Indian Journal of Radio & Space Physics
Vol. 6, December 1977, pp. 281-284

Estimated Temperature Corrections for the Menaka-II Meteorological Rocket Payload

K G VERNEKAR & BRIJ MOHAN
Indian Institute of Tropical Meteorology, Pune 411 005

Received 7 November 1977

The temperature as indicated by the meteorological payload is not the real temperature of the environment. The indicated temperature has to be corrected to get the exact temperature at the particular height. There are various corrections due to the thermistor inertia, its mounting position, descent rate of the parachute and the effect of solar radiation at each height. All these corrections are calculated at intervals of 10 km and the order of correction is calculated in terms of degrees Centigrade for the meteorological payload to be launched with an Indian Rocket Menaka-II. The temperature correction varies from 0·3°C at the ground to 10-15°C at 80 km.

1. Introduction

A meteorological payload to measure temperature and wind from 70 to 30 km is being developed at the Indian Institute of Tropical Meteorology, Pune-5. The carrier rocket Menaka-II will be supplied by TERLS Thumba.

The rocket borne instrument is lifted to an altitude of approximately 70 km by a rocket where the nose cone containing the payload is separated from the rocket. The temperature sensing system then descends, with the help of a parachute. A microbead thermistor having a diameter of 0.005 in is used as a temperature sensor. The parachute was recently flight tested in Menaka-II. This descent rate of parachute is used in this paper for calculating all the temperature errors. The sensor is connected to the instrument body through its mounting which has relatively larger thermal conductivity. In addition, an electric current flows through the thermistor while the thermistor and its lead may be immersed in the electromagnetic field of rf transmitter. Also there is solar radiation incident upon the thermistor (if the flight is in daytime). The contributions of long wave radiation from the immediate environment above and below the moving instrument has also to be considered.

2. Heat Transfer Equation

The total heat transfer equation for a spherical bead thermistor to an instrument package by some type of mounting configuration is given by[1]

$$\dot{H}_{\text{total}} = \dot{H}_{\text{lr}} + \dot{H}_{\text{sr}} + \dot{H}_{\text{cv}} + \dot{H}_{\text{cd}} + \dot{H}_{\text{oh}} + \dot{H}_{\text{rf}} \quad \ldots(1)$$

where $\dot{H}_{\text{total}}$ Total rate of heat transfer to the thermistor, while

$\dot{H}_{\text{lr}}$ Rate of heat transfer by long wave radiation

$\dot{H}_{\text{sr}}$ Rate of heat transfer by solar radiation

$\dot{H}_{\text{cv}}$ Rate of heat transfer by convection

$\dot{H}_{\text{cd}}$ Rate of heat transfer by conduction along lead wires

$\dot{H}_{\text{oh}}$ Rate of ohmic heating

$\dot{H}_{\text{rf}}$ Rate of heat transfer by radio frequency radiation

Last two contributions can be taken care of by the circuit design and placing the thermistor in a neutral zone of the attenna lobe pattern.

Eq. (1) can be written as

$$m_tC_t\left(\frac{dT_t}{dt}\right) = \underbrace{\sigma A_t T_e^4 - \sigma A_t\, T_t^4}_{\text{long wave}} + \underbrace{JaAp}_{\text{solar}} + h_tA_t$$

$$\times \underbrace{\left[\left\{T_e + \left(\frac{rV^2}{2C_p}\right)\right\} - T_t\right]}_{\text{convection}} + \underbrace{\frac{2K\beta}{l}\left(dT_e/dx\right)}_{\text{conduction}} \quad \ldots(2)$$

expressing $T_e = T_t + \Delta t$ and $\frac{dT_e}{dx} = \Delta T_{se} - \Delta T_{te}$

and neglecting higher terms of T_e we get

$$m_tC_t\left(\frac{dT_t}{dt}\right) = -4\sigma A_t T_e^3 \Delta T_{te} + JaAp + h_tA_t$$

$$\times \left[\left\{T_e + \left(\frac{rV^2}{2C_p}\right)\right\} - (T_e + \Delta T_{te})\right] + \frac{2K\beta}{l}\left(\Delta T_{se} - \Delta T_{te}\right) \quad \ldots(3)$$

where

h_tA_t Rate of thermal energy transfer (due to convection) between thermistor and the atmosphere

h_t Convective heat transfer which is a function of altitude

$\frac{2K\beta}{l}$ Rate of thermal energy transfer due to conduction

k Thermal conduction of lead wires

l Length of lead wires

β Cross-sectional area of lead wire

r Recovery factor = 1.1

a Absorption coefficient of thermistor 0·1

$4\sigma A_t T_e^3$ Rate of thermal energy transfer due to long-wave radiation

σ Stefan-Boltzman constant

A_t Area of thermistor

A_p Projected area of thermistor $\frac{1}{4}A_t$

C_t Specific heat of thermistor

C_p Specific heat of air at constant pressure

m_t Mass of thermistor

J Solar constant =0·035 cal/cm²/sec

T_e Temperature of environment

T_t Temperature of thermistor

ΔT_{te} Temperature difference between thermistor and the environment

ΔT_{se} Temperature difference between thermistor and the support post

Solving Eq. (3) we get ΔT_{te}, the correction to the temperature measured by thermistor

$$\Delta T_{te} = \frac{-m_t C_t\left(\frac{dT_t}{dt}\right) + h_t A_t\left(\frac{rV^2}{2C_p}\right) + \left(\frac{2K\beta}{l}\right)\Delta T_{se} + JaAp}{4\sigma A_t T_e^3 + 2K\beta/l + h_t A_t} \quad \dots(4)$$

where

$4\sigma A_t T_e^3 + \frac{2K\beta}{l} + h_t A_t = S$ is the dissipation factor of the thermistor.

On the right hand side in Eq. (4), the numerator in the first term, viz. $m_t C_t \, dT_t/dt$ represents the correction to be applied due to time constant of the thermistor. The second term $h_t A_t \left(\frac{rV}{2C_p}\right)$ is associated with the correction due to aerodynamic heating. The third term gives the correction needed because of conduction along lead wires of the thermistor. Here the length of lead wires is assumed to be very small. The last term gives the correction due to solar heating.

It is necessary to define a time constant of thermistor

$$\tau = \frac{\text{Heat capacity of the thermistor}}{\text{Dissipation factor of the thermistor}} = \frac{m_t C_t}{S}$$

The time constant τ was calculated with known characteristics of the thermistor and dissipation factor S. The thermistor characteristics were as follows.

Mass (m_t)	$= 69 \times 10^{-6}$ μg
Diameter (d)	$= 2.4 \times 10^{-4}$ m
Dissipation constant	= 90 μW/°C
Specific heat	= 0.2 cal/g/°C

In the expression for the dissipation constant S, all values are known excepting h_t, the convective heat transfer coefficient. The procedure to calculate h_t is to find out the Reynold's number $Re = \rho V d/\mu$, where V is the descent rate of parachute, d the diameter of thermistor, ρ density of atmosphere and μ the viscosity of atmosphere. Then the Prandtl number is given by $Pr = C_p\mu/Re$. Finally, Nusselt number $Nu = 2 + 0.37\,(Re)^{0.6}\,(Pr)^{1/3}$ is obtained. Knowing Nusselt number, $h_t = Nuk/d$ is calculated. Hence, the time constant (τ) is determined. Knowing τ first, the correction in Eq. (4) is calculated. Second correction follows knowing h_t and V. Other two corrections are calculated knowing the relevant constants. A 1968 U S standard atmosphere data for density (ρ), viscosity (μ) and thermal conductivity (k) are used for all the calculations. For the purpose of calculation, the entire atmosphere is assumed to be a continuum region. The time constant is given in Fig. 1 (C_p is 0·239 cal/g/°C for the atmosphere.) Fig. 2 gives the descent rates (V) of the parachutes, JITM and Arcus.[2]

Contributions in μW/°K/sec to the dissipation factor by different processes at 80 km are:

Convective term	30·1
Long wave radiation term	0·44
Conduction term	4·0

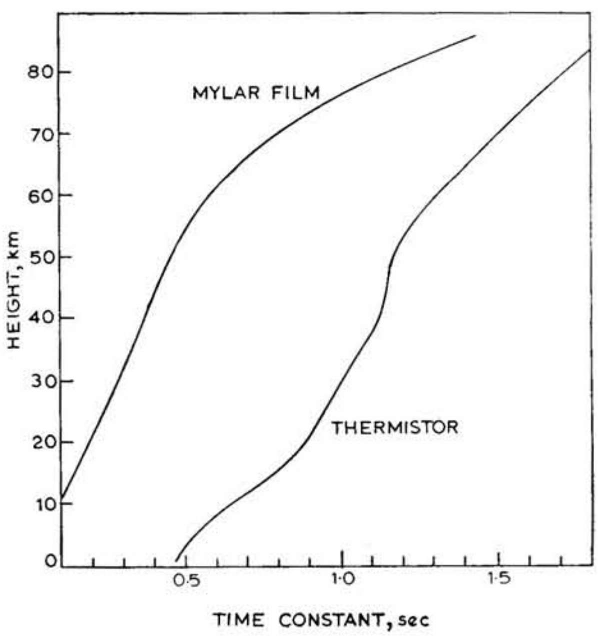

Fig. 1—Variation of time constant with altitude of micro-bead thermistor and Mylar film

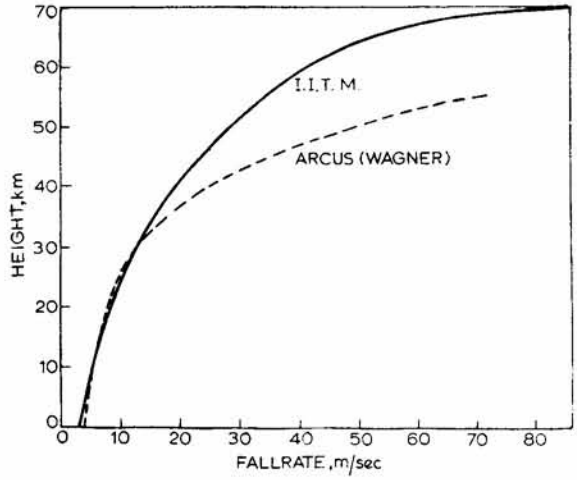

Fig. 2—Descent rate of IITM parachute as compared to that of Arcus parachute of USA

The total contribution comes out to be 34.54 μW/°K/sec at 70 km.

It can be observed that long wave correction is negligible in the case of thermistor.

3. Numerical Values for the Correction Terms

(i) Time lag correction is given by $\frac{m_t C_t}{S}\left(\frac{dT_t}{dt}\right)$. It is found that $\frac{dT_t}{dt}$ is always less than 0·2°C. With this assumption the time-lag correction contributes − 0·23°K at ground to − 0·77°K at 70 km.

(ii) Aerodynamic heating correction is done as follows. The quantity $\left(\frac{h_t A_t}{S}\right)\left(\frac{rV^2}{2C_p}\right)$ accounts for the largest correction to the observed thermistor temperature. The quantity has a value 11°K at 80 km, 3·5°K at 70 km and 0·85°K at 60 km and afterwards decreases rapidly. Near 1 km it has a value of 0·005°K. Therefore the correction varies from − 3·5°K to − 0·85°K between 70 and 60 km altitude.

(iii) The quantity $\left(\frac{2K\beta}{l}\right)\left(\frac{\Delta T_{se}}{S}\right)$ is very important in the design of the temperature sonde. Since the quantity ΔT_{se} (difference in the temperature between the sensing instrument and the environment) tends to be quite large, ΔT_{se} can be made very small by using a suitable mount similar to STS mount using thin mylar film. As such no experiment is conducted to find out the ΔT_{se} at various altitudes with the present payload. Hence these corrections are not analyzed. But a mylar film mount is designed similar to STS and its time constant is found. Taking the values of Arcus rocket, this term has significant value between − 6°C and − 2°C in the range 70-60 km, and negligible value below this height range. In Fig. 1 the time constant of the mylor film is also shown at various altitudes. It can be seen that time constant of mylar film is very small. Any temperature difference between mount post and mylar film will be dissipated by the mylar film and thermistor mounted on the mylar film will have a time constant similar to mylar film. In Fig. 3 values of conduction term correction from Arcus rocket sonde are plotted.

Contributions in μW/°K/sec to the dissipation factor at 70 km are:

Convective term	2928
Longwave radiation term	1528
Conduction term	4
Total	4524

To determine the possible maximum rate of transfer of heat energy by conduction from the mylar mounting posts to the mylar film, it is assumed that film has come to temperature equilibrium with the environment at 70 km and 218 °K, while the posts are at the nose cone temperature about 100 °K more, say at 320 °K. Thus the rate of energy transfer by conduction would be 400 μW. The dissipation factor for film at 70 km is 4500 μW/°K/sec. Thus the film temperature will increase by 0·1 °K, indicating that

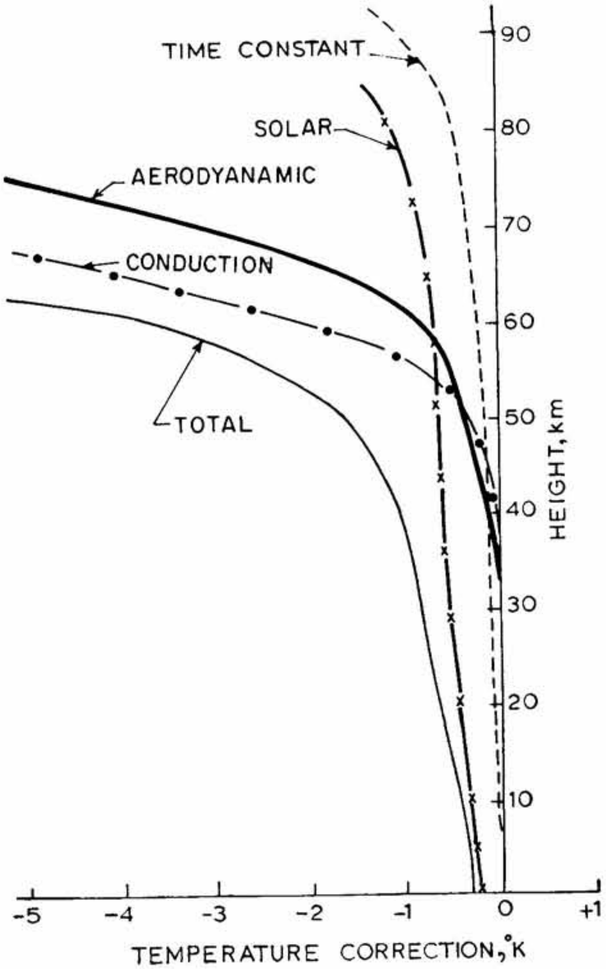

Fig. 3—Temperature corrections at various levels to be applied to the temperature measured by the payload

Table 1—Contributions from Various Correction Terms

Altitude km	Solar correction °C	Convective correction °C	Timelag correction °C	Aerodynamic correction °C
ground	0·23	$4{\cdot}6 \times 10^{-3}$	0·092	$4{\cdot}9\times10^{-3}$
1	0·24	$5{\cdot}3 \times 10^{-3}$	0·094	$5{\cdot}6\times10^{-3}$
5	0·27	$7{\cdot}5 \times 10^{-3}$	0·1	$7{\cdot}9\times10^{-3}$
10	0·32	$1{\cdot}2 \times 10^{-2}$	0·12	$1{\cdot}3\times10^{-2}$
20	0·45	$3{\cdot}1 \times 10^{-2}$	0·19	$3{\cdot}3\times10^{-2}$
30	0·55	8×10^{-2}	0·20	$8{\cdot}6\times10^{-2}$
40	0·58	19×10^{-2}	0·22	$2{\cdot}2\times10^{-1}$
50	0·63	$4{\cdot}4 \times 10^{-1}$	0·22	$5{\cdot}3\times10^{-1}$
60	0·67	$7{\cdot}5 \times 10^{-1}$	0·26	$9{\cdot}1\times10^{-1}$
70	0·77	3·0	0.3	no data available
80	0·99	9·4	0·34	

thermistor and mount are essentially isolated from the instrument body. In the absence of mylar film, for a temperature difference of 100 °K between thermistor mount and environment, the temperature of thermistor (dissipation factor 34 μW/°K/sec) will increase by 13 °K. These are all theoretical values. Thus the usage of mylar film reduces ΔT_{se} considerably, viz. from 13 to 0·1 °K.

(iv) The solar radiation correction term JaA_t denotes correction caused by solar irradiation. Correction due to lead wires is neglected because the lead wire lengths have been reduced considerably. This correction term varies from −0·23 °K at ground to −0·99°K at 80 km.

(v) Correction due to ohmic heating is done as follows. Maximum power dissipation in the circuit is found to be 15 μW and it is well below the dissipation of the thermistor, which is 45 μW. Table 1 gives the contribution from various terms. The same is depicted in the form of graph in Fig. 3.

4. Conclusion

The maximun correction is from the aerodynamic heating and conduction along the lead wires. The conduction term can be reduced by using a mylar film. Aerodynamic term cannot be reduced further as it depends upon the parachute descent value which is critical. Solar correction can be avoided by taking flights in the night time. Time constant correction is very small. Thus the total temperature correction is negative and is maximum above 60 km. Below 40 km it is just a degree and reduces as the altitude decreases.

References

1. Ballard H N, *Stratospheric circulation*, edited by W L Webb. pp. 141-165.
2. Wagner W V, *J. Met*, **18** (1961), 606.