The Measurement of Temperature in the Stratosphere and Mesosphere

HAROLD N. BALLARD

Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.

(Manuscript received 3 June 1966, in revised form 12 September 1966)

ABSTRACT

Careful consideration of the heat transfer equations for a rocket-borne stratospheric temperature sensor in the form of a spherical bead thermistor coupled with an experimental analysis of the physical, thermodynamic and electrical characteristics of the rocketsonde, indicated that the corrections to the observed thermistor temperatures could be substantially reduced through development of a new rocketsonde. Redesign of the rocketsonde temperature sensor reduced the theoretical temperature correction at 65 km from a value of 36C for the Delta-I temperature sensing instrument to approximately 6C for the new design. Temperature data obtained with the new stratospheric temperature sonde STS-1 showed that, after instrument expulsion at 74 km and at rocket nose-cone temperature near 100C, the thermistor temperatures at and below 60 km were, without correction, in close agreement with those predicted by the U. S. 1962 Standard Atmosphere.

1. Introduction

By the end of the International Quiet Sun Year (IQSY) techniques for the determination of temperature in the stratosphere had been implemented in rocket flights at Meteorological Rocket Network stations through the use of various rocketsonde configurations in which the spherical bead thermistor served as the temperature sensing element.¹ Fig. 1 shows the basic elements of such a system.

¹ Ballard, H. N., 1966: The measurement of temperature in the stratosphere and mesosphere. Preprint No. 66-385, Sixth Conf. Applied Meteorology (Aerospace Meteorology), Amer. Meteor. Soc., Los Angeles, Calif.

FIG. 1. Temperature and wind sensing system.

Fig. 2 is a typical atmospheric temperature-time record as obtained with the Delta-I type mounting shown in Fig. 3 and recorded on the TMQ-5 meteorological recorder. Fig. 4 shows the corresponding temperature-altitude profiles obtained from the temperature record of Fig. 2 and as corrected according to the Wagner (1964) correction which is presented in Table 1. The correction magnitudes are dependent upon the expulsion altitude and fall velocity of the thermistor. The instrument position was determined by the AN/FPS-16 radar system.

FIG. 2. Temperature-time record, Delta-I instrument.

2. Principal modes of heat transfer

Represented in Fig. 5 are the principal modes of heat transfer between the thermistor and its surroundings. These modes are long wave radiation R_{be} from the environment below, solar radiation R_s , radio frequency radiation R_{rf} from the rocketsonde transmitter, long wave radiation R_{ai} from the instrument above, long wave radiation R_{ae} from the environment above, long wave radiation R_e from the thermistor to its surrounding environment, heat conduction H_{cd} between the thermistor and the thermistor mount, and convective heat transfer H_{cv} between the thermistor and the surrounding air. In the analysis, the convective heat transfer term includes the effects of aerodynamic and ohmic heating of the thermistor bead.

The heat transfer expressions as written in Fig. 5 are similar to those used by Wagner (1964) in a theoretical study concerning the thermal equilibrium of the bead thermistor with a nonsteady-state heat transfer environment.

The numerical values (expressed in microwatts, Fig. 5) for each transfer term are applicable to the Delta-I rocketsonde (Clark and McCoy, 1965) at an altitude of 65 km. The heat transfer rates are indicative of the relative contribution of each heat transfer process. A study of the various terms indicates that there is:

1) A net loss of energy per unit time of $2 \mu\text{W}$ due to long wave radiation.

FIG. 3. Delta-I temperature sonde thermistor mount.

FIG. 4. Temperature-altitude profile, Delta-I temperature sonde, showing uncorrected and corrected temperatures (Table 1).

2) A net gain of energy per unit time of $15 \mu\text{W}$ caused by solar radiation. (No account was taken of the radiation absorbed by the thermistor leads.)

3) A net gain of energy per unit time of $160 \mu\text{W}$ caused by heat conduction from the thermistor mounting posts. (No consideration was given here to the convective heat transfer from the mounting posts to the surrounding atmosphere.)

4) A net transfer of energy per unit time by convection of $5 \mu\text{W}$ per degree temperature difference between the thermistor and the surrounding atmosphere. [The convective heat transfer coefficient $h_t = 4 \times 10^{-4} \text{ cal cm}^{-2} \text{ sec}^{-1} (\text{°K})^{-1}$ is based upon the work of Barr (1961).]

5) An aerodynamic-heating air temperature increase of 15.0C . (Recovery factor $r = 1.10$, fall velocity $v = 165 \text{ m sec}^{-1}$.)

6) An electrical-heating thermistor temperature increase of 7.8C . [Electrical power dissipation $W = 70 \mu\text{W}$, dissipation factor $S_t = 9 \mu\text{W} (\text{°K})^{-1}$.]

If it is assumed that the thermistor remains at an altitude in the neighborhood of 65 km for a time longer than the response time τ_t of the thermistor, then the rates of input energy to the thermistor listed in 1)–3) above would correspond to a lowering of the thermistor temperature by 0.3C due to the long wave radiation, an increase in the thermistor temperature of approximately 1.7C due to solar radiation, and an increase in the thermistor temperature of 17.8C due to heat conduction from the thermistor supports.

TABLE 1. Total temperature corrections ($^{\circ}\text{C}$) for various fall rates (percentages of standard). Initial expulsion altitude, 70 km.

Altitude in km	Fall rates faster than standard (per cent)												Standard fall rate correction	Fall rates slower than standard (per cent)											
	40	30	20	18	16	14	12	10	8	6	4	2		2	4	6	8	10	12	14	16	18	20	30	40
65	41.5	40.0	38.5	38.0	37.5	37.0	36.5	36.5	36.0	36.0			35.5	35.0	35.0	34.5	34.5	34.0	33.5	33.5	33.5	33.0	32.5	31.5	
64	37.5	36.0	34.5	34.0	34.0	33.5	33.0	32.5	32.5	32.0			32.0	32.0	31.5	31.0	31.0	30.5	30.5	30.5	30.0	29.0	28.5		
63	34.0	33.0	31.5	31.0	31.0	30.5	30.0	29.5	29.5	29.0			29.0	29.0	28.5	28.0	28.0	28.0	27.5	27.5	27.0	26.5	25.5		
62	31.5	30.0	28.5	28.0	28.0	27.5	27.5	27.0	27.0	26.5			26.5	26.5	26.0	25.5	25.5	25.5	25.0	25.0	25.0	24.0	23.5		
61	28.0	26.5	25.5	25.5	25.0	24.5	24.5	24.0	24.0	23.5			23.5	23.5	23.0	23.0	22.5	22.5	22.5	22.0	22.0	21.5	21.0		
60	24.5	23.5	22.5	22.0	22.0	21.5	21.5	21.0	21.0	20.5			20.5	20.5	20.0	20.0	19.5	19.5	19.5	19.5	19.0	18.5	18.0		
59	21.0	20.0	19.0	19.0	18.5	18.5	18.0	18.0	17.5				17.5	17.5	17.0	17.0	17.0	16.5	16.5	16.5	16.5	16.0	15.5		
58	18.0	17.5	16.5	16.5	16.0	16.0	15.5	15.5	15.0				15.0	15.0	15.0	14.5	14.5	14.5	14.5	14.0	14.0	13.5			
57	14.5	14.0	13.0	13.0	13.0	12.5	12.5	12.5	12.0	12.0			12.0	12.0	12.0	11.5	11.5	11.5	11.5	11.5	11.0	11.0	10.5		
56	12.5	11.5	11.0	11.0	11.0	10.5	10.5	10.5	10.0	10.0			10.0	10.0	10.0	10.0	9.5	9.5	9.5	9.5	9.5	9.0	9.0		
55	10.5	9.5	9.5	9.0	9.0	9.0	9.0	8.5	8.5	8.5			8.5	8.5	8.5	8.5	8.5	8.0	8.0	8.0	8.0	8.0			
54	9.0	8.5	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5			7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0			
53	8.0	7.5	7.5	7.5	7.5	7.0	7.0	7.0	7.0	7.0			7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0			
52	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0			6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0			
51	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5			5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5			

These values for the changes in the thermistor temperature were determined by the thermistor dissipation factor. Expressions for the dissipation factor S_t and the time constant τ_t are developed in Eqs. (2.1) through (2.7).

Let the modes of energy transfer be those of radiation R , conduction H_{cd} , convection H_{cv} , plus an incremental input of electrical energy E . Let the initial conditions be such that a thermal steady state has been reached for all processes with electrical energy input E_1 , thermistor temperature $T_1 = T_e + T_{01}$, where T_e is the environment temperature, T_{01} the temperature increment due to electrical heating, and T_s the support post temperature ($= T_e$). Let the conditions be changed such that electrical energy $E_2 > E_1$ is added to the thermistor resulting in the thermistor temperature coming to a new equilibrium value $T_2 = T_e + T_{02} > T_1$, all other external conditions remaining the same. The thermistor dissipation factor is experimentally determined by this method. Then,

$$mc \frac{dT_1}{dt} = \frac{dE_1}{dt} + \frac{dR_1}{dt} + \frac{dH_{cd1}}{dt} + \frac{dH_{cv1}}{dt} = 0, \quad (2.1)$$

$$mc \frac{dT_2}{dt} = \frac{dE_2}{dt} + \frac{dR_2}{dt} + \frac{dH_{cd2}}{dt} + \frac{dH_{cv2}}{dt} = 0. \quad (2.2)$$

Let $P_2 = dE_2/dt$ and $P_1 = dE_1/dt$ (the electrical thermistor power). Subtracting (2.1) from (2.2),

$$P_2 - P_1 = - \left[\frac{d}{dt} (R_2 - R_1) + \frac{d}{dt} (H_{cd2} - H_{cd1}) + \frac{d}{dt} (H_{cv2} - H_{cv1}) \right]. \quad (2.3)$$

Substitution of the expressions for the rates of heat transfer by conduction, convection, and radiation with $T = T_e + T_0$ and $T_0 \ll T_e$ gives

$$P_2 - P_1 = - \left\{ [\sigma A T_e^4 - \sigma A (T_e + T_{02})^4] - [\sigma A T_e^4 - \sigma A (T_e + T_{01})^4] + \frac{2K\beta}{X} [T_s - (T_e + T_{02})] - \frac{2K\beta}{X} [T_s - (T_e + T_{01})] + hA [T_e - (T_e + T_{02})] - hA [T_e - (T_e + T_{01})] \right\}. \quad (2.4)$$

DELTA I ROCKETSONDE-ALTITUDE 65 KM

h -CONVECTIVE HEAT TRANSFER COEFFICIENT
 $= 4 \times 10^{-4} \text{ cal cm}^{-2} \text{ sec}^{-1} \text{ } ^\circ\text{K}^{-1}$

r -RECOVERY FACTOR = 1.10

v -FALL VELOCITY = 165 m/sec

C_p -SPECIFIC HEAT OF AIR (CONSTANT PRESSURE)
 $= 1.0 \times 10^7 \text{ cm}^2 \text{ sec}^{-2} \text{ } ^\circ\text{K}^{-1}$

W -ELECTRICAL POWER ACROSS THERMISTOR
 $= 70 \text{ } \mu\text{ watts}$

$\frac{1}{S}$ -CHANGE IN TEMPERATURE / μ watts OF POWER
 $= .16 \text{ } ^\circ\text{C} / \mu\text{ watts}$

J_1 -SOLAR CONSTANT = $.045 \text{ cal cm}^{-2} \text{ sec}^{-1}$ ($J + 35\%$)

σ -STEFAN BOLTZMANN CONSTANT

A -THERMISTOR SURFACE AREA = $3.22 \times 10^{-3} \text{ cm}^2$

a -ABSORPTION COEFFICIENT FOR ALUMINUM = .1

$$T_{aer} = \frac{rv^2}{2c_p} \quad T_{ohmic} = \frac{W}{S}$$

T -THERMISTOR TEMPERATURE

T_s -THERMISTOR SUPPORT TEMPERATURE

T_0 -TEMPERATURE OF IMMEDIATE ENVIRONMENT

T_{be} -TEMPERATURE OF ENVIRONMENT BELOW

T_{ae} -TEMPERATURE OF ENVIRONMENT ABOVE

T_{ai} -TEMPERATURE OF INSTRUMENT ABOVE

K -THERMAL CONDUCTIVITY OF LEAD WIRE
 $= .074 \text{ cal cm}^{-1} \text{ sec}^{-1} \text{ } ^\circ\text{K}^{-1}$

β -CROSS-SECTIONAL AREA OF LEAD WIRE
 $= 5.1 \times 10^{-6} \text{ cm}^2$

X -LENGTH OF LEAD WIRE = 1 cm

C -SPECIFIC HEAT OF THERMISTOR
 $= .18 \text{ cal gm}^{-1} \text{ } ^\circ\text{K}^{-1}$

M -THERMISTOR MASS = $3.9 \times 10^{-5} \text{ gm}$

$$S = \left[4\sigma AT_0^3 + \frac{2K\beta}{X} + hA \right]$$

$$\tau\text{-TIME CONSTANT} = \frac{mc}{S} = 3.1 \text{ sec}$$

FIG. 5. Principal modes of heat transfer for rocketsonde thermistor.

With the approximation that $T_0 \ll T_e$, the above expression simplifies to

$$P_2 - P_1 = 4\sigma A T_e^3 (T_{02} - T_{01})$$

$$+ \frac{2K\beta}{X} (T_{02} - T_{01}) + hA (T_{02} - T_{01}). \quad (2.5)$$

The dissipation factor S_t then becomes

$$S_t = \frac{P_2 - P_1}{T_{02} - T_{01}} = 4\sigma A T_e^3 + \frac{2K\beta}{X} + hA. \quad (2.6)$$

The time constant τ_t is given by the expression $m_t c_t / S_t$. Thus,

$$\tau_t = \frac{m_t c_t}{4\sigma A_t T_e^3 + \frac{2K\beta}{X} + hA}. \quad (2.7)$$

The term $4\sigma A_t T_e^3$ gives the rate of energy transfer per degree Kelvin by long wave radiation, the term $2K\beta/X$ is the heat transfer rate per degree Kelvin due to conduction along the thermistor leads between the thermistor and the thermistor support, while the term hA_t gives the rate of heat transfer per degree Kelvin by forced convection. Substituting the numerical values of the various quantities for the Delta-I instrument at 65 km (Fig. 5) gives the values of 1, 3, and 5 $\mu\text{W } (^{\circ}\text{K})^{-1}$ for the heat transfer processes of radiation, conduction, and forced convection, respectively. The sum of these three values gives a dissipation factor $S_t = 9 \mu\text{W } (^{\circ}\text{K})^{-1}$ at 65 km, where S_t is the dissipation factor for the thermistor as mounted on the Delta-I instrument.

A sum of the various temperature differences between the thermistor and the surrounding air as caused by aerodynamic and electrical heating, long wave and solar radiation, and heat conduction from the thermistor mounts indicates that the thermistor temperature would exceed that of its environment by approximately 36K at an altitude of 65 km. This is approximately the same value as that obtained by Wagner at an altitude of 65 km with an instrument expulsion altitude of 70 km.

Solution of the time dependent heat transfer equation shows that the time constant τ_t of the thermistor is given by the quantity $m_t c_t / S_t$ where m_t and c_t are the mass and specific heat of the thermistor, respectively. τ_t is simply the ratio of the heat energy absorbed by the thermistor per degree Kelvin to the rate of energy transfer per degree Kelvin.

The calculated value of the time constant τ_t for the Delta-I thermistor at an altitude of 65 km is 3.1 sec with $m_t = 3.9 \times 10^{-5}$ gm, $c_t = 0.18 \text{ cal gm}^{-1} (^{\circ}\text{K})^{-1}$, and $S_t = 9 \mu\text{W } (^{\circ}\text{K})^{-1}$. In a time of 3.1 sec, the thermistor falls approximately 0.5 km indicating that the assumption of the thermistor remaining at an altitude close to 65 km for a time longer than the response time of the thermistor is not valid; however, the numerical values

for the various sources of energy input serve to indicate the most significant sources of temperature difference between the thermistor and the atmosphere at an altitude of 65 km.

3. Rocketsonde redesign

Consideration of the heat transfer equations and an experimental analysis of the physical, thermodynamic and electrical characteristics of the Delta-I rocketsonde indicated that the theoretically predicted temperature differences between the thermistor and the kinetic temperatures of the stratosphere could be substantially reduced. The rocketsonde was redesigned by:

1) Changing the thermistor mounting post configuration and placing a heat sink (time constant less than that of the thermistor) between the thermistor and the instrument body, shortening the thermistor leads to a minimum length consistent with attachment to the heat sink, and by reducing the mass-to-area ratio of the mount plate.

2) Matching the exponential resistance-temperature characteristic of the bead thermistor to the exponential resistance-modulation frequency characteristic of the instrument electronics to produce a modulation frequency which is a linear function of the thermistor temperature and which gives an optimum temperature resolution in the range -65 to $+30^{\circ}\text{C}$:

	BOARD	POST	FILM
THERMAL CONDUCTIVITY (cal./sec. cm. $^{\circ}\text{K}$)	7.4×10^{-4}	5.9×10^{-4}	3.6×10^{-4}
SPECIFIC HEAT (cal./gram $^{\circ}\text{K}$)	3.4	0.4	0.2
DENSITY (grams/cm. 3)	1.8	1.1	1.4

FIG. 6. Thermistor mount, STS-1 instrument.

3) Reducing the electrical power dissipated in the thermistor such that the temperature error due to ohmic heating is negligible.

a) *The thermistor mount.* The thermistor mounting configuration is shown in the drawing of Fig. 6. The dimensions of the thermistor mount were chosen so as to give a maximum height and width consistent with insuring that the thermistor and mount could not be swept off by the nose cone at the time of instrument expulsion. The thermistor mount is constructed from a commercially available mylar polyester aluminized film 1×10^{-3} cm thick which is stretched between two hollow cylindrical support posts of type 6/6 nylon tubing, 3.2 mm outside diameter. The support post wall thickness is that giving a minimum mass-to-area ratio consistent with giving sufficient strength to support the film and thermistor at the time of maximum stress during rocket launch and instrument expulsion. The thickness of the thermistor mount plate was also reduced to a minimum value consistent with necessary rigidity and strength. It is made from woven glass fabric and epoxy resin, Mil. Spec. Mil-P-18177C Type GEE. The thermal conductivity, specific heat, and density of the mylar, nylon tubing, and glass fabric are given in Fig. 6. The mounting posts are glued into holes drilled in the mounting plate.

The aluminum coating of the mylar is removed with a sodium hydroxide solution after the film is properly masked, thus producing insulating strips at the center and at the two edges of the film mount. The mylar film is then stretched between the posts and secured by means of an epoxy glue. The leads of the thermistor (3 mm in length) are joined to the top edge of the mylar film mount, one on each side of the center insulating strip. They are joined to the film by inserting the end of each thermistor lead into a tiny hole which is punched through the mylar and are then secured in place by a small amount of silver paint. The electrical connections to the modulator circuit of the instrument package are secured to the lower edge of the film in a similar manner. A small capacitor (0.001 μ F) is connected so as to shunt the radio-frequency voltage which is induced in the leads by the field of the transmitter tube. The thermistor, mount, and mount plate are then secured to the instrument so that the thermistor is at a null point of the radio frequency field, thus minimizing the heating of the thermistor bead due to the absorption of radio frequency energy from the instrument transmitter.

From considerations identical to those for the dissipation factor S_t of the bead thermistor, the expression for the dissipation factor for the mylar film mount is

$$S_f = 4\sigma A_f T_e^3 + \frac{2k\alpha}{w} + h_f A_f, \quad (3.1)$$

the three terms on the right having values of 2000, 3

and $3200 \mu\text{W}(\text{°K})^{-1}$, respectively, for a total of approximately $5200 \mu\text{W}(\text{°K})^{-1}$. In (3.1),

A_f is the film area ($= 3.2 \text{ cm}^2$),

k is the thermal conductivity of mylar [$= 3.6 \times 10^{-4} \text{ cal sec}^{-1} \text{ cm}^{-1} (\text{°K})^{-1}$],

α is the cross-sectional area of the film ($= 1.3 \times 10^{-3} \text{ cm}^2$; thickness, $1 \times 10^{-3} \text{ cm}$, height, 1.3 cm),

w is the halfwidth of the film from post to film center ($= 1.3 \text{ cm}$),

h_f is the convective heat transfer coefficient for the film [$= 1.3 \times 10^{-4} \text{ cal}^{-1} \text{ cm}^{-2} \text{ sec}^{-1} (\text{°K})$ at 65 km (Ramsdale, 1965)],

$\sigma = 1.38 \times 10^{-12} \text{ cal sec}^{-1} \text{ cm}^{-2} (\text{°K})^{-4}$, and

T_e is the environmental temperature ($= 240\text{K}$ at 65 km).

The values of each term of Eq. (3.1) are based upon the above numerical values and are applicable to the film at an altitude of 65 km.

The corresponding time constant for the film is given by the expression

$$\tau_f = \frac{m_f c_f}{S_f} = \frac{m_f c_f}{4\sigma A_f T_e^3 + \frac{2k\alpha}{w} + h_f A_f}, \quad (3.2)$$

where

m_f is the film mass ($= \rho_f A_f l_f = 4.5 \times 10^{-3} \text{ gm}$),

ρ_f is the film density ($= 1.4 \text{ gm cm}^{-3}$),

A_f is 3.2 cm^2 ,

l_f is the film thickness ($= 1 \times 10^{-3} \text{ cm}$), and

c_f is the film specific heat [$= 0.2 \text{ cal gm}^{-1} (\text{°K})^{-1}$].

Based upon the above values the quantity $m_f c_f$ has a value of $3.6 \times 10^{-3} \text{ J}(\text{°K})^{-1}$ and the time constant of the film at an altitude of 65 km is

$$\tau_f = \frac{m_f c_f}{S_f} = \frac{3.6 \times 10^{-3} \text{ J}(\text{°K})^{-1}}{5.2 \times 10^{-3} \text{ J sec}^{-1} (\text{°K})^{-1}} = 0.7 \text{ sec.} \quad (3.3)$$

The value of 0.7 sec for the time constant of the film mount is less than the value of 3.1 sec for the time constant of the Delta-I mounted thermistor at an altitude of 65 km. Thus, the film will more rapidly come to temperature equilibrium with its environment than does the thermistor. If the temperature sensing instrument is ejected from the rocket nose cone (temperature $= 370\text{K}$) into an environment whose temperature is in the neighborhood of 220K , then the temperature of the film mount will, at times shortly after ejection, be lower than that of the thermistor and heat energy will be conducted from the bead to the film. The reduction of the thermistor lead lengths from approximately 1 cm in the Delta I instrument to $X_m = 0.3 \text{ cm}$ as they are attached to the mylar film in the new design accounts for a change in the value of the quantity $2K\beta/X$ from 3 to $10 \mu\text{W}(\text{°K})^{-1}$. The expression for dissipation factor

S_{tm} of the thermistor on the mylar film support becomes

$$S_{tm} = 4\sigma A_t T_e^3 + \frac{2K\beta}{X_m} + h_t A_t, \quad (3.4)$$

the three terms on the right having values of 1, 10, and $5 \mu\text{W}(\text{°K})^{-1}$, respectively, for a total of $16 \mu\text{W}(\text{°K})^{-1}$. The corresponding thermistor time constant $\tau_{tm} = m_t c_t / S_{tm} = 1.8$ sec. The value of $16 \mu\text{W}(\text{°K})^{-1}$ for the dissipation factor S_{tm} of the thermistor on the mylar mount compares with $9 \mu\text{W}(\text{°K})^{-1}$ for the Delta-I instrument (Fig. 3).

Since the time constant τ_f for the mylar film of 0.7 sec is less than the time constant τ_{tm} of 1.8 sec for the film-mounted thermistor, heat energy is transferred by conduction from the thermistor to the film mount at the rate of $10 \mu\text{W}$ per degree temperature difference between the thermistor and the mount shortly after instrument ejection at 70 km. This energy is then dissipated from the film at the rate of $5200 \mu\text{W}(\text{°K})^{-1}$ by the heat transfer processes of radiation and convection. Reference to Fig. 5 indicates that energy was transferred by conduction from the mounting posts to the thermistor at the rate $3 \mu\text{W}(\text{°K})^{-1}$ at an altitude of 65 km in the Delta-I system.

To determine the possible maximum rate of transfer of heat energy by conduction from the nylon mounting posts to the mylar film, it was assumed that the center of the film had come to temperature equilibrium with the environment at 65 km (240K), while the posts had remained at the nose cone temperature at the time of ejection (370K). The value of $2k\alpha/w$ from Eq. (3.1) is $3 \mu\text{W}(\text{°K})^{-1}$. Thus, for the temperature difference assumed, the rate of energy transfer by conduction would be $390 \mu\text{W}$. The dissipation factor for the film was shown to be $5200 \mu\text{W}(\text{°K})^{-1}$. The temperature of the film due to conduction under the above assumed conditions would increase by approximately 0.1K, indicating that the thermistor and mount are essentially isolated from the instrument body relative to heat transfer by conduction.

To determine the possible maximum rate of heat transfer due to solar radiation and the corresponding maximum temperature change in the bead thermistor, it was assumed that the plane of the mylar film mount was perpendicular to the direction of propagation of the solar radiation and that the thermistor and film were in temperature equilibrium at the time of solar energy incidence. Based upon the values, $J = 0.045 \text{ cal sec}^{-1} \text{ cm}^{-2}$, $A_f = 3.2 \text{ cm}^2$, and $a = 0.05$, the rate of absorption of solar energy by the film would be $JA_f a = 28,800 \mu\text{W}$. The value of the solar constant was increased by a factor of 35 per cent to account for reflections from cloud structures. A similar calculation for the bead thermistor indicated a rate of solar energy absorption of $15 \mu\text{W}$. The dissipation factors for the mylar film mount and thermistor were shown to be 5200 and $16 \mu\text{W}(\text{°K})^{-1}$, respectively. Thus, the temper-

ature of the film would increase by 5.5K in a time of 0.7 sec, while the temperature of the thermistor would increase by 1.0K in a time of 1.8 sec due to direct solar radiation. A temperature difference of 4.5K would then exist between the mylar film and the thermistor with an attendant rate of transfer of energy by conduction from the film to the thermistor of $45 \mu\text{W}$ [based on $10 \mu\text{W}(\text{°K})^{-1}$ from Eq. (3.4)]. The corresponding temperature increase of the thermistor would then be approximately 3K based on a thermistor dissipation constant of $16 \mu\text{W}(\text{°K})^{-1}$. Thus, the maximum temperature increase of the thermistor due to solar radiation would be approximately 4K under the above assumed conditions.

This estimate of the temperature increase caused by solar radiation is probably extreme. The period of oscillation of the parachute is approximately 5 sec, with an angular swing amplitude of 45 deg relative to a vertical line (Beyers *et al.*, 1962). If the thermistor and mount are exposed to direct solar radiation for a period of time and are then shaded by the rocketsonde instrument or parachute for a time as great as 0.7 sec, the mylar film thermistor mount will return to the temperature of the surrounding atmosphere with an attendant transfer of solar heat energy by conduction from the thermistor to the thermistor mount accompanied by a reduction in the thermistor temperature. If the thermistor and mount are shaded for a period of time as great as 1.8 sec, both return to the air temperature. Temperature oscillations with peak-to-peak magnitudes of the order of 5C have been observed with rocketsonde instruments which make use of clear mylar film as the mounting material. The coldest temperature recorded during the oscillation is taken as the environmental temperature when the temperature data are reduced.

The absorption factor of 0.05 for the 0.001 cm thick mylar film thermistor mount was determined on the basis of the transmissivity-wavelength recording shown in Fig. 7 for a sample of uncoated mylar. The film as utilized for the mount in the newly designed instrument is coated with aluminum (400 Å thickness) which

FIG. 7. Transmissivity vs. wavelength of the Mylar film. Wavelength is in microns.

has a reflection coefficient of 0.90, thus giving a resultant extinction coefficient for the aluminum coated mylar mount of the order of 5×10^{-3} . The rate of absorption of solar energy by the film is then approximately $2880 \mu\text{W}$ while the thermistor absorbs energy at the rate of $15 \mu\text{W}$. The corresponding temperature rise of the film is 0.6K [$S_f = 5200 \mu\text{W} (\text{°K})^{-1}$] in a time of 0.7 sec while the increase in the thermistor temperature is 1.0K in a time of 1.8 sec [$S_{tm} = 16 \mu\text{W} (\text{°K})^{-1}$]. Based upon these calculations, the change in the temperature of the thermistor would be less than 1K due to the absorption of solar radiation when an aluminum coated mylar film mount is utilized.

b) Matching of thermistor and instrument character-

istics. To obtain an optimum temperature resolution in the range from -65 to $+30\text{C}$, the exponential resistance-temperature characteristic of the bead thermistor was matched to the exponential resistance-modulation frequency characteristic of the instrument electronics. The criterion followed for obtaining optimum temperature resolution is the result of the following mathematical development which indicates that the change in modulation frequency is directly proportional to the change in temperature, the constant of proportionality being the ratio of the slope of the resistance-temperature characteristic of the thermistor to the slope of the resistance-frequency characteristic of the instrument.

Let T be the thermistor temperature, R the thermistor

FIG. 8. Stratospheric temperature sonde, STS-1.

FIG. 9. Electrical circuit diagram for stratospheric temperature sonde, STS-1.

resistance, f the modulation pulse frequency, a the slope of the instrument resistance-frequency curve, and α the slope of the thermistor resistance-temperature curve. Then for the rocketsonde instrument,

$$\ln R = -af + \ln A \quad \text{and} \quad R = Ae^{-af}. \quad (3.5)$$

The boundary conditions that $f = f_0$ and $R = R_0$ lead to

$$R = R_0 e^{-a(f-f_0)}. \quad (3.6)$$

For the thermistor,

$$\ln R = -\alpha T + \ln B \quad \text{and} \quad R = Be^{-\alpha T}. \quad (3.7)$$

The boundary conditions that $T = T_0$ when $R = R_0$ lead to

$$R = R_0 e^{-\alpha(T-T_0)}. \quad (3.8)$$

Combining Eqs. (3.6) and (3.8) gives

$$R = R_0 e^{-a(f-f_0)} = R_0 e^{-\alpha(T-T_0)} \quad (3.9)$$

leading to

$$f - f_0 = \frac{\alpha}{a}(T - T_0) \quad \text{and} \quad df = \frac{\alpha}{a} dT. \quad (3.10)$$

Therefore, a 1K change in thermistor temperature will produce a change in modulation pulse frequency equal to or greater than 1 pulse sec^{-1} as the ratio $\alpha/a \geq 1$.

The rocketsonde instrument was redesigned such that $\alpha/a = 1$ throughout the temperature range from -65 to $+50^\circ\text{C}$, thus producing a 1 pulse sec^{-1} change in modulation frequency corresponding to a one degree Kelvin change in temperature over this interval. Changes in modulation frequency of the order of 0.4

pulse sec^{-1} can be determined from the TMQ-5 recorder record with a corresponding temperature resolution of approximately 0.4C.

c) *Characteristics of the new design.* The physical and electrical characteristics of the new STS-1 stratospheric temperature sonde are shown in the photograph of Fig. 8 and in the schematic diagram of Fig. 9, respectively. Fig. 10 gives the thermistor resistance-temperature characteristics of the Gulton 42.5CX21 thermistor and the modulation frequency-thermistor resistance characteristic of the new instrument. Both graphs have essentially the same slope throughout the temperature region of interest, thus giving the temperature resolution

FIG. 10. Characteristic curves, STS-1 instrument.

tion discussed in Section 3b. Also shown in Fig. 10 is the electrical power dissipated across the thermistor as a function of thermistor resistance which indicates that the power dissipated does not exceed $3 \mu\text{W}$. The resultant temperature increase of the thermistor due to ohmic heating is, therefore, less than 0.2°C [$16 \mu\text{W}$ ($^\circ\text{K}$) $^{-1}$].

4. Experimental results

Fig. 11 is the temperature-time record as received by the GMD-1 meteorological receiver (1680 Mc) and recorded by the TMQ-5 meteorological recorder. The temperature data were transmitted by the stratospheric temperature sonde STS-1 shown in Fig. 8. The following characteristics of the temperature-time record are perhaps of interest:

- 1) Rocket launch accompanied by an initial cooling of the air inclosed by the nose cone. The temperature decreases by 13K in a time of approximately 10 sec, reaching a minimum value at an altitude of 3 km. This cooling is presumed to be caused by an adiabatic expansion of the air from within the nose cone.
- 2) Subsequent rapid temperature rise in the rocket nose to 80°C at a time 60 sec after launch, followed by a cooling of the nose cone air to 70°C at the time of instrument expulsion from the nose cone.
- 3) Instrument expulsion 131 sec after launch time (73 km). The time rate of temperature change of the thermistor dT/dt was -0.44K sec^{-1} .

FIG. 11. Temperature-time record, STS-1 instrument.

STATION WSMR, N.M.
 ROCKET TYPE ARCAS STS-1 INST.
 DATE 1 DEC 1965 TIME 1745 Z (1045 MST)
 DATE 17 DEC 1965 TIME 2000Z (1300 MST)
 1962 U.S. STD. ATMOS

FIG. 12. Temperature-altitude profile from temperature-time record (see Fig. 11).

- 4) Instrument maximum altitude (apogee) 142 sec after launch time (74 km), where dT/dt was -2.18K sec^{-1} , with fall speed equal to zero.

5) At time 157 sec after launch time (73 km) dT/dt was -0.79K sec^{-1} with a fall speed of 137 m sec^{-1} ; at time 167 sec after launch dT/dt was $+0.32\text{K sec}^{-1}$ with a fall speed of 215 m sec^{-1} .

6) In the time interval from 167 to 179 sec dT/dt was $+0.32\text{K sec}^{-1}$. The fall speed changed from 215 to 325 m sec^{-1} . The position of the instrument changed from 71 to 69 km.

7) At a time equal to 179 sec after launch, the time rate of change of thermistor temperature reversed sharply to -1.05K sec^{-1} from $+0.32\text{K sec}^{-1}$. A correspondingly abrupt change occurred in the fall velocity [from 325 to 225 m sec^{-1}]. The radar plot of instrument position indicated the parachute opened at this time.

8) At a time 293 sec after launch (65 km) dT/dt was -1.28K sec^{-1} . The fall velocity decreased to 170 m sec^{-1} and then continued to decrease to values of 120 m sec^{-1} at 60 km and 70 m sec^{-1} at 50 km.

Fig. 12 is a temperature-altitude profile corresponding to the temperature-time record of Fig. 11. The points corresponding to the points of interest from the temperature-time record (1-8 above) are recognizable in the figure.

The dashed line in Fig. 12 shows the temperature-

altitude record corresponding to the temperature-time record in which an insulating shield was placed around the STS-1 instrument thermistor and thin film mount in the rocket nose cone. The graph shows that the thermistor temperature did not exceed +18°C to the time of instrument expulsion. No data were received after instrument expulsion from this rocket flight.

5. Analysis of the experimental results

a) *Thermistor convective heat transfer coefficient (experimental determination at 70 km).* The two previously described marked changes in the slope of the temperature-time record of Fig. 11 which occurred at times 167 and 179 sec after launch time (71 km–69 km), served to determine the convective heat transfer coefficient of the bead thermistor at an altitude of 70 km. The details of the calculation are as follows.

From the equations of heat transfer for the rocket-sonde thermistor at altitudes of 71 and 69 km, we have

$$m_t c_t \left(\frac{dT_1}{dt} - \frac{dR_1}{dt} + \frac{dH_{cd1}}{dt} + \frac{dH_{cv1}}{dt} + \frac{dS_1}{dt} \right), \quad (5.1a)$$

and

$$m_t c_t \left(\frac{dT_2}{dt} - \frac{dR_2}{dt} + \frac{dH_{cd2}}{dt} + \frac{dH_{cv2}}{dt} + \frac{dS_2}{dt} \right), \quad (5.1b)$$

where the subscripts 1 and 2 refer to the altitudes of 71 km and 69 km, respectively. Let the space and time interval be such that the long wave and solar radiation terms remain constant, that is $dR_1/dt = dR_2/dt$ and $dS_1/dt = dS_2/dt$. The time interval is equal to 12 sec, the space interval is equal to 2 km.

Subtracting (5.1a) from (5.1b) gives

$$m_t c_t \left(\frac{dT_2}{dt} - \frac{dT_1}{dt} \right) = \frac{d}{dt} (H_{cd2} - H_{cd1}) + \frac{d}{dt} (H_{cv2} - H_{cv1}). \quad (5.2a)$$

Substituting the values for H_{cd} and H_{cv} to include the effects of aerodynamic heating with ohmic heating negligible yields

$$m_t c_t \left(\frac{dT_2}{dt} - \frac{dT_1}{dt} \right) = \frac{2K\beta}{X_m} [(T_{f2} - T_2) - (T_{f1} - T_1)] + h_t A_t \left\{ \left[\left(T_{e2} + \frac{rV_2^2}{2c_p} \right) - T_2 \right] - \left[\left(T_{e1} + \frac{rV_1^2}{2c_p} \right) - T_1 \right] \right\}. \quad (5.2b)$$

Assume that the temperature of the film at 71 and 69 km remains essentially constant, i.e., $T_{f2} = T_{f1}$. Then

$$m_t c_t \left(\frac{dT_2}{dt} - \frac{dT_1}{dt} \right) = -\frac{2K\beta}{X_m} [T_2 - T_1] + h_t A_t \left\{ [(T_{e2} - T_{e1}) - (T_2 - T_1)] + \frac{r}{2c_p} (V_2^2 - V_1^2) \right\}. \quad (5.3)$$

Solving Eq. (5.3) for the quantity $h_t A_t$ gives

$$h_t A_t = \frac{m_t c_t \left(\frac{dT_2}{dt} - \frac{dT_1}{dt} \right) + \frac{2K\beta}{X} (T_2 - T_1)}{\left\{ (T_{e2} - T_{e1}) - (T_2 - T_1) + \frac{r}{2c_p} (V_2^2 - V_1^2) \right\}}. \quad (5.4)$$

Substituting numerical values, we have

$$h_t A_t = \frac{28[0.32 + 0.79] + 10(3.2)}{10 - 3.2 + 1.19(30)} = 1.43 \mu\text{W} (\text{°F})^{-1}. \quad (5.5)$$

The numerical values in Eq. (5.5) are based upon data obtained from the temperature-time record (Fig. 11), the radar plot of the instrument position and from the U. S. 1962 Standard Atmosphere, i.e.,

$$\begin{aligned} \frac{dT_2}{dt} &= +0.32 \text{ K sec}^{-1}, & \frac{dT_1}{dt} &= -0.79 \text{ K sec}^{-1}, \\ T_{e2} - T_{e1} &= 10 \text{ K (71–69 km)}, & T_2 - T_1 &= 3.2 \text{ K}, \\ \frac{2K\beta}{X_m} &= 10 \mu\text{W} (\text{°K})^{-1}, & r &= 1.19 \text{ (from Wagner)}, \\ V_2 &= 325 \text{ m sec}^{-1}, & V_1 &= 215 \text{ m sec}^{-1}, \\ m_t c_t &= 28 \mu\text{J} (\text{°K})^{-1}, & c_p &= 1.0 \times 10^7 \text{ cm}^2 \text{ sec}^{-2} (\text{°K})^{-1}. \end{aligned}$$

The solution of Eq. (5.5) for h_t , with $A_t = 3.2 \cdot 10^{-3} \text{ cm}^2$, gives a value for h_t of $1.1 \times 10^{-4} \text{ cal cm}^{-2} \text{ sec}^{-1} (\text{°K})^{-1}$. The theoretical value of the convective heat transfer coefficient h_t for the thermistor at 65 km is $4.0 \times 10^{-4} \text{ cal cm}^{-2} \text{ sec}^{-1} (\text{°K})^{-1}$.

b) *Rates of change of thermistor temperature with time (74 km–50 km).* It was shown in Fig. 5 that the net exchange of energy by long-wave radiation between the thermistor at 65 km and its environment was small relative to the convective and conductive modes of heat transfer. A similar calculation for the thermistor at 74 km indicates a net dissipation of energy to its environment by radiation of $20 \mu\text{W}$.

Assume that the atmospheric temperature at 74 km is that of the U. S. 1962 Standard Atmosphere ($T_e = 200\text{K}$) and that the temperature of the mylar film mount immediately after ejection from the rocket is at the thermistor temperature ($T_f = T$). Fig. 12 indicates that the thermistor temperature immediately after instrument expulsion was approximately 300K while the fall velocity dz/dt was equal to zero. In Section 5a, it was determined experimentally that the quantity $h_t A_t = 1.43 \mu\text{W} (\text{°K})^{-1}$. By extrapolation, let the value of $h_t A_t$ at 74 km be $0.9 \mu\text{W} (\text{°K})^{-1}$. Then, the expression for the time rate of change of temperature of the thermistor at 74 km under the above conditions becomes

$$\left. \begin{aligned} m_t c_t \frac{dT}{dt} &= -20 \mu\text{W} + h_t A_t (T_e - T) \\ m_t c_t \frac{dT}{dt} &= -20 \mu\text{W} - 0.9 (130) \mu\text{W} \\ \frac{dT}{dt} &= -\frac{137 \mu\text{W}}{28 \mu\text{J} (\text{°K})^{-1}} = -5 \text{K sec}^{-1} \end{aligned} \right\} \quad (5.6)$$

Thus, the theoretically predicted value for dT/dt at 74 km is -5K sec^{-1} . From Fig. 11 and item 4), Section 4, the observed value of dT/dt was -2.2K sec^{-1} . As the instrument descended dT/dt changed from a negative value to a positive value of $+0.32 \text{K sec}^{-1}$ when the vertical velocity exceeded 215 m sec^{-1} . At an altitude of 69 km (Figs. 11, 12) the parachute opened, the vertical velocity changed from 325 to 225 m sec^{-1} . At this point dT/dt was equal to -1.05K sec^{-1} .

To determine the cause of the discrepancy between the calculated and the observed values of dT/dt immediately after instrument expulsion, the horizontal component of the instrument velocity was determined at several altitude points below 74 km. Given in Table 2 are the horizontal and vertical components of instrument velocity and the resultant velocity relative to the earth's surface.

The time rate of change thermistor temperature immediately after instrument expulsion was determined with consideration being given to the aerodynamic heating associated with the horizontal velocity component. From Eq. (5.6) and with a determined hori-

TABLE 2. Instrument velocities (m sec^{-1}).

Altitude (km)	Horizontal	Vertical	Resultant
74	300	0	300
71 (Positive dT/dt)	300	215	370
69 (Parachute open)	300	325	450
65	160	170	235
64	{ Parachute wind sensitive	165	165 + wind velocity
60		125	125 + wind velocity
50		70	70 + wind velocity

zontal speed of 300 m sec^{-1} , recovery factor $r = 1.25$, $h_t A_t = 0.9 \mu\text{W} (\text{°K})^{-1}$ and $(T_e - T) = -130\text{K}$, we have

$$\left. \begin{aligned} m_t c_t \frac{dT}{dt} &= -20 \mu\text{W} \text{ (radiation)} \\ &\quad + h_t A_t \left[T_e + \frac{r v^2}{2 c_p} - T \right] \\ m_t c_t \frac{dT}{dt} &= -20 \mu\text{W} + 0.9 [-130 + 56] \mu\text{W} \\ \frac{dT}{dt} &= -\frac{87 \mu\text{W}}{28 \mu\text{J} (\text{°K})^{-1}} = -3 \text{K sec}^{-1} \end{aligned} \right\} \quad (5.7)$$

Comparison of the numerical values for dT/dt from Eqs. (5.6) and (5.7) with the observed rates of change of temperature of the thermistor with time at an apogee altitude of 74 km shows that inclusion of aerodynamic heating associated with the horizontal component of velocity of 300 m sec^{-1} , gives a calculated value for dT/dt of -3K sec^{-1} ; the observed value is -2.2K sec^{-1} .

It would appear that any corrections to observed thermistor temperature must include the horizontal velocity component in the aerodynamic heating calculation down to the altitude at which the parachute becomes fully wind sensitive.

c) *Experimental determination of thermistor temperature corrections.* Reference to Fig. 12 shows that the rate of change of the thermistor temperature with altitude becomes zero at 64 km. The long-wave radiation correction to the thermistor temperature was shown to be negligible at 65 km (Fig. 5). Thus, for the temperature-height data at 65 km, the thermistor heat transfer equation becomes

$$m_t c_t \frac{dT}{dz} \frac{dz}{dt} = \frac{2K\beta}{X_m} [T_f - T] + h_t A_t \left[T_e + \frac{r V^2}{2 c_p} - T \right] = 0. \quad (5.8)$$

Substituting the values $2K\beta/X_m = 10 \mu\text{W} (\text{°K})^{-1}$, $h_t A_t = 5 \mu\text{W} (\text{°K})^{-1}$ and $r V^2/2 c_p = 15\text{K}$ (at 65 km) into Eq. (5.8) gives

$$10(T_f - T) + 5(T_e - T) + 75 = 0. \quad (5.9)$$

If the temperature of the film $T_f = T$, then from Eq. (5.9), $T_e - T = -15\text{C}$. If the temperature of the film $T_f = T_e$, then $T_e - T = -5\text{C}$. Thus, the thermistor tem-

STATION WSMR, N.M.
 ROCKET TYPE ARCAS STS-1 (5)
 DATE 15 MARCH 1966 TIME 2004 Z (1304 MST)

FIG. 13. Temperature-altitude profiles, STS-1 instrument, showing uncorrected and corrected temperatures (Table 3).

perature at 65 km lies between the limits

$$T_e + 5K \leq T_{65} \leq T_e + 15K. \quad (5.10)$$

The aerodynamic temperature increase at 60 km is 6K while the term $h_t A_t$ has a value of $7 \mu W(^{\circ}K)^{-1}$. From Fig. 12, a calculation identical to that of Eq. (5.8) and (5.9) gives

$$T_e + 2.5K = T_{60} \leq T_e + 6.0K. \quad (5.11)$$

The same calculation for 50 km with $h_t A_t = 20 \mu W(^{\circ}K)^{-1}$ and $rV^2/2c_p = 1.5K$ gives

$$T_e + 1.0K \leq T_{50} \leq T_e + 1.5K. \quad (5.12)$$

6. Summary

The improved response of the stratospheric temperature sonde (STS-1) is indicated in Figs. 11 and 12. The sensitivity of the temperature sensing instrument made possible the detection of a change in thermistor temperature of $+3^{\circ}C$ when the fall velocity changed from 215 to 325 m sec⁻¹ just prior to the time of parachute opening. Calculations based upon these data (Section 5a) led to a determination of the thermistor convective heat transfer coefficient at 70 km which agreed favorably with its theoretically determined value.

A study of the slope of the temperature-time record of Fig. 11 shows that the value of dT/dt at the time

of sensor expulsion from the rocket was increased to a value of $-2.2K \text{ sec}^{-1}$ for the STS-1 instrument. The inclusion of the horizontal component of instrument velocity in the correction for aerodynamic heating gave a theoretical value for dT/dt at time of expulsion of $-3K \text{ sec}^{-1}$.

The improved response and sensitivity of the instrument was accomplished through the utilization of a heat dissipative mylar mount between the sensing thermistor and instrument body, reduction in the electrical power across the thermistor, and the matching of the instrument and thermistor characteristics (Section 3b).

The development of a mathematical expression for the dissipation factor S (Section 2) gave a means of predicting the temperature rise for a given rate of heat energy input to the thermistor and mylar film mount. The calculated values for the thermistor and film dissipation factors at 65 km were 16 and $5200 \mu W(^{\circ}K)^{-1}$, respectively, with corresponding time constants of 1.8 and 0.7 sec. The transmittance-wavelength study in the spectral region from 0.2 to 2.4μ for the mylar film indicated that the temperature increase in the thermistor due to the absorption of solar radiation when mounted on the aluminum-coated mylar film is approximately $1^{\circ}C$ (approximately $4^{\circ}C$ for uncoated mylar).

The magnitudes of the temperature differences between the mylar film mounted thermistor and the atmosphere at altitudes of 65, 60, and 50 km were empirically determined from Fig. 12 when the rate of change of temperature with altitude was zero. These were:

$$T_e + 5K \leq T \leq T_e + 15K \quad 65 \text{ km}$$

$$T_e + 2.5K \leq T \leq T_e + 6K \quad 60 \text{ km}$$

$$T_e + 1.0K \leq T \leq T_e + 1.5K \quad 50 \text{ km}$$

Table 3 gives the theoretically computed correction to the observed thermistor temperature for the STS-1 instrument at the indicated fall velocities and altitudes. The corresponding correction for the Delta-I instrument is given for the purpose of comparison.

Fig. 13 shows the temperature-altitude profile obtained with stratospheric temperature sonde STS-1 and the profile as corrected according to the values given in Table 3.

An insulating shield was placed around the instrument thermistor and thin film mount in the rocket nose cone such that the maximum temperature in the nose

TABLE 3. Temperature correction factors for the STS-1 and Delta-I instruments.

Altitude (km)	Fall velocity (m sec ⁻¹)	STS-1 correction ($^{\circ}K$)	Delta-I correction ($^{\circ}K$)
65	167	-6.2	-35.5
60	125	-3.8	-20.5
55	90	-2.2	-8.5
50	61	-1.1	-5.4

cone prior to the time of instrument expulsion was 45°C. In addition, a parachute identified as a "disk-gap-band" mylar parachute² replaced the conventional "hemispherical" silk parachute discussed in Section 2 and was utilized to support the stratospheric temperature sonde from which the temperature-altitude profile of Fig. 13 was obtained.

The differences in the temperature-altitude profiles of Figs. 12 and 13 in the vicinity of 70 km can be attributed primarily to the differences in the deployment characteristics of the two types of parachutes.

In Fig. 13 the temperature indicated by the circle at an altitude of 74 km is the temperature obtained when the observed thermistor temperature was corrected for the aerodynamic heating of the thermistor associated with the horizontal component of instrument velocity of 313 m sec⁻¹ when the vertical component of velocity was zero. The dashed line joins this temperature-altitude point to the temperature value at 65 km as corrected according to the theoretical correction values given in Table 3, thus giving a semi-empirical temperature-altitude profile in the interval from 74 to 65 km.

² Murrow, H. N., and C. V. Eckstrom, 1966: Description of a new parachute for use with meteorological rockets and a consideration of improvements in meteorological measurements. Preprint No. 66-399, Sixth Conf. Applied Meteorology (Aerospace Meteorology), Amer. Meteor. Soc., Los Angeles, Calif.

Acknowledgments. I wish to thank the personnel of the Atmospheric Sciences Laboratory (ASL), White Sands Missile Range and the personnel of Schellenger Research Laboratories (SRL), The University of Texas at El Paso, who contributed to the research and development program described in this report. I wish to particularly thank Mr. Claude Tate (ASL) and Mr. Mike Izquierdo (SRL) for instrument development, Mr. Bun Ling Yee (SRL) for sensor calibrations and thermistor mount construction, Mr. Cantrell Craig (SRL) for data reduction, Prof. John Whitacre (SRL), and Mr. Bruce Kennedy (ASL) for engineering services.

REFERENCES

- Barr, W. C., 1961: Theoretical considerations in the design of atmospheric temperature-sensing elements. USASRD Tech. Report 2195, Ft. Monmouth, N. J., 15 pp.
- Beyers, N. J., O. W. Thiele and N. K. Wagner, 1962: Performance characteristics of meteorological rocket wind and temperature sensors. Technical Report SELWS-M-4, U. S. Army Electronics Research and Development Activity, White Sands Missile Range, N. Mex., 30 pp.
- Clark, G., and J. McCoy, 1965: Measurement of stratospheric temperature. *J. Appl. Meteor.*, 3, 365-370.
- Ramsdale, D. J., 1965: Theoretical time constant for the thin film temperature sensor. Tech. Report, Schellenger Research Laboratories, Texas Western College, El Paso, Tex., 15 pp.
- Wagner, N. K., 1964: Theoretical accuracy of a meteorological rocketsonde thermistor. *J. Appl. Meteor.*, 3, 461-469.