(6), HEAD10(6), HEAD11(6), HEAD12(6)
5*   DIMENSION HEAD13(6), HEAD14(6), HEAD15(6), HEAD16(6), HEAD17(7)
6*   1, HEAD18(6)
7*   DIMENSION AB(500,3), ABD(500,4), ZA1(500,5), ZB2(500,3), TO(500),
8*   ZD4(500), XX(2), YY(2), ZC3(500,2), ZC4(500)
9*   DIMENSION Z1(1000), Z2(1000)
10*  COMMON /DAT/ AAA(1000), BBB(1000), CCC(1000)
11*  COMMON /YL/ P
12*  COMMON /XXX/ LLL, STAIR
13*  COMMON /ANT/ T(100), X(100,4), XBAR(100,4), XDOT(100,4), XDDOT(100,4)
14*  COMMON /ANT/ MF, MB, ML, MS, MK, MJ, MN, N, IO, TAP, TP, TMLTP
15*  COMMON /FSCI/ TENT, TEDOT, ZMARK, DTIME, LRUN
16*  COMMON /VAB/ BS(10), CS(10), AS(300), PO(300), AAS(10)
17*  COMMON /GASH/ DTCOND, DTDYN, DTRAD, DTAERO, DTELEC
18*  COMMON /DIST/ TOO, XR, XS, XD, XDD, YR, YS, YD, YDD, ZR, ZS, ZD, ZDD, TE, TO, II
19*  COMMON /DIST/ TER, TOD
20*  COMMON /RFAC/ ZSR(15), ZRB(15), ZRW(15)
21*  COMMON /CLEN/ CLB, CLW, CLF, CLFILM
22*  COMMON /REG/ IC, IS, IT, IF
23*  COMMON /AP/ ZOT, TINF, RHO, VS, AMU, AK, AMFP, RTV, TPINF
24*  COMMON TOTRAD(3)
25*  COMMON EPS(5), RHOC(5), D(5), W(5), ZKD(5)
26*  COMMON S, SMB, ZLL, T1, R0, ZL, XEDGE
27* 1 FORMAT (4A1)
28* 2 FORMAT (3F10.3)
29* 3 FORMAT (2E15.5)
30* 4 FORMAT (3E15.5)
31* 5 FORMAT (6E15.5)
32* C.....READ THE SENSOR PARAMETERS AND RADIATION INPUT
33*  READ 2, (ZSR(I), ZRB(I), ZRW(I), I=1,13)
34*  READ 1, IC, IS, IT, IF
35*  READ 6, CLB, CLW, CLFILM, XEDGE
36*  READ 2, (TOTRAD(I), I = 1,3)
37*  READ 6, (D(I), I=1,4)
38*  READ 6, (RHOC(I), I=1,4)
39*  READ 6, (EPS(I), I = 1,4)
40*  READ 5, (W(I), I=1,3)
41*  READ 5, (ZKD(I), I=1,3)
42*  READ 6, R0, ZL
43*  READ 6, S, SMB, ZLL, T1
44* C.....READ THE PLOT ANOTATION
45*  READ 69, NC1, (HEAD1(I), I = 1,4)
46*  READ 69, NC2, (HEAD2(I), I = 1,5)
47*  READ 69, NC3, (HEAD3(I), I = 1,4)
48*  READ 69, NC4, (HEAD4(I), I = 1,4)
49*  READ 69, NC5, (HEAD5(I), I = 1,3)
50*  READ 69, NC6, (HEAD6(I), I = 1,4)
51*  READ 69, NC7, (HEAD7(I), I = 1,4)
52*  READ 69, NC8, (HEAD8(I), I = 1,6)
53*  READ 69, NC9, (HEAD9(I), I = 1,6)
54*  READ 69, NC10, (HEAD10(I), I = 1,6)
55*  READ 69, NC11, (HEAD11(I), I = 1,5)
56*  READ 69, NC12, (HEAD12(I), I = 1,6)
57*  READ 69, NC13, (HEAD13(I), I = 1,2)
58*  READ 69, NC14, (HEAD14(I), I = 1,4)
59*  READ 69, NC15, (HEAD15(I), I = 1,5)
60*  READ 69, NC16, (HEAD16(I), I = 1,5)
61*  READ 69, NC17, (HEAD17(I), I = 1,6)
62*  READ 69, NC18, (HEAD18(I), I = 1,5)
63* 69 FORMAT(12, 2X, 6A6)
64*  PRINT 100
65* 100 FORMAT (1M1,31HSONDE CONFIGURATION PARAMETERS: /)
66*  PRINT 101, (TOTRAD(I), I = 1,3)
67* 101 FORMAT(19H TOTAL RADIATION , 3F10.2)

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68* PRINT 107, (D(I), I=1,4)
69* 107 FORMAT (1H,5MD(I),15X,4E15.5)
70* PRINT 108, (RHOC(I), I=1,4)
71* 108 FORMAT (1H,9MRHO-C(I),11X,4E15.5)
72* PRINT 109, (EPS(I), I=1,4)
73* 109 FORMAT(9H EPSILON , 12X, 4E15.5 )
74* PRINT 110, (W(I), I=1,3)
75* 110 FORMAT (1H,5MW(I),15X,3E15.5)
76* PRINT 111, (ZKD(I), I=1,3)
77* 111 FORMAT (1H,6MKD(I),14X,3E15.5)
78* PRINT 112, RO
79* 112 FORMAT (1H,5WRO,17X,E15.5)
80* PRINT 113, ZL
81* 113 FORMAT (1H,12MWIRE LENGTH,8X,E15.5)
82* PRINT 118, S
83* 118 FORMAT (1H,17MFILM STRIP WIDTH,3X,E15.5)
84* PRINT 119, SMG
85* 119 FORMAT (1H,5X,13HINNER-LENGTH,2X,E15.5)
86* PRINT 120, ZLL
87* 120 FORMAT (1H,5X,13HOUTER-LENGTH,2X,E15.5)
88* PRINT 121, T1
89* 121 FORMAT (1H,5X,5MT1,12X,E15.5)
90* IP = 0
91* AMASS = 2.33
92* AREA = 16.4
93* C = AMASS/AREA
94* XO = 0.0289644
95* R = 8.31432
96* NAVG = 5
97* ND = 1
98* II = 0
99* MF = 20
100* MB = 1
101* IO = 1
102* CLF = CLFILM
103* N = 4
104* MSTAR = 41
105* I = 0
106* C.....READ RADAR TAPE
107* CALL VARBIN(NW,1MA,Z,800)
108* DO 8 JJ = MSTAR,NW,20
109* I = I + 1
110* ILP = 0
111* XAVG = 0.0
112* YAVG = 0.0
113* ZAVG = 0.0
114* JLST = JJ + 16
115* C.....AVERAGE FIVE RADAR WORDS TOGETHER
116* DO 15 JJI = JJ,JLST,4
117* ILP = ILP + 1
118* IF(ILP,NE,3) GO TO 14
119* T(I) = Z(JJI)
120* TIM = T(I)
121* CALL RATIO (TEMP,TIM,ND,C1)
122* X(I,4) = TEMP
123* 14 XAVG = XAVG + Z(JJI+1)
124* YAVG = YAVG + Z(JJI+2)
125* ZAVG = ZAVG + Z(JJI+3)
126* 15 CONTINUE
127* X(I,1) = XAVG / 5.0
128* X(I,2) = YAVG / 5.0
129* X(I,3) = ZAVG / 5.0
130* 8 CONTINUE
131* ILP = 0
132* IZMARK = X(1,3)/10000.
133* ZMARK = IZMARK*10000 + 5000
134* IF(X(1,3) .LT. ZMARK) ZMARK = IZMARK*10000

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135* C.....ZMARK = 5000 METER INTERVAL PRINT OUT INDEX
136* PRINT 123,ZMARK
137* 123 FORMAT (1H, F15.0)
138* C.....CALL INITIAL TO OBTAIN INITIAL VALUES OF THE FIRST AND SECOND DER.
139* CALL INITIAL
140* K = 1
141* L = 11
142* J = 1
143* IND = 0
144* LL1 = 0
145* LET = 0
146* LRUN = 0
147* C.....MAXIMUM PLOT SIZE
148* CALL IDPLOT(40.0,26.0)
149* CALL PLOT(0.9,0.9,-3)
150* 10 CONTINUE
151* C.....READ RADAR TAPE
152* CALL VARBIN(NW,1MA,Z,800)
153* IF(NW,EQ,0) GO TO 50
154* DO 16 JJ=1,NW,20
155* JLST = JJ + 16
156* N = 3
157* MB = 1
158* C.....CALL DIRSIT TO OBTAIN FIRST AND SECOND DERIVATIVES
159* CALL DIRSIT
160* ZOT = Z5
161* TEMP = TE
162* TEDOT = TD
163* DTIME = T(2) - T00
164* IF(LL1,EQ, 1) GO TO 421
165* PRINT 12
166* PRINT 11
167* PRINT 13
168* 421 CONTINUE
169* C.....CALL WIND TO OBTAIN THE HORIZONTAL WIND
170* CALL WIND( DPRU, WX, WY, 0, DRAG)
171* C.....CALL FSCINV TO OBTAIN AIR TEMPERATURE GIVEN SENSOR TEMPERATURE
172* CALL FSCINV
173* C.....PRINT OUT TIME, POSITION, WIND, AND TEMPERATURE
174* PRINT 9,T00,Z5,TE,TPINF, TEDOT,WX,WY,RTV,ZD,XR,YR
175* LRUN = LRUN + 1
176* IF(IND,NE, 0) GO TO 51
177* IND = 1
178* LL1 = LL1 + 1
179* LET = LET + 1
180* C.....STORE VARIABLES TO BE PLOTTED
181* AAA(LET) = ZOT
182* BBB(LET) = TPINF
183* CCC(LET) = 0
184* AB(LL1,1) = XR
185* AB(LL1,2) = YR
186* AB(LL1,3) = ZR
187* YO(LL1) = T00
188* ABD(LL1,1) = XD
189* ABO(LL1,2) = YD
190* ABD(LL1,3) = ZD
191* ZA1(LL1,1) = DTCND/5.0
192* ZA1(LL1,2) = DTAERO/5.0
193* ZA1(LL1,3) = DTDYN/5.0
194* ZA1(LL1,4) = DTELEC/5.0
195* ZA1(LL1,5) = DTRAD/5.0
196* ZB2(LL1,1) = (TE-180.0)/20.0
197* ZB2(LL1,2) = (TPINF - 180.0)/20.0
198* ZB2(LL1,3) = (STAIR - 180.0)/20.0
199* ZC3(LL1,1) = WX*0.05
200* ZC3(LL1,2) = WY*0.05
201* ABD(LL1,4) = RTV
202* ZC4(LL1) = P/5.0E+02
203* ZD4(LL1) = C1

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204*      GO TO 53
205*      51 IND = 0
206*      53 IP = IP + 1
207*      XAVG = 0.0
208*      YAVG = 0.0
209*      ZAVG = 0.0
210*      C.....AVERAGE FIVE RADAR WORDS TOGETHER
211*      DO 20 JJ1 = JJ,JLST,4
212*      ILP = ILP + 1
213*      IF(ILP,NE,3) GO TO 21
214*      TIM = Z(JJ1)
215*      Y(ML) = TIM
216*      CALL RATIO (TEMPT,TIM,ND,C1)
217*      X(ML,4) = TEMPT
218*      21 XAVG = XAVG + Z(JJ1+1)
219*      YAVG = YAVG + Z(JJ1+2)
220*      ZAVG = ZAVG + Z(JJ1+3)
221*      20 CONTINUE
222*      ILP = 0
223*      X(ML,1) = XAVG / 5.0
224*      X(ML,2) = YAVG / 5.0
225*      X(ML,3) = ZAVG / 5.0
226*      IF(X(ML,3) .LT. 21000.0) GO TO 41
227*      IF(LL1 .EQ. 500) GO TO 41
228*      GO TO 59
229*      41 DO 71 I = K,L,J
230*      GO TO (30,31,32,33,34,35,36,37,38,39,40), I
231*      C.....PLOT POSITION OF THE ROCKET
232*      30 IF(IP .GT. 1200) GO TO 72
233*      CALL GRAF(HEAD5,HEAD2,NC5,NC2,0.0,1200.0,-60.0,80.0,200.0,20.0,
234*      16.0,6.0,0.0,1)
235*      XX(1) = 0.0
236*      XX(2) = 6.0
237*      YY(1) = 4.0
238*      YY(2) = 4.0
239*      CALL LINE(XX,YY,2,1)
240*      72 DO 87 JI = 1,3
241*      JZ = 3
242*      DO 87 JK = 1,LL1
243*      A = ZO(JK)/200.0
244*      B = AB(JK,JI)/20000.0 + 4.0
245*      CALL PLOT(A,B,JZ)
246*      87 JZ = 2
247*      GO TO 71
248*      C.....PLOT SPEED OF THE ROCKET
249*      31 IF(IP .GT. 1200) GO TO 74
250*      CALL GRAF(HEAD3,HEAD1,NC3,NC1,-200.0,200.0,20.0,80.0,50.0,10.0,
251*      18.0,6.0,7.0,1)
252*      XX(1) = 11.0
253*      XX(2) = 11.0
254*      YY(1) = 0.0
255*      YY(2) = 6.0
256*      CALL LINE(XX,YY,2,1)
257*      74 DO 75 JI = 1,4
258*      JZ = 3
259*      DO 75 JK = 1,LL1
260*      A = ABD(JK,JI)/50.0 + 11.0
261*      B = (AB(JK,3) - 20000.0)/10000.0
262*      CALL PLOT(A,B,JZ)
263*      75 JZ = 2
264*      GO TO 71
265*      C.....PLOT THE HORIZONTAL WINDS
266*      32 IF(IP .GT. 1200) GO TO 77
267*      CALL GRAF(HEAD4,HEAD1,NC4,NC1,-60.0,60.0,20.0,80.0,20.0,10.0,
268*      16.0,6.0,16.0,1)
269*      XX(1) = 19.0
270*      XX(2) = 19.0
271*      YY(1) = 0.0

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272*      YY(2) = 6.0
273*      CALL LINE(XX,YY,2,1)
274*      77 JZ = 3
275*      DO 78 JK = 1,LL1
276*      A = ZC3(JK,2) + 19.0
277*      B = (AB(JK,3) - 20000.0)/10000.0
278*      CALL PLOT(A,B,JZ)
279*      78 JZ = 2
280*      DO 79 JK = 1,LL1,5
281*      A = ZC3(JK,1) + 19.0
282*      B = (AB(JK,3) - 20000.0)/10000.0
283*      79 CALL SYMBL4(A,B,.10,14.,0.0,1)
284*      GO TO 71
285*      C.....PLOT AIR, SENSOR, AND STANDARD TEMPERATURES
286*      33 IF(IP .GT. 1200) GO TO 80
287*      CALL GRAF(HEAD7,HEAD1,NC7,NC1,180.0,360.0,20.0,80.0,20.0,10.0,
288*      16.0,6.0,23.0,1)
289*      80 DO 81 JI = 1,3
290*      JZ = 3
291*      DO 81 JK = 1,LL1
292*      A = ZB2(JK,JI) + 23.0
293*      B = (AB(JK,3) - 20000.0)/10000.0
294*      CALL PLOT(A,B,JZ)
295*      81 JZ = 2
296*      GO TO 71
297*      C.....PLOT THE SENSOR TEMPERATURE IN FREQUENCY
298*      34 IF(IP .GT. 1200) GO TO 93
299*      CALL GRAF(HEAD5,HEAD6,NC5,NC6,0.0,1200.0,0.0,240.0,200.0,40.0,
300*      16.0,6.0,30.0,1)
301*      93 JZ = 3
302*      DO 94 JK = 1,LL1
303*      A = ZD4(JK)/40.0
304*      B = TO(JK)/200.0 + 30.0
305*      CALL PLOT(B,A,JZ)
306*      94 JZ = 2
307*      GO TO 71
308*      C.....PLOT THE AIR TEMPERATURE CORRECTIONS
309*      35 XL = 3.0
310*      IF(IP .GT. 1200) GO TO 90
311*      CALL GRAF(HEAD8,HEAD1,NC8,NC1,-15.0,15.0,20.0,80.0,5.0,10.0,
312*      16.0,6.0,0.0,1)
313*      GO TO 90
314*      36 XL = 10.0
315*      IF(IP .GT. 1200) GO TO 90
316*      CALL GRAF(HEAD9,HEAD1,NC9,NC1,-15.0,0.0,20.0,60.0,5.0,10.0,3.0,
317*      16.0,7.0,10.1)
318*      GO TO 90
319*      37 XL = 13.0
320*      IF(IP .GT. 1200) GO TO 90
321*      CALL GRAF(HEAD10,HEAD1,NC10,NC1,-10.0,10.0,20.0,80.0,5.0,10.0,
322*      14.0,6.0,11.0,1)
323*      GO TO 90
324*      38 XL = 17
325*      IF(IP .GT. 1200) GO TO 90
326*      CALL GRAF(HEAD11,HEAD1,NC11,NC1,-5.0,5.0,20.0,80.0,5.0,10.0,
327*      12.0,6.0,16.0,1)
328*      GO TO 90
329*      39 XL = 20.0
330*      IF(IP .GT. 1200) GO TO 90
331*      CALL GRAF(HEAD12,HEAD1,NC12,NC1,-5.0,5.0,20.0,80.0,5.0,10.0,
332*      12.0,6.0,19.0,1)
333*      90 JZ = 3
334*      DO 92 JK = 1,LL1
335*      A = ZAI(JK,I-5) + XL
336*      B = (AB(JK,3) - 20000.0)/10000.0 + 10.0
337*      CALL PLOT(A,B,JZ)
338*      92 JZ = 2
339*      GO TO 71

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340* C.....PLOT THE STANDARD PRESSURE
341* 40 IF(IP.GT. 1200) GO TO 99
342* CALL GRAF(HEAD13,HEAD1,NC13,NC1,0,0,30,0,20,0,80,0,5,0,10,0,6,0,
343* 16,0,22,10,1)
344* 99 DO 201 JK = 1,LL1,5
345* A = ZC4(JK) + 22.0
346* IF(A.GT. 28.0) A = 28.0
347* B = (AB(JK,3) - 20000.0)/10000.0 + 10.0
348* 201 CALL SYMBL4(A,B,0.1,1H,0.0,1)
349* 71 CONTINUE
350* IF(K.EQ. 1) GO TO 96
351* K = 1
352* L = 11
353* J = 1
354* 96 IF(K.EQ. 11) GO TO 97
355* K = 11
356* L = 1
357* J = -1
358* 97 CONTINUE
359* DO 98 I = 1,3
360* AB(I,I) = AB(LL1,I)
361* AB(I,1) = AB(LL1,I)
362* ZA1(I,I) = ZA1(LL1,I)
363* 98 ZB2(I,I) = ZB2(LL1,I)
364* TO(I) = TO(LL1)
365* AB(I,4) = AB(LL1,4)
366* ZA1(I,4) = ZA1(LL1,4)
367* ZA1(I,4) = ZA1(LL1,4)
368* ZD4(I) = ZD4(LL1)
369* ZC3(I,2) = ZC3(LL1,2)
370* ZC3(I,2) = ZC3(LL1,2)
371* ZC4(I) = ZC4(LL1)
372* LL1 = I
373* IF(X(ML,3).LT. 21000.0) GO TO 50
374* 50 IF(LRUN,LT,52) GO TO 16
375* LRUN = 0
376* PRINT 12
377* PRINT 11
378* PRINT 13
379* 16 CONTINUE
380* GO TO 10
381* C.....REWIND THE TEMPERATURE AND RADAR TAPES
382* 50 CALL REWIND(1HA,0)
383* CALL REWIND(1HB,0)
384* C.....CALL INTEG TO OBTAIN PRESSURE AND DENSITY
385* DO 207 I = LL1,1,-1
386* CALL INTEG(I,LET,PRES,DEN)
387* Z1(I) = PRES
388* 207 Z2(I) = DEN
389* JZ = 3
390* C.....PLOT THE PRESSURE
391* DO 209 I = 1,LET
392* A = Z1(I)/5.0E+02 + 22.0
393* IF(A.GT. 28.0) A = 28.0
394* B = (AAA(I) - 20000.0)/10000.0 + 10.0
395* CALL PLOT(A,B,JZ)
396* 209 JZ = 2
397* CALL PLOT(0.0,18.0,-3)
398* C.....PLOT DENSITY
399* CALL GRAF(HEAD14,HEAD1,NC14,NC1,0,0,5,0,20,0,80,0,1,0,
400* 110,0,5,0,6,0,0,0,1)
401* JZ = 3
402* DO 211 I = 1,LET
403* A = Z2(I)*1.0E+02
404* IF(A.GT. 5.0) A = 5.0
405* B = (AAA(I) - 20000.0)/10000.0
406* CALL PLOT(A,B,JZ)
407* 211 JZ = 2

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408* C.....PLOT VISCOSITY
409* CALL GRAF(HEAD15,HEAD1,NC15,NC1,0,0,5,0,20,0,80,0,1,0,10,0,5,0,
410* 16,0,6,0,1)
411* JZ = 3
412* DO 213 I = 1,LET
413* A1 = 1.458E-06*BBB(I)*(3./2.)/(BBB(I)+110.4)
414* A = A1/(3.0E-06) + 6.0
415* IF(A.GT. 11.0) A = 11.0
416* B = (AAA(I) - 20000.0)/10000.0
417* CALL PLOT(A,B,JZ)
418* 213 JZ = 2
419* C.....PLOT SPEED OF SOUND
420* CALL GRAF(HEAD16,HEAD1,NC16,NC1,0,0,4,0,20,0,80,0,1,0,10,0,4,0,
421* 16,0,12,0,1)
422* JZ = 3
423* DO 215 I = 1,LET
424* A1 = SORT(1.4*R*BBB(I)/X0)
425* A = A1/100.0 + 12.0
426* IF(A.GT. 16.0) A = 16.0
427* B = (AAA(I) - 20000.0)/10000.0
428* CALL PLOT(A,B,JZ)
429* 215 JZ = 2
430* C.....PLOT THERMAL CONDUCTIVITY
431* CALL GRAF(HEAD17,HEAD1,NC17,NC1,0,0,5,0,20,0,80,0,1,0,10,0,5,0,
432* 16,0,17,0,1)
433* JZ = 3
434* DO 217 I = 1,LET
435* A1=6.325E-07*BBB(I)**(3./2.)/(BBB(I)+245.4*10.**(-12./BBB(I)))
436* A = A1*4186.0465*2.0E+02 + 17.0
437* IF(A.GT. 22.0) A = 22.0
438* B = (AAA(I) - 20000.0)/10000.0
439* CALL PLOT(A,B,JZ)
440* 217 JZ = 2
441* C.....PLOT MEAN FREE PATH
442* CALL GRAF(HEAD18,HEAD1,NC18,NC1,0,0,4,0,20,0,80,0,1,0,10,0,4,0,
443* 16,0,23,0,1)
444* JZ = 3
445* DO 219 I = 1,LET
446* A1=R*BBB(I)/(Z1(I)*(2.**.5)*3.1415926*6.02257*+26*(3.65E-10)**.2)*
447* 11.0E+03
448* A = A1/(2.0E+05) + 23.0
449* IF(A.GT. 27.0) A = 27.0
450* B = (AAA(I) - 20000.0)/10000.0
451* CALL PLOT(A,B,JZ)
452* 219 JZ = 2
453* C.....END PLOTS
454* CALL FINI
455* RETURN
456* 9 FORMAT (1H ,F9.3,F12.2,3F13.4,3F12.4,3F10.2)
457* 12 FORMAT (1H1,3X,4HTIME,6X,8HALTITUDE,3X,11H SENSOR ,2X,11H AIR
458* 1 ,2X,11HSENSOR TEMP,4X,6HNORTH ,6X,6HEAST ,5X,8H AIR
459* 210H FALL ,4X, 16HPOSITION(METERS) )
460* 11 FORMAT(26X,11HTEMPERATURE,2X,11HTEMPERATURE,1X,11H RATE ,
461* 13X,9H WIND ,3X,9H WIND ,3X,7H SPEED ,5X,10H RATE ,
462* 210H EAST , 10H NORTH )
463* 13 FORMAT(3X,3HSEC,9X,5HMMETER,9X,5HDEG K,AX,5HDEG K,8X,5HDEG K,4X,
464* 16H M/SEC,6X,6H M/SEC,7X,6H M/SEC,2X,6H M/SEC / )
465* END

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1* SUBROUTINE FSCINV
2* C.....FSCINV COMPUTES AIR TEMPERATURE GIVEN SENSOR TEMPERATURE
3* DIMENSION TE(5), ZLAMBDA(5), AK(5), BK(5), TEMP(5)
4* DIMENSION CAPH(5), AERO(5), TEA(5), TAU(5)
5* COMMON /GASH/ DTCOND,DTDYN,DTRAD,DTAERO,DTELEC
6* COMMON /CLN/ CLB, CLW, CLF, CLFILM
7* COMMON /HR/ CONV(3), RECF(3)
8* COMMON /AP/ ALTIID, TINF, RHO, VS, AMU, AA, AMFP, VEL, TAIR
9* COMMON /XXX/ LLL
10* COMMON /FSCI/ TBEAD, TSDOT, ZMARK, DTIME, LRUN
11* COMMON /YLP/
12* COMMON /XXY/ IRB, IRW, IRF
13* COMMON TOTRAD(3)
14* COMMON EPS(5), RHOC(5), D(5), ELECT(5), ZKD(5)
15* COMMON S, XIN, XOUT, T1, R0, XWIRE, XEDGE
16* DATA CP,PI,SIGMA/1003., 3.1416, 5.6687E-8/
17* C.....OBTAIN STANDARD TEMPERATURE AND PRESSURE
18* 337 CALL ATMO
19* TEMP(1) = TBEAD
20* IF(LLL.EQ.1) GO TO 10
21* LLL = 1
22* C.....INITIALLY SET THE SENSOR TEMPERATURE EQUAL TO THE BEAD TEMPERATURE
23* DO 20 I = 1,4
24* 20 TEMP(I) = TBEAD
25* 10 IK = 1
26* CLF1 = CLF
27* CLF = 5
28* C.....COMPUTE CONVECTION COEFFICIENTS AND RECOVERY FACTORS
29* CALL HANDR(IK)
30* HO = CONV(3)
31* RF = RECF(3)
32* IK = 0
33* CLF = CLF1
34* CALL HANDR(IK)
35* HH1 = CONV(3)
36* CONV(3) = ((CONV(3)*CLF + HO*XEDGE)/(CLF+XEDGE)+CONV(3))/2.0
37* RECF(3) = ((RECF(3)*CLF + RF*XEDGE)/(CLF+XEDGE)+RECF(3))/2.0
38* DO 30 I = 1,3
39* 30 CAPH(I) = CONV(I) + 4.*SIGMA*EPS(I)*TEMP(I)**3
40* C.....COMPUTE DECAY LENGTHS
41* ZLAMBDA(2) = SQRT(4.*CAPH(2)/ZKD(2))
42* ZLAMBDA(3) = SQRT(2.0*(HH1+4.0*SIGMA*EPS(4)*TEMP(3)**3)/ZKD(3))
43* ZLAMBDA(3) = SQRT(2.*CAPH(3)/ZKD(3))
44* ARG1 = ZLAMBDA(2)*XWIRE
45* ARG2 = ZLAMBDA(3)*XOUT
46* ARG3 = ZLAMBDA(2)*XIN
47* CWG=ZKD(2)*D(2)/(2.*D(1)**2)
48* CWF=PI*D(2)*ZKD(2)/(4.*ZKD(3)*S)
49* DEC2 = 3.0/ZLAMBDA(2)
50* DECAY = 3./ZLAMBDA(2)
51* IF(DECAY.LE. CLFILM) GO TO 51
52* DECAY = CLFILM
53* 51 DO 40 I = 1,3
54* TEA(I)=3.*SIGMA*EPS(I)*TEMP(I)**4
55* AERO(I) = RECF(I)*VEL**2/(2.*CP)
56* AK(I) = CONV(I)/CAPH(I)
57* BK(I)=(CONV(I)*AERO(I)+TOTRAD(I)+TEA(I)+ELECT(I))
58* 1/CAPH(I)
59* C.....TE = EQUILIBRIUM TEMPERATURE
60* 40 TE(I) = AK(I)*TAIR + BK(I)
61* C.....CHANGE IN FILM TEMPERATURE
62* DTFILM=2.0/(2.*RHOC(4)*D(4)+ D(3)*RHOC(3)) *DTIME*(CONV(5)
63* 1*(TAIR+AERO(3)-TEMP(3))+TOTRAD(3)-SIGMA*EPS(3)*TEMP(3)**4)
64* C.....AVERAGE WIRE TEMPERATURE
65* TWIRE=TE(2)+(TEMP(3)-TE(2))*(COSH(ARG1))/(COSH(ARG1)
66* 1-1.)/(SINH(ARG1)+ARG1)+(TEMP(1)-TE(2))*SINH(ARG1)/ARG1
67* TEMP(2) = TWIRE

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68* C.....COMPUTE CONDUCTION PARAMETERS
69* HK=ZKD(2)*D(2)/(2.*D(1)**2*TANH(ARG1))
70* AK1=CONV(2)*(1.-1./COSH(ARG1))/CAPH(2)
71* AK2=((1.-1./COSH(ARG1))*(CONV(2)*AERO(2)+TOTRAD(2)+TEA(2))/CAPH(2)
72* 1+TEMP(3)/COSH(ARG1))
73* SAM = CONV(1)/(HK*AK1)
74* C.....COMPUTE TIME CONSTANTS
75* TAU(3) = (2.*RHOC(4)*D(4)+ D(3)*RHOC(3))/(2.*CAPH(3))
76* TAU(2)=RHOC(2)*D(2)/(4.*CAPH(2))
77* TAU(1)=RHOC(1)*D(1)/(6.*CAPH(1))
78* TAU(4)=RHOC(1)*D(1)/(6.*(CAPH(1)+HK))
79* TE(4)=((CONV(1)+HK*AK1)*TAIR+CONV(1)*AERO(1)+TOTRAD(1)+TEA(1)
80* 1+ELECT(1)+HK*AK2)/(CAPH(1)+HK)
81* DENOM = CONV(1) + HK*AK1
82* C.....COMPUTE AIR TEMPERATURE CORRECTIONS
83* DTCOND = HK*((1.-AK1)*TEMP(1)-AK2)/DENOM
84* DTDYN = RHOC(1)*D(1)*TSDOT/(6.*DENOM)
85* DTRAD = -(TOTRAD(1)-SIGMA*EPS(1)*TEMP(1)**4)/ENOM
86* DTAERO = -CONV(1)*AERO(1)/DENOM
87* DTELEC = -ELECT(1)/DENOM
88* C.....COMPUTE AIR TEMPERATURE
89* TAIR = TBEAD+DTCOND+DTRAD+DTAERO+DTELEC+DTDYN
90* C.....FIND THE LENGTH OF FILM TO COMPUTE H AND R
91* 15 DCLF = ABS(DECAY - CLF)
92* IF(DCLF.LT. 1.0E-03) GO TO 70
93* CLF = DECAY
94* GO TO 10
95* 70 IF(ALTITD.GT. ZMARK) GO TO 341
96* ZMARK = ZMARK - 5000.0
97* SONG = ZMARK + 5000.0
98* C.....PRINT OUT BLOCK
99* PRINT 431, SONG
100* 431 FORMAT(1H1, 50X, F10.2, 12H METER )
101* PRINT 399
102* 399 FORMAT( /24H ATMOSPHERIC PARAMETERS )
103* PRINT 400, ALTIID,TBEAD,P,RHO,VS,AMU,AA,AMFP
104* 400 FORMAT( ' ALTITUDE( METER)=', E20.5, ' SENSOR TEMP(DEG K)=',
105* 1620.4, ' PRESSURE(NEWTON/M**2)=', E20.4, ' DENSITY(KGM/M**3)=',
106* 2E20.4, ' VELOCITY OF SOUND(M/SEC)=', 620.4, ' VISCOSITY(KGM/M**2)
107* 3=', E20.4, ' THERMAL CONDUCTIVITY(WATTS/METER)=', E20.4, ' MEAN P
108* 4PATH(METER)=', E20.4 )
109* PRINT 401
110* 401 FORMAT( / 29H HEAT CONDUCTION PARAMETERS )
111* PRINT 402
112* 402 FORMAT( / 48X,5H BEAD,15X,5H WIRE,15X,5H FILM,14X,6HSEFILM )
113* PRINT 403, HK, AK1, AK2
114* 403 FORMAT(5X,'HK(WATTS/(M**2*DEG K))=',67X,620.4 /5X,'K1=',87X,6
115* 15X, 'K2(DEG K)=', 81X, 620.4 )
116* PRINT 404, ZLAMBDA(2), ZLAMBDA(3)
117* 404 FORMAT(5X, 'LAMBDA(1/METER)=',35X, 2620.4)
118* PRINT 405, DEC2, DECAY
119* 405 FORMAT(5X,'3*DECAY LENGTH(METER)=',28X,2620.4 )
120* PRINT 406, DTCOND
121* 406 FORMAT(5X, 'CONDUCTION TEMP CORRECTION(DEG K)=',54X,620.3 )
122* PRINT 407
123* 407 FORMAT( / 32H AERODYNAMIC HEATING PARAMETERS )
124* PRINT 408
125* 408 FORMAT(5X, (CONV(I), I = 1,3)
126* PRINT 409, (RECF(I), I = 1,3)
127* 409 FORMAT(5X,22H RECOVERY COEFFICIENT=, 8X, 3620.4 )
128* PRINT 411, IRB, IRW, IRF
129* 411 FORMAT(5X,14H FLOW REGION=, 16X, 3(14X,A6))
130* PRINT 410, (AERO(I), I = 1,3)
131* 410 FORMAT(5X,'AERODYN HEAT( DEG K)=', 8X, 3620.4 )
132* PRINT 412, DTAERO
133* 412 FORMAT(5X,' AERODYNAMIC TEMP CORRECTION(DEG K)=', 53X,620.3)
134* PRINT 413
135*

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136* 413 FORMAT( / 24H DYNAMIC LAG PARAMETERS )
137* PRINT 402
138* PRINT 415, (TAU(I), I = 1,4)
139* 415 FORMAT(5X, 'TIME CONSTANT(SEC)=', 11X, 4620.4 )
140* PRINT 437, (TEMP(I), I = 1,3)
141* 437 FORMAT(5X, 'TEMPERATURE(DEG K)=', 10X, 3620.4 )
142* PRINT 416, (TE(I), I = 1,4)
143* 416 FORMAT(5X, 'EQUILIBRIUM TEMP(DEG K)=', 5X, 4620.4 )
144* PRINT 422, (AK(I), I = 1,3)
145* 422 FORMAT(5X, 8H AK(I)=, 22X, 3620.4 )
146* PRINT 423, (BK(I), I = 1,3)
147* 423 FORMAT(5X, 'BK(I)(DEG K)=', 17X, 3620.4 )
148* PRINT 439, TSDOT
149* 439 FORMAT(5X, 'TEMP TIME DER(DEG K/SEC)=', 64X, 620.3)
150* PRINT 417, DTIDN
151* 417 FORMAT(5X, 'DYNAMIC TEMP LAG CORRECTION(DEG K)=', 53X, 620.3 )
152* PRINT 418
153* 418 FORMAT( / 30H RADIATION HEATING PARAMETERS )
154* PRINT 402
155* PRINT 420, (TOTRAD(I), I = 1,3)
156* 420 FORMAT(5X, 'TOTAL RADIATION INPUT(W/M**2)=', 3620.4 )
157* PRINT 424, DTRAD
158* 424 FORMAT(5X, 'RADIATION TEMP CORRECTION(DEG K)=', 55X, 620.3 )
159* PRINT 425
160* 425 FORMAT( / 29H ELECTRIC HEATING PARAMETERS )
161* PRINT 402
162* PRINT 426, ELECT(1)
163* 426 FORMAT(5X, 'ELECTRIC HEATING(WATTS/M**2)=', 60X, 620.3 )
164* PRINT 427, DTELEC
165* 427 FORMAT(5X, 'ELECTRIC TEMP CORRECTION(DEG K)=', 55X, 620.3 / 1H1 )
166* 339 PRINT 12
167* PRINT 11
168* PRINT 13
169* LRUN = 0
170* 341 CONTINUE
171* 12 FORMAT (1H1, 5X, 4HTIME, 6X, 8HALTITUDE, 3X, 11H SENSOR, 2X, 11H AIR
172* 1, 5X, 11H SENSOR TEMP, 4X, 6HNORTH, 6X, 6HEAST, 5X, 8H AIR,
173* 210H FALL, 4X, 16H POSITION (METERS) )
174* 11 FORMAT(20X, 11H TEMPERATURE, 2X, 11H TEMPERATURE, 1X, 11H RATE,
175* 13X, 9H WIND, 3X, 9H WIND, 3X, 7H SPEED, 5X, 10H RATE,
176* 210H LAST, 10H NORTH )
177* 13 FORMAT(3X, 3H SEC, 9X, 5H METER, 9X, 5H DEG K, 8X, 5H DEG K, 8X, 5H DEG K, 4X,
178* 16H M/SEC, 6X, 6H M/SEC, 7X, 6H M/SEC, 2X, 6H M/SEC / )
179* (.....INCREMENT THE FILM TEMPERATURE
180* TEMP(3) = TEMP(3) + DTFILM
181* RETURN
182* EN

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SUBROUTINE WIND( DPRU, WX, WY, 6, DRAG)
C.....WIND COMPUTES HORIZONTAL WINDS
COMMON /AP/ ZOT, TINF, RHO, VS, AMU, AK, AMFP, RTV, TAIR
COMMON /DIST/ TOO, XR, XS, XD, XDD, YD, YDD, ZR, ZS, ZD, ZDD, TE, TD, II,
1TEN, TDO
COMMON /CAT/ XLAT, XLONG
COMMON /XXX/ LLL
IF(LLL.EQ. 1) GO TO 101
C.....COMPUTE GRAVITY
GRAV = 9.79976
XX = (6378.099*1.0E+03)**2
ZZ = (6356.631*1.0E+03)**2
RADUS=SQRT(XX*ZZ/(XX*SIN(XLAT)**2+ZZ*COS(XLAT)**2))
GA = 3.0*GRAV/RADUS**2
GB = -2.0*GRAV/RADUS

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16* GC = GRAV
17* 101 G = 6A*ZOT**2 + 6B*ZOT + 5C
18* C.....ABSOLUTE AIR SPEED
19* VEL=SQRT(XD**2+YD**2+ZD**2)
20* DPRU=(ZDD+G)/ZD
21* WX=-(XDD/DPRU)+XD
22* WY=-(YDD/DPRU)+YD
23* RXV=XD-WX
24* RYV=YD-WY
25* C.....RELATIVE AIR SPEED
26* RTV=SQRT(RXV**2+RYV**2+ZD**2)
27* C.....DRAG FORCE
28* DRAG = DPRU*RTV
29* RETURN
30* END

```

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1* SUBROUTINE ATAIAT (NP)
2* C.....ATAIAT FITS A LEAST SQUARES CURVE TO THE REFERENCE TEMPERATURE
3* COMMON /DATAIA/ XL(50),YL(50)
4* COMMON /TATA/ C(4)
5* DIMENSION A(4,4), B(4,50)
6* N = 3
7* MD = NP
8* SUM1 = 0.0
9* SUM2 = 0.0
10* SUM3 = 0.0
11* SUM4 = 0.0
12* DO 1 K=1,MD
13* DELTK = XL(K)
14* SUM1 = SUM1 + DELTK
15* D2 = DELTK*DELTK
16* SUM2 = SUM2 + D2
17* D3 = D2*DELTK
18* SUM3 = SUM3 + D3
19* D4 = D3 * DELTK
20* SUM4 = SUM4 + D4
21* 1 CONTINUE
22* AB1 = SUM2*MD - SUM1*SUM1
23* AB2 = SUM3*MD - SUM1*SUM2
24* AB3 = SUM3*SUM1 - SUM2*SUM2
25* DET = SUM4*AB1
26* DET1 = SUM3*AB2
27* DET2 = SUM2*AB3
28* DETR = DET - DET1 + DET2
29* A(1,1) = AB1/DETR
30* A(2,1) = -AB2/DETR
31* A(3,1) = AB3/DETR
32* A(1,2) = A(2,1)
33* A(2,2) = (SUM4*MD - SUM2*SUM2)/DETR
34* A(3,2) = -(SUM4*SUM1 - SUM2*SUM3) / DETR
35* A(1,3) = A(3,1)
36* A(2,3) = A(3,2)
37* A(3,3) = (SUM4*SUM2 - SUM3*SUM3)/DETR
38* DO 3 J=1,MD
39* DELTJ = XL(J)
40* DELT2 = DELTJ*DELTJ
41* DO 3 K=1,N
42* B(K,J) = A(K,1)*DELT2 + A(K,2)*DELTJ + A(K,3)
43* 3 CONTINUE
44* DO 5 J=1,MD
45* DO 5 I = 1,N
46* C(I) = C(I) + B(I,J)*YL(J)
47* 5 CONTINUE
48* PRINT 51, (C(I), I=1,3 )
49* DO 6 JJ = 1,MD
50* XX = XL(JJ) * XL(JJ)
51* VAL = C(1) * XX + C(2) * XL(JJ) + C(3)
52* PRINT 51, VAL, XL(JJ), YL(JJ)
53* 6 CONTINUE
54* 51 FORMAT (1H, 3F20.10 )
55* RETURN
56* END

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1* SUBROUTINE GRAF(HEAD1,HEAD2,NC1,NC2,XST,XEND,YST,YEND,XDIV,YDIV,
2* 1XLT,YLT,MM,NN,N)
3* C.....GRAF DRAWS A RECTANGULAR GRID FOR PLOTTING
4* DIMENSION HEAD1(6), HEAD2(6)
5* YZ1 = (YLT/12.0)**.25/8.0
6* XZ2 = (XLT/12.0)**.25/8.0
7* Z3 = (YLT/12.0)**.25/7.0
8* Z4 = (XLT/12.0)**.25/7.0
9* DO 20 I = 1,4
10* IF(I.NE. 1) GO TO 30
11* A = MM
12* B = NN
13* CALL NUMBER(A-.2 ,B,YZ1,YST,90.0,N)
14* CALL PLOT(A,B,3)
15* MA = (YEND-YST)/YDIV
16* Y = B
17* DO 40 J = 1,MA
18* B = Y + YLT/MA*J
19* CALL PLOT(A,B,2)
20* CALL PLOT(A+YZ1,B,2)
21* YNUM = YST + YDIV*FLOAT(J)
22* CALL NUMBER(A-.2 ,B-.2 ,YZ1,YNUM,90.0,N)
23* CALL PLOT(A,B,3)
24* 30 IF(I.NE. 2) GO TO 50
25* A = MM
26* B = NN + YLT
27* X = A
28* CALL PLOT(A,B,3)
29* 100 MA = (XEND - XST)/XDIV
30* DO 60 J = 1,MA
31* A = X + XLT/MA*J
32* CALL PLOT(A,B,2)
33* CALL PLOT(A,B+XZ2,2)
34* 60 CALL PLOT(A,B,3)
35* 50 IF(I.NE. 3) GO TO 70
36* A = MM + XLT
37* B = NN + YLT
38* CALL PLOT(A,B,3)
39* MA = (YEND - YST)/YDIV
40* Y = B
41* DO 80 J = 1,MA
42* B = Y - YLT/MA*J
43* CALL PLOT(A,B,2)
44* CALL PLOT(A+YZ1,B,2)
45* 80 CALL PLOT(A,B,3)
46* 70 IF(I.NE. 4) GO TO 20
47* A = MM + XLT
48* B = NN
49* CALL NUMBER(A-.2 ,B+.2 ,XZ2,YEND,0.0,N)
50* CALL PLOT(A,B,3)
51* MA = (XEND - XST)/XDIV
52* X = A
53* DO 90 J = 1,MA
54* A = X - XLT/MA*J
55* CALL PLOT(A,B,2)
56* CALL PLOT(A,B+XZ2,2)
57* XNUM = XEND - FLOAT(J)*XDIV
58* CALL NUMBER(A-.2 ,B-.2 ,XZ2,XNUM,0.0,N)
59* CALL PLOT(A,B,3)
60* 20 CONTINUE
61* XX = MM + XLT/2.0 - Z4*NC1*6.0/14.0
62* YY = NN - U.5
63* CALL SYMBL4(XX,YY,Z4,HEAD1,0.0,NC1)
64* XX = MM - U.5
65* YY = NN + YLT/2.0 - Z3*NC2*6.0/14.0
66* CALL SYMBL4(XX,YY,Z3,HEAD2,90.0,NC2)
67* RETURN
68* END

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1* SUBROUTINE RATIO(TEMP,TIM,ND,C2)
2* C.....RATIO EVALUATES TEMPERATURE(K) GIVEN FREQUENCY
3* COMMON /INTP/ FR(900),TEP(900),FMRK1,FMRK2
4* DIMENSION S(800)
5* COMMON /TEMP/ X(800), Y(800)
6* COMMON /TATA/ C(4)
7* COMMON /MIT/ II
8* C(1) = -.0000188652
9* C(2) = .0124469306
10* C(3) = 185.8372497559
11* T = TIM * TIM
12* C1 = C(1) * T + C(2) * TIM + C(3)
13* 55 DO 33 I = ND,II
14* N = I + 1
15* IF( TIM . LT.X(N)) GO TO 44
16* 33 CONTINUE
17* 44 ND = N - 2
18* IF(TIM .GE. X(II)) GO TO 131
19* SLP = (Y(N) - Y(II)) / (X(N) - X(II))
20* C2 = SLP * (TIM - X(II)) + Y(II)
21* C.....C1 = REFERENCE FREQUENCY C2 = SENSOR FREQUENCY
22* RATIO = C2 / C1
23* IF(RATIO.LT.FMRK1) GO TO 12
24* IF(RATIO.GT.FMRK2) GO TO 12
25* DO 1 I = 1,800,10
26* N = I
27* IF(RATIO.LT.FR(I)) GO TO 2
28* 1 CONTINUE
29* 2 ND = N - 11
30* DO 3 I = ND,N
31* IF(RATIO.LT.FR(I)) GO TO 4
32* 3 CONTINUE
33* C.....LINEAR INTERPOLATE IN THE CALIPRATION CURVE TO OBTAIN TEMPERATURE
34* 4 LL = I - 1
35* SLP = (TEP(LL) - TEP(I)) / (FR(LL) - FR(I))
36* TEMP = SLP * (RATIO - FR(I)) + TEP(I)
37* TEMP = TEMP + 273.15
38* RETURN
39* 131 X(1) = X(II-1)
40* X(2) = X(II)
41* Y(1) = Y(II-1)
42* Y(2) = Y(II)
43* II = 2
44* ND = 1
45* C.....READ THE TEMPERATURE TAPE
46* 141 CALL VARBIN(NW,1NB,S,800)
47* DO 150 I = 1,NW,2
48* IF(S(I+1).LT. 10.0) GO TO 150
49* IF(S(I+1).GT. 165.0) GO TO 150
50* II = II + 1
51* X(II) = S(I) - 12.0
52* Y(II) = S(I+1)
53* 150 CONTINUE
54* IF(II .LE. 2) GO TO 141
55* GO TO 55
56* 12 PRINT 13,RATIO,TIM,C1,C2,FMRK1,FMRK2,ND
57* 13 FORMAT(27H OUT OF INTERPOLATING RANGE ,6F15.8, 16)
58* NZ1 = ND - 20
59* NZ2 = ND + 20
60* PRINT 101, (X(I), Y(I), I = NZ1, NZ2)
61* 101 FORMAT( 7H TIME=, E15.8, 7H FREQ=, E15.8)
62* 20 RETURN
63* END

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1* SUBROUTINE ATMO
2* C.....ATMO COMPUTES STANDARD TEMPERATURE AND PRESSURE
3* COMMON /XXX/ LLL, STAIR
4* COMMON /VAB/ B(10), C(10), A(300), PO(300), AA(10)
5* COMMON /YL/ P
6* COMMON /AP/ ALT, TINF, RHO, VS, AMU, AK, AMFP, VEL, TAIR
7* DIMENSION SIT(300), SAM(300)
8* IF(LLL.EQ. 1) GO TO 57
9* DO 25 I = 1,5
10* IF(I.EQ. 3) GO TO 25
11* C(I) = C(I)*1.0E-03
12* 25 CONTINUE
13* DO 250 I = 1,272
14* J = 273 - I
15* SIT(I) = A(J)*1.0E+03
16* 250 SAM(I) = PO(J)*1.0E+02
17* DO 207 I = 1,272
18* A(I) = SIT(I)
19* 207 PO(I) = SAM(I)
20* 57 DO 10 I = 1,5
21* JJ = I
22* IF(ALT.LE. AA(I).AND. ALT.GT. AA(I+1)) GO TO 20
23* 10 CONTINUE
24* 20 IF(JJ.EQ. 3) GO TO 30
25* IF(LLL.EQ. 1) GO TO 61
26* TAIR = B(JJ) + C(JJ)*ALT
27* 61 STAIR = B(JJ) + C(JJ)*ALT
28* GO TO 131
29* 30 IF(LLL.EQ. 1) GO TO 65
30* TAIR = C(JJ)
31* 65 STAIR = C(JJ)
32* 131 KL = 1
33* DO 101 I = KL,272
34* KL = I
35* IF(ALT.LE. A(I).AND. ALT.GE. A(I+1)) GO TO 59
36* 101 CONTINUE
37* 59 P = PO(KL+1)-(A(KL+1)-ALT)*(PO(KL+1)-PO(KL))/(A(KL+1)-A(KL))
38* RETURN
39* END

1* SUBROUTINE INTEG(LL,LET,PRES,DEN)
2* C.....CALCULATES PRESSURE AND DENSITY GIVEN AIR TEMPERATURE
3* DIMENSION C(2), D(2), E(2)
4* COMMON /DAT/ ATD(1000), BTMP(1000), CGR(1000)
5* COMMON /STD/ A(50), B(50)
6* XO = 0.0289644
7* R = 8.31432
8* IF(LL.LT. LET) GO TO 10
9* C.....LINEAR INTERPOLATE IN THE RA08 PRESSURE
10* DO 20 I = 1,50
11* J = I
12* IF(ATD(LL).GE. A(I+1).AND. ATD(LL).LE. A(I)) GO TO 70
13* 20 CONTINUE
14* 70 PRES = B(J+1)-(A(J+1)-ATD(LL))*(B(J+1)-B(J))/(A(J+1)-A(J))
15* DEN = XO*PRES/(R*BTMP(LL))
16* RETURN
17* 10 K1 = LL
18* K = LL + 1
19* I = 1
20* C.....INTEGRATE USING OVERLAPPING LAGRANGE POLYNOMIALS
21* DO 30 J = K1,K
22* IF(J.EQ. LET) GO TO 30

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23* IF(J.EQ. 1) GO TO 30
24* X1 = ATD(J-1)
25* X2 = ATD(J)
26* X3 = ATD(J+1)
27* TERM1 = CGR(J-1)*XO/(R*BTMP(J-1))/((X1-X2)*(X1-X3))
28* TERM2 = CGR(J)*XO/(R*BTMP(J))/((X2-X1)*(X2-X3))
29* TERM3 = CGR(J+1)*XO/(R*BTMP(J+1))/((X3-X1)*(X3-X2))
30* C(I) = TERM1 + TERM2 + TERM3
31* D(I) = -(X2+X3)*TERM1-(X1+X3)*TERM2-(X1+X2)*TERM3
32* E(I)=X2*X3*TERM1+X1*X3*TERM2+X1*X2*TERM3
33* 30 I = I + 1
34* IF(K.NE. LET) GO TO 40
35* C(2) = C(1)
36* D(2) = D(1)
37* E(2) = E(1)
38* 40 IF(K1.NE. 1) GO TO 90
39* C(1) = C(2)
40* D(1) = D(2)
41* E(1) = E(2)
42* 90 XINT=(C(1)+C(2))*(ATD(K1)**3-ATD(K)**3)/6.0+(D(1)+D(2))*
43* 1(ATD(K1)**2-ATD(K)**2)/4.0+(E(1)+E(2))*(ATD(K1)-ATD(K))/2.0
44* PRES = PRES*EXP(-XINT)
45* DEN = XO*PRES/(R*BTMP(LL))
46* RETURN
47* END

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1* SUBROUTINE INITAL
2* COMMON /ANT/ T(100),X(100,4),XBAR(100,4),XDOT(100,4),XD00T(10
3* COMMON /ANT/ MF,MB,ML,MS,MK,MJ,MN,N,IG,TAP,TP,TMLTP
4* DIMENSION S6(4),S7(4),S8(4),XSMALL(4)
5* MJ = MB + 1
6* MS = MJ - MB
7* MK = MJ + 1
8* MN = MJ + MF - 1
9* ML = MN + 1
10* MPP = ML
11* TMLTP = T( ML ) - T( MN )
12* TP=T(MJ)
13* TAP = T(MJ) - T(MS)
14* PA = 1.75
15* S1=0.
16* S2=0.
17* S3=0.
18* S4=0.
19* S5=0.
20* S9=0.
21* DO 120 I = 1,N
22* S6(I) = 0.0
23* S7(I) = 0.0
24* 120 S8(I) = 0.0
25* DO 2778 J = 1,MF
26* DIFT = T(J) - T(1)
27* DO 122 I = 1, N
28* S6(I) = S6(I) + X(J,I)
29* S7(I) = S7(I) + DIFT * X(J,I)
30* 122 S8(I) = S8(I) + .5 * DIFT **2 *X(J,I)
31* S1 = 1. + S1
32* S2 = S2 + DIFT
33* S3 = S3 + DIFT **2
34* S9 = S3 *.5
35* S4 = S4 + DIFT **3 *.5
36* 2778 S5 = S5 + DIFT **4 *.25
37* DD = S1*S3*S5 + 2.*S2*S9*S4 - S3*S9**2 - S1*S4**2 - S5*S2**2

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38* COF1 = S3*S5 - S4**2
39* COF2 = S9*S4 - S2*S5
40* COF3 = S2*S4 - S3*S9
41* COF4 = S1*S5 - S9**2
42* COF5 = S2*S9 - S1*S4
43* COF6 = S1*S3 - S2**2
44* DO 133 I = 1, N
45* XBAR(1,I) = ( COF1 * S6(I) + COF2*S7(I) + COF3*S8(I)) / DD
46* XDOT(1,I) = ( COF2*S6(I) + COF4*S7(I) + COF5*S8(I)) / DD
47* XDDOT(1,I) = (COF3*S6(I) + COF5*S7(I) + COF6*S8(I)) / DD
48* DELT = T(2) - T(1)
49* XBAR(2,I) = XBAR(1,I) + DELT*XDOT(1,I) + .5*XDDOT(1,I)*DELT**2
50* 133 XDOT(2,I) = XDOT(1,I) + DELT*XDDOT(1,I)
51* DO 1002 NR = 2,MJ
52* NR1 = NR + 1
53* MMR = NF + NR
54* S2 = 0.
55* T0 = T(NR)
56* DO 144 I = NR1, MMR
57* 144 S2 = S2 + ( T(I) - T0) **4
58* DO 155 I = 1, N
59* S1 = 0.
60* DO 166 J = NR1, MMR
61* DIFT = T(J) - T0
62* XSMALL(1) = X(J,I) - XBAR(NR,I) - XDOT(NR,I) * DIFT
63* 166 S1 = S1 + XSMALL(1) * DIFT**2
64* DNU = 2. * XDDOT(NR-1,I) * PA**2 + S1
65* DDE = 2. * PA **2 + .5 * S2
66* XDDOT(NR,I) = DNU / DDE
67* IF(NR.EQ,MJ) GO TO 155
68* DELT = T(NR1) - T(NR)
69* XBAR(NR1,I) = XBAR(NR,I) + DELT*XDOT(NR,I) + .5*XDDOT(NR,I)*DELT**2
70* XDOT(NR1,I) = XDOT(NR,I) + XDDOT(NR,I)*DELT
71* 155 CONTINUE
72* 1002 CONTINUE
73* DO 1003 J = MK, ML
74* DIFT = T(J) - T(MJ)
75* DO 1003 I = 1, N
76* XDDOT(J,I) = XDDOT(MJ,I)
77* XDOT(J,I) = XDOT(MJ,I) + DIFT*XDDOT(MJ,I)
78* 1003 XBAR(J,I) = XBAR(MJ,I) + DIFT*XDOT(MJ,I) + .5*XDDOT(MJ,I)*DIFT**2
79* MDR=ML+1
80* DO 2125 JL =1,4
81* DO 2125 J=1,MDR
82* PRINT 2122,J,T(J),X(J,JL),XBAR(J,JL),XDOT(J,JL),XDDOT(J,JL)
83* 2123 CONTINUE
84* 2125 CONTINUE
85* 2122 FORMAT (1H ,I3,5X,F5.1,5X,4F20.7 )
86* RETURN
87* END

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```

1* SUBROUTINE DIRSIT
2* DIMENSION TDIF(200),DIFF(200),NDEX(200)
3* COMMON /ANT/ T(100),X(100,4),XBAR(100,4),XDOT(100,4),XDDOT(100,4)
4* COMMON /ANT/ MF,MB,ML,MS,MK,MJ,MN,N,IQ,TAP,TP,TMLTP
5* COMMON /DIST/ T00,XR,XS,XD,XDD,YR,YS,YD,YDD,ZR,ZS,ZD,ZDD,TE,TD,II
6* COMMON /DIST/ TER,TDD
7* K = 1
8* TMLTP = T(ML) - T(MN)
9* DO 9 INDEX = 1,2
10* MJ = MB + 1
11* MS = MJ - 1
12* MK = MJ + 1
13* 31 CONTINUE

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14* TP = T( MJ )
15* TAP = T(MJ) - T(MS)
16* 32 NS=0
17* NL=0
18* DO 50 I=MK,ML
19* DELX=X(I,K)-XBAR(I,K)
20* IF(DELX.LT.0.)GO TO 40
21* NS=NS+1
22* DIFF(NS) = DELX
23* TDIF(NS) = T(I)
24* NDEX(NS) = I
25* GO TO 50
26* 40 NL=NL+1
27* NZ1 = NL + MF
28* DIFF(NZ1)=DELX
29* TDIF(NZ1)=T(I)
30* NDEX(NZ1) = I
31* 50 CONTINUE
32* IF(II.EQ.1) GO TO 5
33* PRINT 10, NL,NS
34* 10 FORMAT (8H TEST 1 , 2I5 )
35* 5 CONTINUE
36* IF ( IABS( NL - NS ) . LE . IQ) GO TO 200
37* IF ( NL . LT . NS ) GO TO 110
38* NT = NL + MF
39* LLI = MF + 1
40* SGN=-1.
41* GO TO 1005
42* 110 NT=NS
43* LLI = 1
44* SGN=1.
45* 1005 SS=1000000.
46* IF(II.EQ.1) GO TO 6
47* PRINT 1, SGN,TAP,NL,NS
48* 1 FORMAT (8H STEP 1 ,2F15.5, 2I5)
49* 6 CONTINUE
50* 105 DO 1111 IX=LLI,NT
51* SL = 6. * SGN * DIFF(IX) / ( ( TDIF(IX) - T(M0))**3 - ( TDIF(IX)
52* 1 - TP ) ** 3 )
53* IF ( SL . GT . SS ) GO TO 1111
54* SS=SL
55* MI = IX
56* 1111 CONTINUE
57* TCOR = TOIF(MI)
58* TBAR = T( MS )
59* IR = MS
60* 185 SS=SGN*SS
61* IF(II.EQ.1) GO TO 7
62* PRINT 2, NS,MI,TCOR,SS,TBAR
63* 2 FORMAT (8H STEP 2 ,2I5,F15.5,20.10,F15.5 )
64* 7 CONTINUE
65* DO 190 I=IR,MJ
66* TEMP=T(I)-T(MS)
67* XDDOT(I,K)=XDDOT(I,K)+SS*TEMP
68* XDOT (I,K)= XDOT(I,K)+SS*TEMP**2/2.
69* 190 XBAR (I,K)= XBAR(I,K)+SS*TEMP**3/6.
70* POLY1=SS*TAP
71* POLY2=SS*TAP*TAP*TAP/6.
72* POLY3=SS*TAP*TAP/2.
73* DO 195 I=MK,ML
74* XDDOT(I,K)=XDDOT( I,K) +POLY1
75* TITP=T(I)-TP
76* XDOT (I,K)=XDOT(I,K)+POLY1*TITP+POLY3

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77* IF(T(I),EQ,TCOR)GO TO 193
78* XBAR(I,K)=XBAR(I,K)+POLY2+POLY3*TITP+POLY1*TITP**2/2.
79* GO TO 195
80* 193 XBAR(I,K) = X(I,K) + SGN * ( .2982E-07 ) * ABS( X(I,K) )
81* 195 CONTINUE
82* DO 2121 I=LLI,NT
83* NDIX=NDIX(I)
84* IF((X(NDIX,K) - XBAR(NDIX,K))*SGN.GT.0.) GO TO 2121
85* IF(I.NE.MI)XBAR(NDIX,K)=X(NDIX,K)-SGN*(.2982E-07)*ABS(X(NDIX,K))
86* 2121 CONTINUE
87* GO TO 32
88* 200 CONTINUE
89* NVB = K
90* K = K + 1
91* IF(K.LE.N) GO TO 31
92* MB = MB + 10
93* 9 CONTINUE
94* T00 = T(1)
95* XR = X(1,1)
96* XS = XBAR(1,1)
97* XD = XDOT(1,1)
98* XDU = XDDOT(1,1)
99* YR = X(1,2)
100* YS = XBAR(1,2)
101* YD = XDOT(1,2)
102* YDU = XDDOT(1,2)
103* ZR = X(1,3)
104* ZS = XBAR(1,3)
105* ZD = XDOT(1,3)
106* ZDO = XDDOT(1,3)
107* TER = X(1,4)
108* TE = XBAR(1,4)
109* TD = XDOT(1,4)
110* TDO = XDDOT(1,4)
111* DO 206 K = 1,NVB
112* DO 205 I=1,MN
113* X(I,K)=X(I+1,K)
114* XBAR(I,K)=XBAR(I+1,K)
115* XDOT(I,K)=XDOT(I+1,K)
116* XDDOT(I,K)=XDDOT(I+1,K)
117* 205 CONTINUE
118* 206 CONTINUE
119* DO 207 I = 1,MN
120* T(I) = T(I+1)
121* 207 CONTINUE
122* DO 220 K = 1,NVB
123* J=ML
124* XBAR(J,K) = XBAR(J-1,K) + TMLTP*XDOT(J-1,K) + TMLTP*TMLTP*XDDOT(J
125* I-1,K) * .5
126* XDOT(J,K) = XDOT(J-1,K) + TMLTP*XDDOT(J-1,K)
127* 221 XDDOT(J,K) = XDDOT(J-1,K)
128* 220 CONTINUE
129* IF(II.EQ.1) GO TO 8
130* DO 2125 JL = 1,4
131* DO 3 J=1,ML
132* PRINT 2122,J,T(J),X(J,JL),XBAR(J,JL),XDOT(J,JL),XDDOT(J,JL)
133* 3 CONTINUE
134* 2125 CONTINUE
135* 2122 FORMAT (1H ,I3,5X,F5.1,5X,4F20.7 )
136* II = 1
137* 8 CONTINUE
138* RETURN
139* END

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1* SUBROUTINE HANDR(IK)
2* COMMON /AP/ ZOT, TINF, RHO, VS, AMU, AK, AMFP, VEL, TAIR
3* COMMON /RFAC/ ZSR(15), ZRB(15), ZRW(15)
4* COMMON /REG/ IC, IS, IT, IF
5* COMMON /CLEN/ CLB,CLW,CLF,CLFILM
6* COMMON /HR/ HB,HW,HF,RB,RW,RF
7* COMMON /XXY/ IRB, IRW, IRF
8* COMMON /YL/ P
9* DATA CP/1003./
10* DATA ACB, ACW, ACF/0.9, 0.9, 0.9/
11* XO = .0289644
12* R = 8.31432
13* AMU = 1.458E-06*TAIR**(.3/.2.)/(TAIR+110.4)
14* AK = 6.325E-07*TAIR**(.3/.2.)/(TAIR+245.4*10.**(-12./TAIR))
15* AK = AK*.8186.0465
16* VS = SQRT(1.4*R*TAIR/XO)
17* RHO = P*XO/(R*TAIR)
18* AMFP = R*TAIR/(P*(2.**.5)*3.1415926*6.02257E+26*(3.65F-10)**2)
19* AMFP = AMFP*.1E+03
20* IF(IK.EQ. 1) GO TO 12
21* AM=VEL/V5
22* SR=0.837*AM
23* PR=CP*AMU/AK
24* ARB=1.167
25* ARW=1.167
26* IF (SR .GT. 10.) GO TO 2
27* DO 1 I=1,13
28* DSR=ZSR(I)-SR
29* IF (DSR .LT. 0.) GO TO 1
30* ERRR=DSR/(ZSR(I)-ZSR(I-1))
31* DIFFRB=ZRB(I)-ZRB(I-1)
32* DIFFRW=ZRW(I)-ZRW(I-1)
33* CORRRB=ERRR*DIFFRB
34* CORRRW=ERRR*DIFFRW
35* ARB=ZRB(I)-CORRRB
36* ARW=ZRW(I)-CORRRW
37* GO TO 2
38* 1 CONTINUE
39* 2 REB=RHO*VEL*CLB/AMU
40* AMRB=AM/REB
41* AMSRB=AM/SQRT(REB)
42* IRB=IC
43* IF (REB .LE. 1. .AND. AMRB .GT. 0.01) IRB=IS
44* IF (REB .LE. 1. .AND. AMRB .GT. 0.1) IRB=IT
45* IF (REB .GT. 1. .AND. AMSRB .GT. 0.01) IRB=IS
46* IF (REB .GT. 1. .AND. AMSRB .GT. 0.1) IRB=IT
47* IF (AMRB .GT. 3.) IRB=IF
48* AKNB=AMFP/CLB
49* RB=0.85*(AKNB*(ARB-0.85))/(AKNB+0.3)
50* IF (IRB .NE. IF .AND. IRB .NE. IT) GO TO 4
51* FHB=289.*ACB*VS*RHO
52* IF (SR .LT. 1.E-8) GO TO 3
53* T=1./(1.+0.3275911*SR)
54* ERFA=0.254829592*T-0.284496736*T**2+1.42141374*T**3
55* ERFB=-1.453152027*T**4+1.061405429*T**5
56* ERF=1.-(ERFA+ERFB)*EXP(-SR**2)
57* FHB=0.44311*FHB*((2.*SR+1./SR)*ERF+1.12838*EXP(-SR**2))
58* 3 HB=FHB
59* IF (IRB .EQ. IF) GO TO 5
60* 4 ANUCB=2.+0.37*REB**0.6*PR**0.333
61* HB=ANUCB*AK/CLB
62* IF (IRB .EQ. IC) GO TO 5
63* ANUSB=ANUCB/(1.+3.42*ANUCB*AM/(REB*PR))
64* SHB=ANUSB*AK/CLB

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65* HB=SHB
66* IF (IRB.EQ. 15) GO TO 5
67* IF (AMRB.LT. 1.) GO TO 5
68* Y=0.91024*ALOG(AMRB)
69* HB=Y*FHB+(1.-Y)*SHB
70* 5 REW=RHO*VEL*CLW/AMU
71* AMRW=AM/REW
72* AMSRW=AM/SORT(REW)
73* IRW=IC
74* IF (REW.LE. 1. .AND. AMRW.GT. 0.01) IRW=IS
75* IF (REW.LE. 1. .AND. AMRW.GT. 0.1) IRW=IT
76* IF (REW.GT. 1. .AND. AMSRW.GT. 0.01) IRW=IS
77* IF (REW.GT. 1. .AND. AMSRW.GT. 0.1) IRW=IT
78* IF (AMRW.GT. 3.) IRW=IF
79* AKNW=AMFP/CLW
80* RW = 0.845 + (AKNW*(RW - 0.845))/(AKNW + 0.3)
81* IF (IRW.NE. IF .AND. IRW.NE. IT) GO TO 7
82* Y=0.5*SR**2
83* Z=T/3.75
84* IF (Z.GT. 1.) PRINT 6
85* 6 FORMAT(1H,51HVELOCITY TOO LARGE FOR BESSEL FUNCTION APPROXIMATOR)
86* BMOA=1.+3.5156229*Z**2+3.0899424*Z**4+1.2067492*Z**6
87* BMOB=0.2659732*Z**8+0.0360768*Z**10+0.0045813*Z**12
88* BMO=BMOA+BMOB
89* BM1TA=0.5+0.87890594*Z**2+0.51490869*Z**4+0.15084934*Z**6
90* BM1TB=0.02658733*Z**8+0.00301532*Z**10+0.00032411*Z**12
91* BM1T=BM1TA+BM1TB
92* HWA=289.*ACW*VS*RHO*EXP(-T)
93* HWB=(1.+2.*T)*BMO+2.*T**2*BM1T
94* FHW=HWA+HWB
95* HW=FHW
96* IF (IRW.EQ. IF) GO TO 12
97* 7 CONTINUE
98* ANUCW=2.+0.37*(REW**0.6)*(PR**0.333)
99* ANUSW=ANUCW/(1.+3.42*ANUCW*AM/(REW*PR))
100* SHW=ANUSW*AK/CLW
101* HW=SHW
102* IF (IRW.EQ. 15) GO TO 120
103* IF (AMRW.LT.1.0) GO TO 120
104* Y=0.91024*ALOG(AMRW)
105* HW=Y*FHW+(1.-Y)*SHW
106* 120 CONTINUE
107* IF (AMSRW.GT.0.03) GO TO 12
108* 8 IF (REW.GT. 4000.) GO TO 9
109* CHW=(AK/CLW)*(0.43+0.48*REW**0.5)
110* GO TO 11
111* 9 IF (REW.GT. 40000.) GO TO 10
112* CHW=(AK/CLW)*(0.43+0.174*REW**0.618)
113* GO TO 11
114* 10 CHW=(AK/CLW)*(0.43+0.0239*REW**0.805)
115* 11 HW=CHW
116* RW = 0.845
117* IF (AMSRW.LT.0.003) GO TO 12
118* QUAN = 1000.0*AMSRW
119* Y = ALOG10(QUAN) - 0.48
120* HW = Y * SHW + (1. - Y) * CHW
121* 12 REF=RHO*VEL*CLF/AMU
122* AMRF=AM/REF
123* AMSRF=AM/SORT(REF)
124* IRF=IC
125* IF (REF.LE. 1. .AND. AMRF.GT. 0.01) IRF=IS
126* IF (REF.LE. 1. .AND. AMRF.GT. 0.1) IRF=IT
127* IF (REF.GT. 1. .AND. AMSRF.GT. 0.01) IRF=IS
128* IF (REF.GT. 1. .AND. AMSRF.GT. 0.1) IRF=IT
129* IF (AMRF.GT. 3.) IRF=IF
130* IF (IRF.NE. IF .AND. AMRF.LT. 1.) GO TO 13
131* RFF=1.167
132* RF=RFF
133* FHF=289.*ACF*VS*RHO
134* HF=FHF
135* IF (IRF.EQ. IF) GO TO 17

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136* 13 AKNFT=ANFP/CLF
137* AKNFT=AKNF*(SORT(REF)/7.2)
138* RFT = 0.845 + (AKNFT*0.322)/(AKNFT + 0.3)
139* RF=RFT
140* X2=(REF*PR)/(6.9*AM**2)
141* X=SORT(X2)
142* IF (X.GT. 2.5) GO TO 14
143* T=1./(1.+0.3275911*X)
144* ERFA=0.258829592*T-0.284496736*T**2+1.421413741*T**3
145* ERFB=-1.453152027*T**4+1.061405429*T**5
146* ERFX=(ERFA+ERFB)*EXP(-X2)
147* ANUF=(EXP(X2)*ERFX-1.+1.1283792*X)*AM*2.62
148* GO TO 15
149* 14 ANUF=((0.5641896/X)-1.+1.1283792*X)*AM*2.62
150* 15 SHF=(AK/CLF)*ANUF
151* HF=SHF
152* IF (AMRF.LT. 1.) GO TO 16
153* Y=0.91024*ALOG(AMRF)
154* RF=Y*RFF+(1.-Y)*RFT
155* HF=Y*FHF+(1.-Y)*SHF
156* GO TO 17
157* 16 IF (AMSRF.GT.0.03) GO TO 17
158* IF (AMSRF.GT.0.003) GO TO 260
159* RF = 0.845
160* HF = (AK/CLF)*.664*(REF**0.5)*(PR**0.333)
161* GO TO 17
162* 260 CONTINUE
163* QUAN = 1000. * AMSRF
164* Y = ALOG10(QUAN) - 0.48
165* IF (IRF.EQ. IC) RF = .845
166* CHF = (AK/CLF)*0.664*(REF**0.5)*(PR**0.333)
167* HF = Y * HF + (1.0 - Y) * CHF
168* 17 CONTINUE
169* RETURN
170* END

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25000.00 METERS

ATMOSPHERIC PARAMETERS

ALTITUDE(METER)= .24992+05
 SENSOR TEMP(DEG K)= 218.4
 PRESSURE(NEWTON/M**2)= .2552+04
 DENSITY(KGM/M**3)= .4081-01
 VELOCITY OF SOUND(M/SEC)= 295.9
 VISCOSITY(KGM/(M*SEC))= .1428-04
 THERMAL CONDUCTIVITY(WATTS/METER)= .1962-01
 MEAN FREE PATH(METER)= .1991-05

HEAT CONDUCTION PARAMETERS

	BEAD	WIRE	FILM	SENSOR
HK(WATTS/(M**2*DEG K))=				237.3
K1=				.9992
K2(DEG K)=				.4375
LAMDA(1/METER)=		2510.	148.4	
3*DECAY LENGTH(METER)=		.1195-02	.2022-01	
CONDUCTION TEMP CORRECTION(DEG K)=				-.153

AERODYNAMIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
CONV COEF(WATTS/(M**2*DEG K))=	213.9	1220.	23.44	
RECOVERY COEFFICIENT=	.8643	1.034	.8450	
FLOW REGION=	S	S	C	
AERODYN HEAT(DEG K)=	.1211	.1449	.1184	
AERODYNAMIC TEMP CORRECTION(DEG K)=				-.574-01

DYNAMIC LAG PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TIME CONSTANT(SEC)=	.4856	.1497-02	.5657	.2303
TEMPERATURE(DEG K)=	218.4	218.3	219.4	
EQUILIBRIUM TEMP(DEG K)=	218.6	218.1	219.4	218.4
AK(I)=	.9989	.9998	.9505	
BK(I)(DEG K)=	.9537	.2952	12.30	
TEMP TIME DER(DEG K/SEC)=				-.535-01
DYNAMIC TEMP LAG CORRECTION(DEG K)=				-.123-01

RADIATION HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TOTAL RADIATION INPUT(W/M**2)=	119.7	144.8	99.50	
RADIATION TEMP CORRECTION(DEG K)=				-.237

ELECTRIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
ELECTRIC HEATING(WATTS/M**2)=				20.0
ELECTRIC TEMP CORRECTION(DEG K)=				-.443-01

35000.00 METERS

ATMOSPHERIC PARAMETERS
 ALTITUDE(METER)= .34993+05
 SENSOR TEMP(DEG K)= 237.0
 PRESSURE(NEWTON/M**2)= .5752+03
 DENSITY(KGM/M**3)= .8503-02
 VELOCITY OF SOUND(M/SEC)= 307.7
 VISCOSITY(KGM/(M*SEC))= .1524-04
 THERMAL CONDUCTIVITY(WATTS/METER)= .2110-01
 MEAN FREE PATH(METER)= .9555-05

HEAT CONDUCTION PARAMETERS

	BEAD	WIRE	FILM	SENSOR
HK(WATTS/(M**2*DEG K))=				158.7
K1=				.9902
K2(DEG K)=				3.634
LAMDA(1/METER)=		1679.	136.0	
3*DECAY LENGTH(METER)=		.1787-02	.2215-01	
CONDUCTION TEMP CORRECTION(DEG K)=				-.651

AERODYNAMIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
CONV COEF(WATTS/(M**2*DEG K))=	160.8	545.5	19.93	
RECOVERY COEFFICIENT=	.9136	1.347	.8455	
FLOW REGION=	S	T	C	
AERODYN HEAT(DEG K)=	.7363	1.085	.6814	
AERODYNAMIC TEMP CORRECTION(DEG K)=				-.372

DYNAMIC LAG PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TIME CONSTANT(SEC)=	.6456	.3346-02	.6500	.3252
TEMPERATURE(DEG K)=	237.0	236.9	236.8	
EQUILIBRIUM TEMP(DEG K)=	237.1	237.0	236.8	237.0
AK(I)=	.9981	.9994	.9284	
BK(I)(DEG K)=	1.935	1.449	17.98	
TEMP TIME DER(DEG K/SEC)=				-.268
DYNAMIC TEMP LAG CORRECTION(DEG K)=				-.878-01

RADIATION HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TOTAL RADIATION INPUT(W/M**2)=	119.7	144.8	99.50	
RADIATION TEMP CORRECTION(DEG K)=				-.320

ELECTRIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
ELECTRIC HEATING(WATTS/M**2)=				20.0
ELECTRIC TEMP CORRECTION(DEG K)=				-.629-01

50000.00 METERS

ATMOSPHERIC PARAMETERS

ALTITUDE(METER)= .49986+05
 SENSOR TEMP(DEG K)= 280.0
 PRESSURE(NEWTON/M**2)= .7992+02
 DENSITY(KGM/M**3)= .1061-02
 VELOCITY OF SOUND(M/SEC)= 328.8
 VISCOSITY(KGM/(M*SEC))= .1663-04
 THERMAL CONDUCTIVITY(WATTS/METER)= .2330-01
 MEAN FREE PATH(METER)= .7661-04

HEAT CONDUCTION PARAMETERS

	BEAD	WIRE	FILM	SENSOR
HK(WATTS/(M**2*DEG K))=				68.39
K1=				.7907
K2(DEG K)=				73.06
LAMDA(1/METER)=		707.9	128.1	
3*DECAY LENGTH(METER)=		.4238-02	.2343-01	
CONDUCTION TEMP CORRECTION(DEG K)=				-8.20

AERODYNAMIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
CONV COEF(WATTS/(M**2*DEG K))=	66.45	96.55	15.75	
RECOVERY COEFFICIENT=	1.149	1.610	.8539	
FLOW REGION=	T	T	S	
AERODYN HEAT(DEG K)=	14.17	19.85	10.53	
AERODYNAMIC TEMP CORRECTION(DEG K)=				-7.81

DYNAMIC LAG PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TIME CONSTANT(SEC)=	1.554	.1882-01	.7747	.7685
TEMPERATURE(DEG K)=	280.0	277.2	269.5	
EQUILIBRIUM TEMP(DEG K)=	278.3	283.5	269.6	279.5
AK(I)=	.9926	.9950	.8743	
BK(I)(DEG K)=	17.71	22.29	40.14	
TEMP TIME DER(DEG K/SEC)=				-.359
DYNAMIC TEMP LAG CORRECTION(DEG K)=				-.310

RADIATION HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
TOTAL RADIATION INPUT(W/M**2)=	119.7	144.8	99.50	
RADIATION TEMP CORRECTION(DEG K)=				-.704

ELECTRIC HEATING PARAMETERS

	BEAD	WIRE	FILM	SENSOR
ELECTRIC HEATING(WATTS/M**2)=				20.0
ELECTRIC TEMP CORRECTION(DEG K)=				-.166

APPENDIX B

SENSOR PARAMETERS

The following is a list of input parameters for the ARCAS bead-wire-film temperature sensor as contained in various references.

Thermistor		
Parameter	Value	Reference
D	$.32 \cdot 10^{-3} \text{ m}$	19
ρ	$3.9 \cdot 10^3 \text{ kg/m}^3$	17
C	$5.0 \cdot 10^2 \text{ J/(kg}^\circ\text{K)}$	17
ϵ_L	.10	17
ϵ_S	.16	17

Platinum (90% - Iridium (10%) wire		
Parameter	Value	Reference
D	$.25 \cdot 10^{-4} \text{ m}$	19
ρ	2161 kg/m^3	7
C	$135.2 \text{ J/(kg}^\circ\text{K)}$	7
k	$30.98 \text{ J/(mS}^\circ\text{K)}$	7
ϵ_L	.10	17
ϵ_S	.19	17
ℓ	.0032 m	1

Silver film		
Parameter	Value	Reference
D	$.4 \cdot 10^{-5} \text{ m}$	1
ρ	$10.5 \cdot 10^3 \text{ kg/m}^3$	5, 7
C	$233.6 \text{ J/(kg}^\circ\text{K)}$	7
k	$407.7 \text{ J/(S}^\circ\text{Km)}$	7
ϵ_L	.02	20
ϵ_S	.01	15
ℓ inner	.03 m	1
ℓ outer	.036 m	1

Mylar film		
Parameter	Value	Reference
D	$.25 \cdot 10^{-4} \text{ m}$	1
ρ	$1.394 \cdot 10^3 \text{ kg/m}^3$	8
C	$1.32 \cdot 10^3 \text{ J/(kg}^\circ\text{K)}$	8
k	$.152 \text{ J/(s}^\circ\text{Km)}$	8
ϵ_L	.451	15
ϵ_S	.0281	15

A procedure is discussed next for calculating the emissivity over the entire film. The outer legs of the film strip consist of a composite silver-mylar layer. The total emissivity of this strip can be computed from the following equation.

$$\epsilon_{\text{My-Ag}} = \epsilon_{\text{My}} + (1 - \alpha_{\text{My}}) \left[(1 - \alpha_{\text{Ag}}) \epsilon_{\text{My}} + \epsilon_{\text{Ag}} \right]^{19} \quad (61)$$

For long wave radiation, the emissivities are

$$\epsilon_{\text{My}} = .451, \quad \epsilon_{\text{Ag}} = .02, \quad \epsilon_{\text{My-Ag}} = .710$$

For short wave radiation, the emissivities are

$$\epsilon_{\text{My}} = .028, \quad \epsilon_{\text{Ag}} = .01, \quad \epsilon_{\text{My-Ag}} = .065$$

The inner film strip has the radiation emission properties of silver. In order to determine an effective emissivity over the entire film, the emissivities of the inner and outer film strips are averaged together, using their lengths as weighting factors.

$$\epsilon_{\text{fL}} = \left[2(.710) .036 \text{ m} + .02 (.03 \text{ m}) \right] / \left[2(.036 \text{ m}) + .03 \text{ m} \right] = .51$$

$$\epsilon_{\text{fS}} = \left[2(.065) .036 \text{ m} + .01 (.03 \text{ m}) \right] / \left[2(.036 \text{ m}) + .03 \text{ m} \right] = .05$$

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