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Temperature measurement from aircraft using vortex thermometer

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ABSTRACT. The paper describes a technique of measuring temperature on board an aircraft using a vortex thermometer. An accuracy of 0·1°C is obtained.

1. Introduction

During the cloud seeding experiments conducted in the monsoon season 1973 by the Indian Institute of Tropical Meteorology in and around Poona, measurements of temperture of upper atmosphere were carried out using a vortex thermometer mounted on a DC-3 aircraft. Measurement of true air temperature from a high speed aircraft is complicated by the heating effect caused by air moving past the sensor. At an air speed of 250 kmph a thermometer exposed to the air stream indicates a temperature 3 to 4°C higher than the true air temperature. This error is expressed as $\triangle T = \alpha V^2$, where V is the speed of the aircraft and α, the correction factor. The heating effect caused by the moving air can be eliminated by using vortex tubes where lowering of temperature of high velocity air stream occurs along the axis of the tube. There are two types of vortex tubes, namely (*i*) axial flow and (*ii*) normal flow. Normal flow vortex tube has been adopted for construction of one such thermometer, it being easier to fabricate. The design is similar to one used by Vonnegut (1950).

Fig. 1 shows the details of the vortex tube thermometer. Exact lowering of temperature along axis of the tube can be attained by adjusting valve C. This was adjusted in the laboratory by simulating aircraft speed of 80 to 240 kmph. It was fixed immediately below the co-pilots' window of the aircraft.

2. Principle of measurement

The block diagram of the system designed for measurement of temperature is shown in Fig. 2 and the details are indicated in Fig. 3 The temperature sensing device consists of a thermistor which is placed in one arm of a resistance bridge. A precision 10 KΩ helipot forms another arm of the bridge. By adjusting it, the bridge can be balanced for any value of thermistor resistance from 3 to 6 KΩ. The output of the bridge is amplified by an operational amplifier and fed to a voltage controlled oscillator (VCO) consisting of two ICs (Graem *et al.*, *see* Ref.). A meter has been incorporated to indicate the bridge balance. When the bridge output voltage is zero, a fixed bias voltage of 1.5 V provides a reference frequency of 130 Hz. This frequency is used as a time mark and is controlled by a manual switch. The output of VCO is fed to a battery operated magnetic tape recorder.

For recovery of data, the tape is played back in the laboratory and a print-out of frequency obtained through a frequency converter and a digital printer. A Hewlett-Packard frequency counter type 5532-A and printer type H-23562-A were used for this purpose. Analogue output of Visicorder (Honeywell type 906 T) has also been used in parallel. This has been shown in Fig. 2(b).

The temperature sensing thermistor is linearised over the temperature range of 0–50°C and a calibration of the thermistor is obtained. Fig. 4 shows this linearised calibration curve (Vernekar 1971). It has a time constant of 1.2 sec. Fig. 5 shows the output frequency of VCO with helipot set at different resistance values. It is necessary to change the setting of helipot as the output frequency of VCO is found to be linear only upto 300 Hz for a maximum input of 3 volts. The output of VCO is, therefore, restricted to 250 Hz corresponding to an input of 2.5 volts. By setting the helipot at 3.5, 4.5, 5.0 and 5.5 KΩ, the ouput of the bridge is limited to 1.0 volts. A set of calibration curves of the VCO are drawn by changing the resistance in the thermistor arm as shown in Fig. 5.

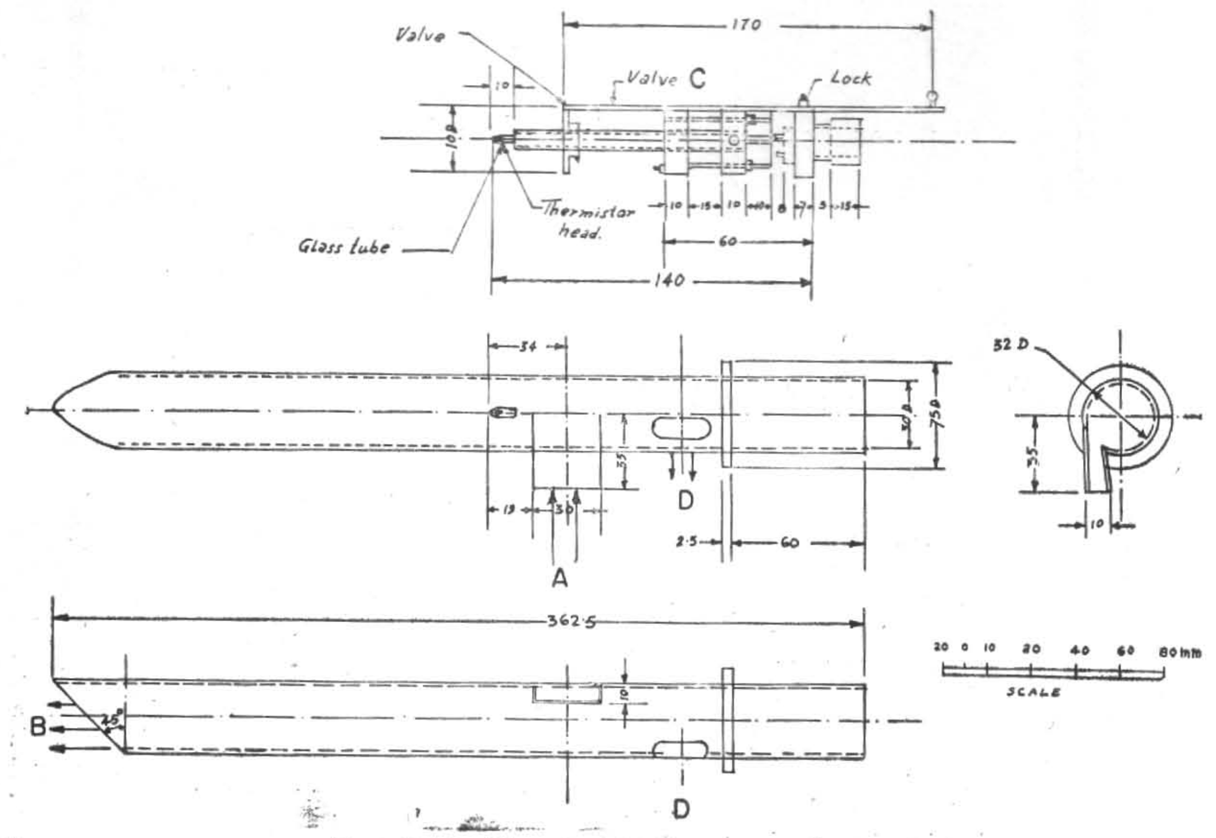

Fig. 1. Details of the vortex tube (Dimensions are in mm)

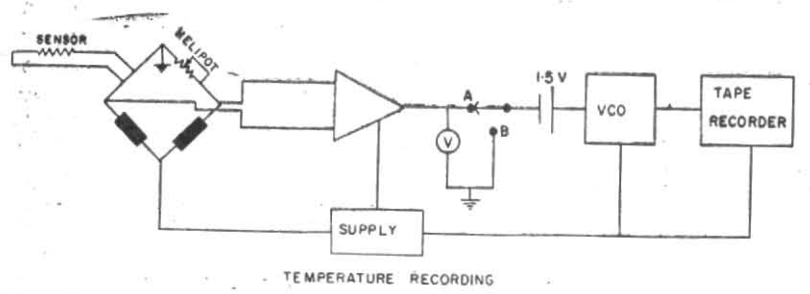

Fig. 2(a)

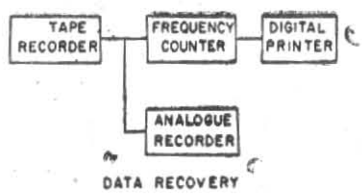

Fig. 2(b)

During flight, data were collected with the helipot set at one of the above known values. As soon as the amplifier output exceeded 1.0 volt, the helipot was set to a new value and output was nulled as indicated by the panel meter.

After playing back the tape in the laboratory a frequency print output every three seconds is obtained. Frequency *versus* resistance of VCO graphs, follow an equation of the type $y=mx+c$. Here knowing m the slope, c the constant and the frequency x, the resistance y of thermistor can be evaluated. The data was processed on an IBM 1620 computer. The final temperature values are obtained for every 3 seconds of the entire flight. Another programme was also processed to compute the profiles of every two minutes of the flight. Fig. 6 shows the record of one such flight on 13 August 1973.

3. Verification of vortex thermometer readings

Two checks were carried to verify the readings of the vortex thermometer. A small brass sphere with thermistor embedded in it was mounted on the housing of the vortex thermometer and its temperature was recorded and compared with the temperature indicated by the vortex thermometer. The readings were also varied with the radiosonde data by making a flight over the radiosonde station at Santacruz airport.

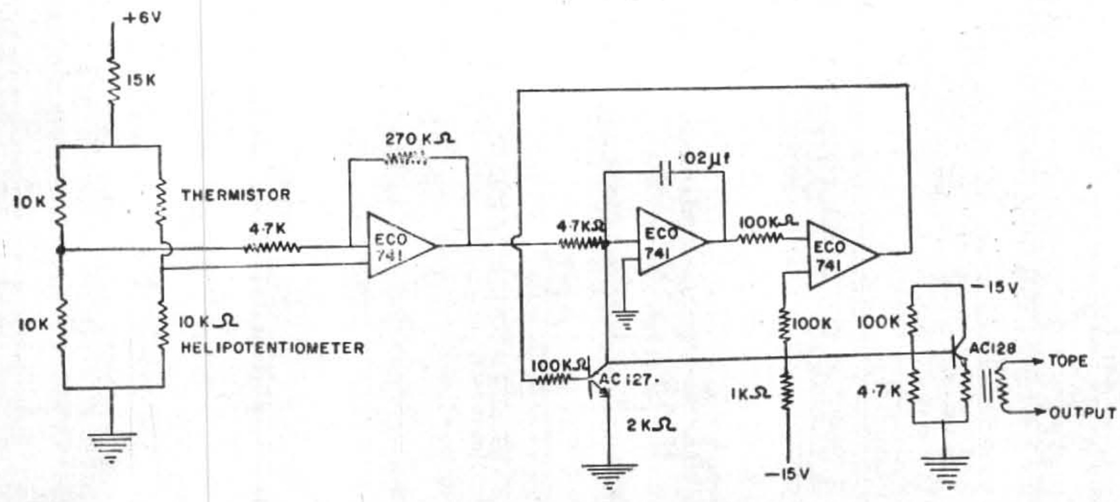

Fig. 3. Wheatstone bridge and VCO circuit

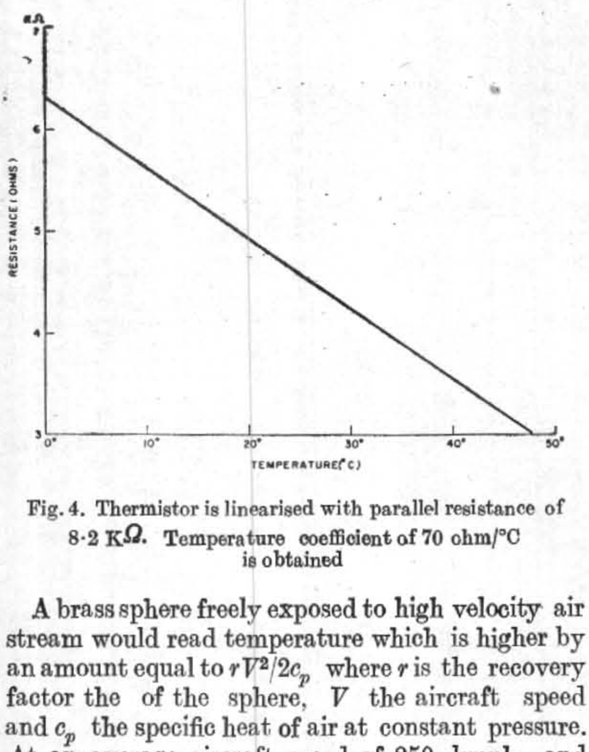

Fig. 4. Thermistor is linearised with parallel resistance of 8·2 KΩ. Temperature coefficient of 70 ohm/°C is obtained

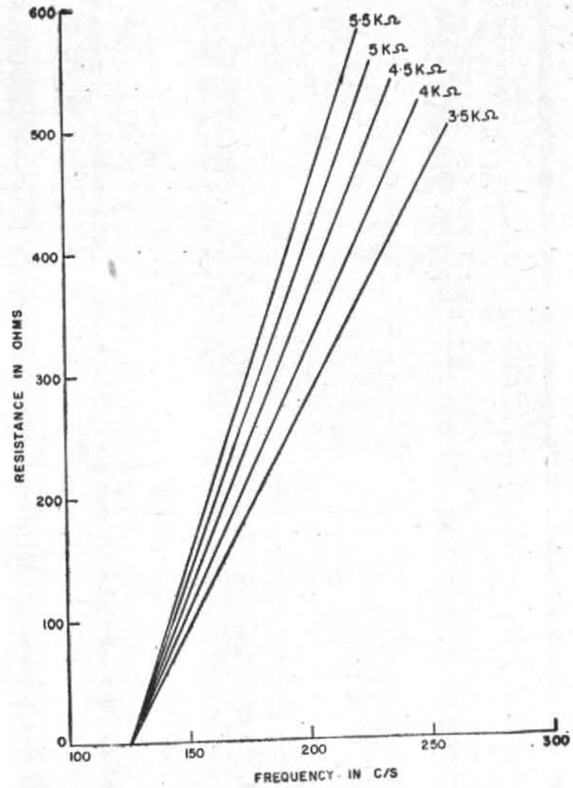

Fig. 5. Calibration for frequency response of VCO with variation in thermistor resistance of different helipot values

A brass sphere freely exposed to high velocity air stream would read temperature which is higher by an amount equal to $rV^2/2c_p$ where r is the recovery factor the of the sphere, V the aircraft speed and c_p the specific heat of air at constant pressure. At an average aircraft speed of 250 kmph and assuming a value of 0.7 for the recovery factor, the average correction for sphere was found to be about 1.0°C. This correction was also evaluated for various altitudes. Table 1 gives the results of comparison between the temperature indicated by the sphere and the vortex thermometer. It may be seen that the two temperatures agree within $\pm$ 0.2°C.

A number of aircraft soundings were taken over radiosonde/rawin station at Santacruz airport. Comparison of readings obtained on 30 September 1973 indicates that except for a maximum difference of 0.9° C at 5500 ft, the average diffrence is of the order of 0.3°C

4. Sensitivity, accuracy and stability

The overall sensitivity depends upon the actual temperature coefficient of the thermistor and it

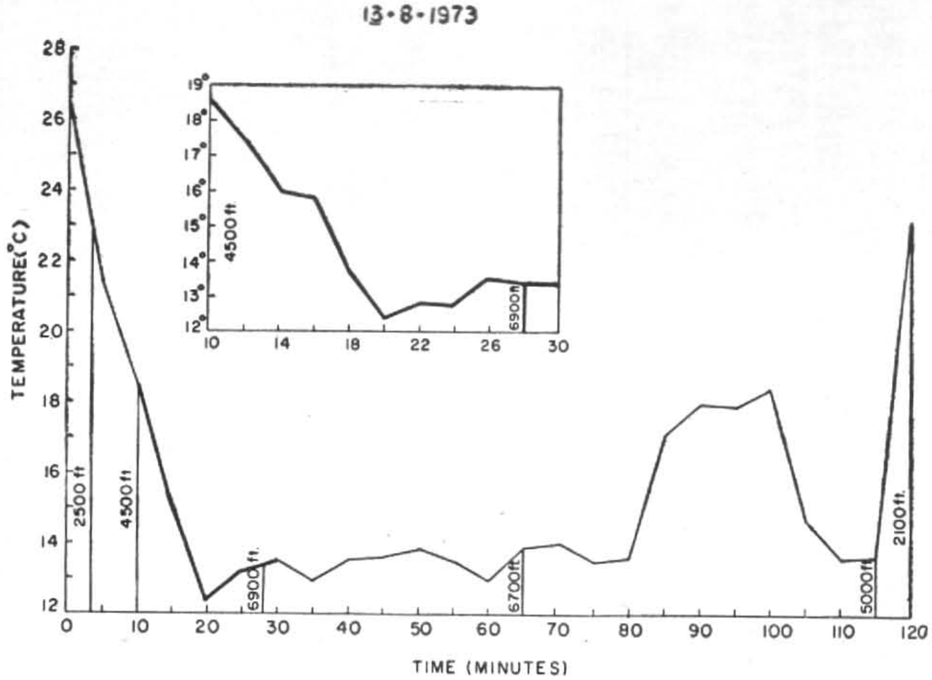

Fig. 6. Temperature obtained on 13 August 1973 for a 120-min flight. Inset shows the fine structure at 2-min interval

TABLE 1

Comparison of temperature indicated by the sphere and the vortex thermometer on 2 October 1973

Time (IST)	Altitude (m)	Temp. of brass sphere (corrected for aerodynamic heating) (°C)	Indicated temp. by vortex thermistor (°C)	Temp. difference (°C)
1530	601	19·7	19·8	—0·1
1548	550	22·1	22·1	0·0
1650	1890	13·9	14·1	+0·2

depends upon the setting of the helipot in one arm of the bridge. At a setting of 3.5 KΩ the VCO output varies by 20 Hz for 70Ω change corresponding to 1°C variation. At 5.5 KΩ setting, it is 12 Hz. Thus for setting of helipot at 3.5 KΩ and 5.5 KΩ, the sensitivity varies from $\pm$ 0.05°C to $\pm$ 0.08°C for $\pm$ 1 Hz.

The accuracy of reading was found to be of the order of $\pm$1 Hz which is equivalent to 0.3 per cent over the working range. Tests conducted in the laboratory indicated that a maximum variation of $\pm$1 Hz occurs when the instrument is continuously operated for a period of six hours. This maximum deviation corresponds to 0.6 per cent. The normal duration of flight being 3 hours, a variation of more than this magnitude is not likely to occur.

Thus an overall sensitivity of 0.1°C and a maximum error of one per cent can be accepted for the instrument and the computer was programmed accordingly.

5. Preliminary data analysis

Some typical records obtained with the vortex thermometer are shown in Figs. 7 and 8. Fig. 7 shows the temperature profile for the flight on 23 August 1973 at 1500 hr. The data from the ascending aircraft are plotted along with the radiosonde data for the same day for 1630 hr from Santacruz. The total duration of the flight was from 1500 to 1620 hr. Lapse rates of 13.5° C/km, 9.0°C/km, 5.0° C/km were observed at 2000, 5000, 8000 ft respectively. The lapse rate from 2000 to 5000 ft is nearly equal to the dry adiabatic lapse rate.

An isothermal layer was found between 6000 and 7000 ft which is shown more prominently in the

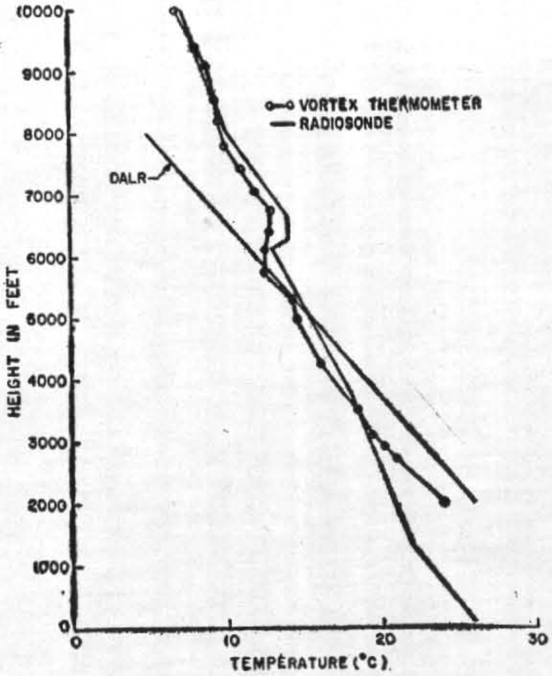

Fig. 7. Comparison of temperature data obtained by vortex thermometer and radiosonde on 3 September 1973 at Santacruz.
(*Courtesy*: India met. Dep.

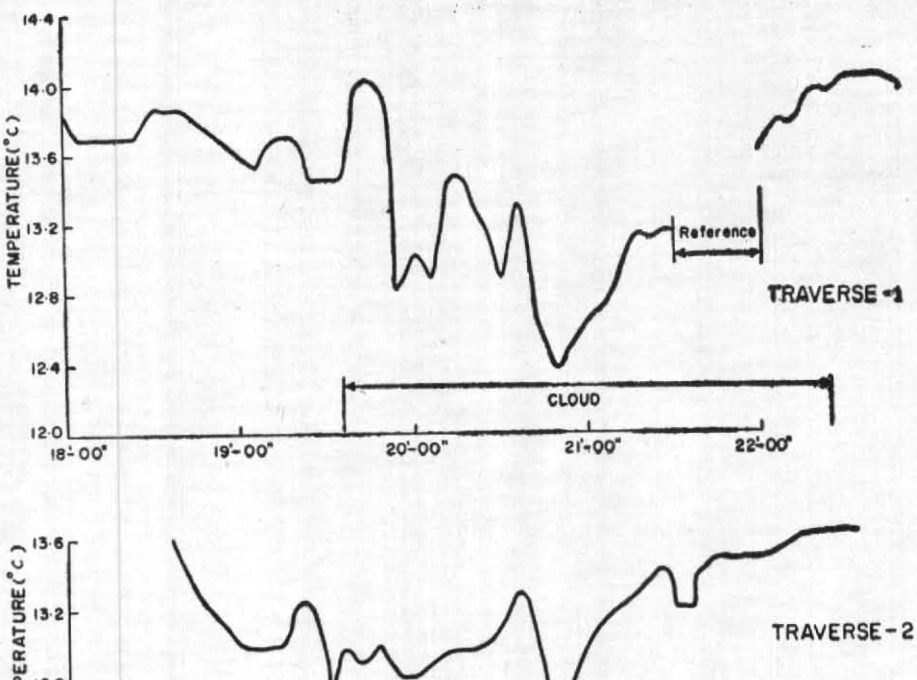

Fig. 8

radiosonde data. Fig. 8 shows the temperature profile in cloud and outside the cloud, when two traverses were made in the same cloud with a time gap of one minute (Traverse path was not the same during second traverse). An increase of 0.1°C to 0.3°C was found as soon as the cloud was entered. A minimum temperature 12.5°C was confirmed in the second traverse. Other features are being studied correlating with the liquid water content meter.

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