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# Doppler Navigator and its application to Meteorological Reconnaissance Flights in India

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## 1. Introduction

Meteorological reconnaissance flights by aircraft are arranged as a routine measure in all the advanced countries of the world for the purpose of collecting valuable upper air data both for day-to-day forecasting as well as for investigation and research. In India too, aeroplane meteorological flights were undertaken between 1927 and 1936 by Royal Air Force squadrons based here. The valuable data obtained by these flights have been analysed by Narayanan (1931) and Ananthakrishnan (1939). During World War II, R.A.F. squadrons based in this country carried out routine vertical soundings of the atmosphere from Madras and few other aerodromes to supplement the radiosonde data. This was discontinued when the R.A.F. moved out of India after the termination of war. With the introduction of the Canberra aircraft into the Indian Air Force in 1958, Meteorological reconnaissance flights have been revived in this country. During 1959, reconnaissance flights at the rate of one per week from two airfields in India were undertaken and from the beginning of 1960, the flights have been increased to two per week from each of these two stations.

The Canberra aircraft is equipped with a Doppler Navigator which enables the direct measurement of the ground speed and drift of the aircraft, from which the spot wind can be calculated accurately. The ground position of the aircraft is indicated on a counter as latitude and longitude or as miles flown along the track.

## 2. Doppler Navigator

J. E. Clegg has been very largely responsible for the successful development in Britain of the Doppler system of aerial navigation and in recognition of this, he was presented with the gold medal for 1959 of the Institute of Navigation.

Prior to the advent of Doppler Navigator, the pilot had no means at his hand to know the ground speed and drift of his aircraft by any instrument. He had to obtain this information indirectly by plotting the track of the aircraft on a map. The track was plotted by taking fixes either visually of some prominent landmarks or by radio means. Two such fixes taken at a known interval of time gave the ground speed. The angle between the course and the track-made-good gave the drift. From the air-speed, the ground speed and the drift, the wind velocity was determined by the triangle of velocities with the help of a computer. This gave average wind over few minutes. Besides, when flying above the overcast, visual observation of the ground became impossible. In the Doppler Navigator, both the ground speed and the drift are indicated directly on dials. These are instantaneous readings and with the help of the computer the wind speed and direction can be accurately calculated within 10 seconds.

## 3. Doppler Frequency

If a source of radiant energy is moving relative to an observer, the frequency of the radiated energy appears to change when received by the observer and this change in

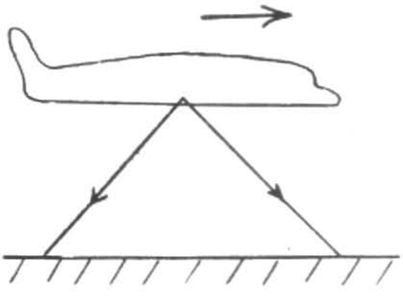

Fig. 1

frequency is proportional to the speed of the source relative to the observer. As the source approaches, the apparent frequency is higher than the frequency radiated and as the source recedes the apparent frequency is lower. This principle of the Doppler Effect is applied to measure directly the ground speed of the aircraft.

Electromagnetic waves transmitted from an aircraft in flight strike the ground and get reflected. Due to the relative motion of the aircraft to the ground, the apparent frequency of the waves as observed on the ground changes slightly. For the reflected wave ground acts as a secondary source of radiant energy at the new frequency. This is received at the aircraft with a second change of frequency again due to the relative velocity between the source (the ground) and the observer (the aircraft). The difference in frequency between the transmitted and received energy is known as the Doppler Frequency and its magnitude is proportional to the speed of the aircraft relative to the ground.

If $V$ is the ground velocity of the aircraft in level flight and $\theta$ the inclination of the electromagnetic wave to the axis of the aircraft, the relative velocity between the transmitter and the ground is $V \cos \theta$. If the receiver is on the ground, the change in frequency is $V \cos \theta \, n/c$ where $n$ is the frequency and $c$ the velocity of the electromagnetic waves. If the receiver and the transmitter are both carried in the aircraft, the Doppler frequency is $2V \cos \theta \, n/c$.

### 4. Doppler Beat Frequency

If only one beam is used, then the Doppler frequency is obtained from the difference of the transmitted and received frequencies. If this difference is to be measured, then the transmitted frequency must be controlled very accurately. This is not practical and the need for doing so is avoided by using two beams; one looking forward of the aircraft and the other looking backward both symmetrical to the axis of the aircraft as illustrated in Fig. 1. The Doppler frequency produced by the forward looking beam is slightly different from the Doppler frequency produced by the backward looking beam because in the first case the aircraft is approaching the point of reflection on the ground and in the second case is going away from the point of reflection. The two returning signals are mixed together to produce beat frequencies and the resulting frequency which is double the Doppler frequency is called Doppler Beat Frequency (D. B. F). The D. B. F. becomes equal to $4V \cos \theta \, n/c$. The two beams also counteract the effect of pitch movement as the angle of depression of forward and backward beams vary inversely.

In actual practice $\theta$ is arranged to be 60°; $\cos \theta$ becomes 1/2.

$n = 8800$ Mc/sec or $8800 \times 10^6$ cycles/sec
$c = 3 \times 10^{10}$ cm/sec

For $V = 100$ knots or 6000 cm/sec, the D.B.F. works out to be of the order of 3 kilocycles per second. For a planned speed range of 100 to 700 knots, the range of D.B.F. will be from 3 to 21 Kc/sec. To enable the measuring circuit to discriminate between D.B.F. and Pulse Rate Frequency (P.R.F.) of the transmitter, the P.R.F. must be either below or above the D.B.F. range. To give good illumination of the ground, the P.R.F. is kept double the highest D.B.F. that is to be measured. 50 Kc/sec is chosen as the P.R.F. The high P.R.F. of 50 Kc/sec means that continuous transmission is not possible since the magnetron would soon overheat and break down. A pulsed transmission is, therefore, used, the pulse width being 0·45 micro-

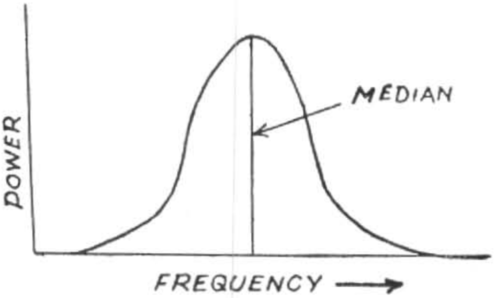

Fig. 2

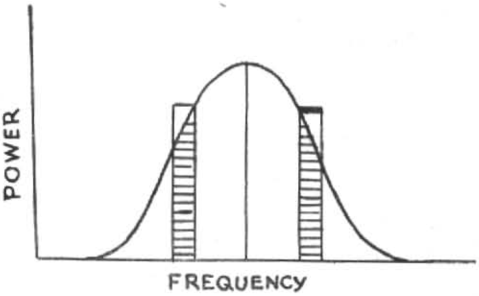

Fig. 3

seconds. It is operated in a burst of 50 Kc/sec for 40 milliseconds and is quiescent for 460 milliseconds before the next burst. Thus it operates twice a second and gives a peak power output of 8 kilowatts.

### 5. Measurement of Doppler Beat Frequency

The transmitted beam is conical and greater the distance to the reflecting surface, the wider the beam becomes at the surface. At the beam edges there is a loss of power and the power of reflection from the beam edges will be less than the power of reflection from the centre of the beam. Only the signals transmitted down the centre of the beam are striking the reflecting surface at an angle of 60°. On either side of the centre, the angle is not 60° and a different frequency will be produced by these reflections. The D.B.F. is not a spot frequency but a spread-out or band frequency about a central frequency, the central frequency giving the most powerful return. The D.B.F. may be presented graphically (Fig. 2). This is known as Doppler Spectrum and the central frequency is the median frequency. The ground speed of the aircraft is proportional to this median frequency. If the ground speed increases, the median frequency also increases and the hump moves to the right. If the ground speed decreases, it moves to the left.

The system used to measure D.B.F. is to take the median frequency of the Doppler Spectrum and on either side of it generate a frequency 'window'. The windows are produced by a motor driven device known as Phonic Wheel Velodyne (P.W.V.). A velodyne is an automatic control system for rotating a shaft with great stability and controlling the speed of rotation accurately. A phonic wheel consists of a wheel, with teeth cut in its periphery like a gear wheel mounted on a motor shaft. A voltage is induced in a pick up coil when the wheel revolves. The frequency of the voltage depends on the number of teeth on the wheel and on the speed of the motor. On the same shaft are fixed two wheels, one with 236 teeth and the other 252 teeth. The first produces [low frequency output and the second high frequency output. Both the outputs are fed through 0 -- 150 C/S filter to produce narrow windows (Fig. 3). The speed of the motor is controlled by two coils A and B (Fig. 4). The power of the coil A is derived by the position of the windows along the frequency axis and the power of the coil B is derived by the power difference $E_o$ between the two windows. Consider the P.W.V. to be measuring the correct D.B.F. Then the power to coil A will rotate the motor at such a speed that the phonic wheel will produce windows symmetrically placed about the median frequency as in Fig. 3. Thus there will be no power difference between the windows and the coil B will be inoperative. Consider now a change of D.B.F. caused by an increase in ground speed (Fig. 5).

There will now be a power difference between the windows which will bring coil B into operation. The motor will increase in speed, thus increasing the Phonic Wheel

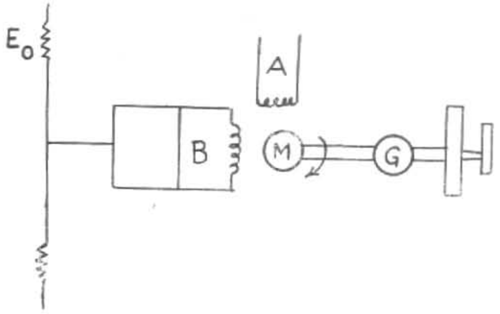

Fig. 4

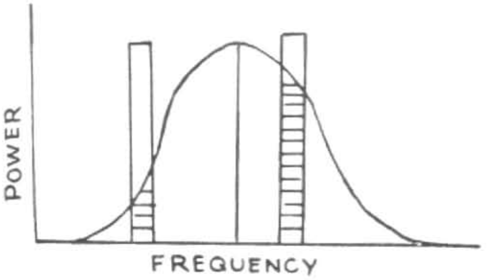

Fig. 5

frequencies and causing the windows to search for the median frequency. A movement of the windows increases the power to coil A while decreasing the power to coil B ($E_0$) until the correct median frequency is measured.

The windows are thus locked to the median frequency and as the median frequency changes so does the speed of P.W.V. The speed of rotation of the motor shaft will, therefore, be proportional to the ground speed and the number of revolutions of the shaft will give with suitable calibration, the distance flown.

### 6. Aerial System

The aerial array consists of four slotted linear arrays lying parallel to each other in a directional horn assembly. The axis of the aerial is horizontal. The linear arrays are arranged in phased and anti-phased pairs with a common feed at one end, thus providing forward and backward looking beams. The beam width at the half power point is 2½ degrees.

The two pairs of aerials are energized alternately by a special Y section of waveguide which oscillates about a vertical hinged joint to form a waveguide switch. The horn assembly deflects one pair of beams to a mean angle of 20 degrees left of the vertical plane. The forward beam is switched from port to starboard whilst the rearward beam is simultaneously switched from starboard to port. The net result is that when one forward beam is displaced to starboard of the aircraft track the other backward beam is simultaneously displaced to the port; when the forward beam is displaced to port, the backward beam is simultaneously displaced to starboard and the positions are reversed twice a second by a suitable switch.

### 7. Measurement of Drift Angle

The drift angle is measured by comparing the Doppler Frequency when the forward beam is displaced to starboard ($fb_1$) and the backward beam is displaced to port ($fb_2$), to the frequency when the forward beam is displaced to port ($fb_3$) and the backward beam to starboard ($fb_4$). The aerial system illuminates two hyperbolic strips, one forward and one backward of the aircraft's position. The beams are switched every half second. When there is no drift and the aerial is aligned (Fig. 6) with the aircraft's heading, the D.B.Fs. from each pair of beams are equal. Each half second these equal D.B.Fs. are fed through the tracker circuits and produce equal outputs at the integrator unit (for ground speed and distance measurement) and at the azimuth unit for drift measurement. Since outputs are equal no voltage is produced at the azimuth unit.

If the aircraft drifts to port (Fig. 7), the D.B.Fs. from each pair of beams will be different and the discriminator outputs will change every half second. $b_1 + b_2 < b_3 + b_4$. These changing outputs produce a voltage at the azimuth unit (and differing ground speed on the indicator) which energises the azimuth motor.

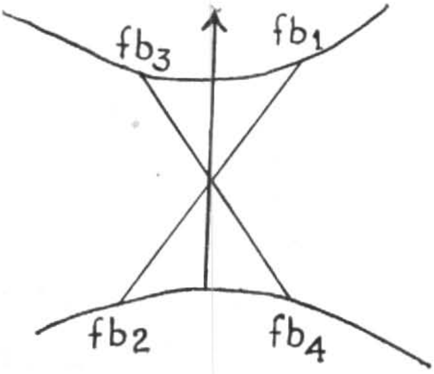

Fig. 6

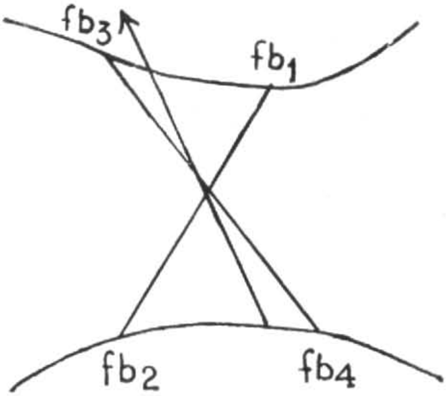

Fig. 7

This motor rotates the aerial system until it lies along the aircraft's track, so that the D.B.Fs. from each pair of beams are equal again. The aerial is kept locked to the track of the aircraft. A synchronous transmitter is geared to the azimuth motor and feeds the drift motor on the indicator with the angle through which the aerial has been turned from the centre line of the aircraft.

### 8. Accuracy

Drift is measured every second to an accuracy of 0·1 degree. The basic accuracy of the Doppler Navigator in level flight is 0·1 per cent in the distance flown. The ground speed meter is calibrated in $\frac{1}{2}$ degree from 20 degrees port to 20 degrees starboard.

### 9. Applications of the Doppler Navigator to Meteorology

The airspeed of the aircraft is shown in the instrument called Airspeed Indicator. The ground speed and the drift are shown in the Doppler Navigator. The vector difference between the airspeed and the ground speed gives the wind at the flight level. Since both the airspeed and the ground speed are instantaneous readings, the wind speed thus calculated is also an instantaneous reading. Thus the Doppler Navigator enables us to get a spot wind reading. The wind speed is computed with the help of a computer and it takes hardly 10 seconds to do the computation. The ideal thing from the point of view of meteorologist is to have the wind speed and direction also indicated on dials which has been achieved in later models. This spot wind can be taken at quick intervals. The distance flown between two readings of the wind is shown directly on the indicator. This enables the wind-shear to be measured accurately. Wind readings in quick succession also enables the fine structure of the wind to be measured especially near the jet stream.

Under no wind conditions, the aircraft's course and track are identical and the drift is zero. Also the ground speed is the same as the airspeed. Due to wind (whenever there is any cross component), the aircraft's track becomes different from the course, the angle between the two being the drift. During pre-flight planning, the navigator makes use of the forecast winds and calculates the course he has to fly and also estimates his ground speed. If the actual wind is the same as the forecast winds at his flight level, there will be no drift and the ground speed will be the same as estimated by him. But if the actual wind is different from the forecast winds, at once the drift meter shows it out. Also the ground speed indicated on the dial will be different from the estimated one. Larger the drift angles farther is the forecast wind from the actual. Thus with the introduction of the Doppler Navigator, the accuracy of the forecast winds is being tested every second and indirectly the forecaster is continuously under trial.

The presence of a jet stream cannot be seen usually even by a pilot flying at that level. But the Doppler Navigator reveals it. Suppose an aircraft is flying from south to north and he suddenly meets with a westerly jet stream. His aircraft will drift towards starboard (right) and the drift meter reveals it. As the speed of the jet increases, the drift also increases. The maximum drift will be when the jet core is reached. Thereafter the drift decreases. Thus the Doppler Navigator enables the jet stream to be discovered.

When once the presence of the jet stream is detected by the sudden drift, the wind direction can be measured and the aircraft can be flown at right angles to this direction so as to enable the wind data along the cross-section of the jet stream to be determined. This technique has been used in many met. reconnaissance flights to get the wind and the temperature data of the jet stream cross-sections. It is observed that entrance to jet stream is invariably accompanied by clear air turbulence. Turbulence can be quantitatively measured from the 'g' meter which is available in the Canberra aircraft.

The air temperature is directly read on the thermometer. After applying the correction for the true air speed of the aircraft, the true temperature of the air at the flight level is determined. It is found that at the level of the jet core, the horizontal temperature gradient across it is very very small. In the case of a westerly jet stream, the temperature decreases from south to north below the level of jet core and above this level the gradient is reversed, *i.e.*, the temperature increases as one goes from south to north across the jet. From this simple rule, the pilot can judge whether the core of the jet stream is above him or below him. He can then hunt for the jet stream core more successfully.

## 10. Flight Met. Observations

The Doppler Navigator indicator dials are placed in the Canberra aircraft in front of the navigator's seat. This navigator's seat in the Canberra aircraft is such that he cannot see outside and take any cloud observation. The cloud and weather observations are taken by the pilot who has full view of the air space in front of him. The pilot passes the weather and cloud data to the navigator on intercom who notes it down. Before the flight, both the crew members are briefed fully regarding the path to be followed, heights to be flown and the significant weather to be looked for. They are instructed to take observations every five or ten minutes. At the end of the flight, the proforma is completed and the crew members come to the Met. Office for de-briefing. The meteorological officer goes through the report with them and queries them for any further amplification or clarification. The report is put in Recco Code and sent to the central office for broadcast. A special met. report of the reconnaissance flight taken on 7 July 1960 is given in Table 1.

## 11. Discussion of the Data

The existence of an easterly jet stream in summer over India at about 15°N latitude at about 150-mb level was known by the work of Venkiteshwaran (1950), Krishna Rao (1952) and Koteswaran (1956). On this day an easterly jet stream was suspected and the pilot was briefed to fly from Poona to Cape Comorin and back. He was asked to take wind observations every 5 minutes especially when flying across the jet stream. The aircraft took off at 0918 IST and set course to Cape Comorin. It was gradually climbing and when it came to 15°N latitude, it had reached 43,000 ft pressure altitude. It levelled out and flew between 43 and 44 thousand feet upto Cape Comorin. This indicated altitude amounts to about 46 to 47 thousand feet true altitude (above mean sea level). The aircraft returned at a pressure altitude of 46 to 47 thousand feet, *i.e.*, at a true height of 50,000 ft. The route followed was Cape Comorin, Tiruchirapalli, 11° 10′ N and 79°20′ E and then straight to Poona.

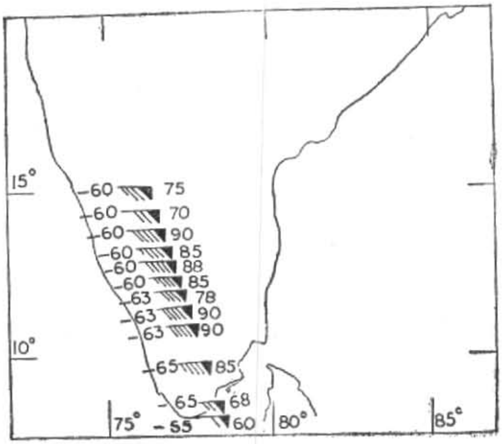

Fig. 8. 43-44 thousand feet pressure altitude — 7 July 1960

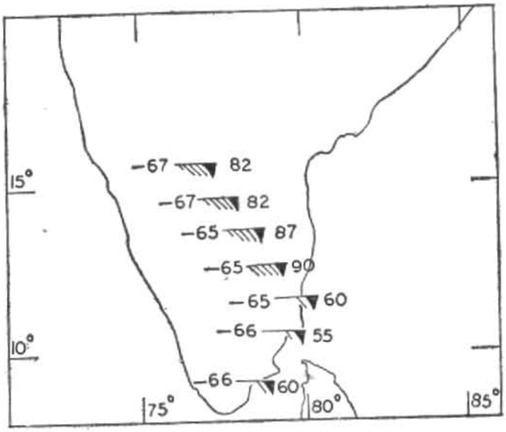

Fig. 9. 46-47 thousand feet pressure altitude — 7 July 1960

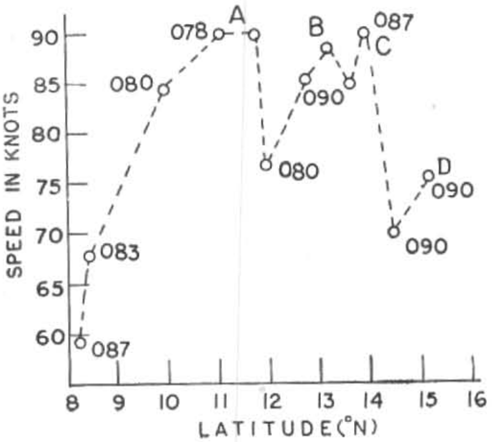

Fig. 10

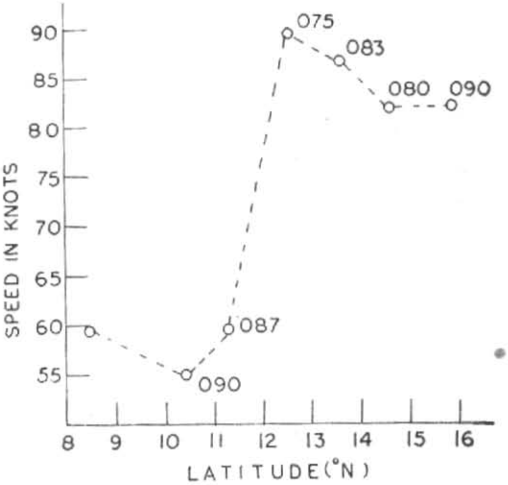

Fig. 11

### 11.1. *Winds*

The observed winds for the outward and inward legs of the flight are plotted in Figs. 8 and 9. Each full feather represents 10 kts and half feather 5 knots and pennant 50 kts in the usual notation. Actual wind speed and temperature are also plotted.

Also, the wind speed is plotted against atitude both for the outward and inward egs in Figs.10 and 11 and the consecutive points are joined by straight lines. The direction of wind is indicated below the wind profile. An easterly jet stream of 90 knots was encountered between 14°N and 10°N, *i.e.*, over a distance of about 260 miles. Inside this broad jet stream, three distinct and separate maxima are noticed thus revealing the fine structure of the jet stream. The humps are marked as A, B and C in Fig. 10. The maximum values of the winds are 90, 88 and 90. The minimum between the

## TABLE 1

### Flight Met. Observations

| | | |
|---|---|---|
| Date: 7 July 1960 | Aircraft No. XXX Squadron XX | Met. Reccce Serial No. : XX |
| Route : Poona–Cape Comorin–Poona | Time of take-off : 0918 IST | Name of Pilot : Flt. Lt. Talwar |
| | Time of landing : 1250 IST | Name of Navigator : Flt. Lt. D.K. Saxena |

| Time (IST) | Position | | Pressure Altitude (ft) | Temp. (°C) | Wind | | Visibility | Clouds | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lat. N (deg. & min.) | Long. E | | | Dir. (deg.) | Speed (kt) | | Type | Amt (octa) | Base (ft) | Top (ft) | |
| 0915 | Poona A/F | | | +28 | | | 5 n.m. | *St* | 5 | 1200 | 3500 | |
| 0920½ | 1825 | 7358 | 10000 | +11 | 273 | 27 | Covered below | *Sc*<br>*Ac* | 4<br>5 | 4000<br>15000 | 6000<br>25000 | |
| 0925 | 1802 | 7415 | 15000 | +02 | 340 | 15 | In clouds | ,, | ,, | ,, | ,, | |
| 0926 | 1746 | 7418 | 20000 | —05 | 270 | 15 | ,, | ,, | ,, | ,, | ,, | |
| 0929 | 1722 | 7423 | 25000 | —12 | 105 | 30 | On top cloud | *Ci* | 2 | 28000 | — | |
| 0933 | 1655 | 7430 | 30000 | —23 | 095 | 30 | In *Ci* | In clouds | | | | |
| 0942 | 1535 | 7450 | 40000 | —53 | 080 | 60 | Flying through the layer of clouds | | | | | Moderate clear air turbulence |
| 0947 | 1505 | 7510 | 43000 | —55 | 080 | 75 | Clear on top clouds | *Ac*<br>*Ci* | 5<br>1 | —<br>41000 | 25000<br>43000 | Do.<br>Entering Jet-stream |
| 0955 | 1430 | 7525 | ,, | —58 | 090 | 70 | Ground observed | *Ci* | 2 | 41000 | 43000 | |
| 1000 | 1355 | 7532 | ,, | —58 | 087 | 90 | V. good | *Ac* | 8 | — | 25000 | Severe clear air turbulence |
| 1004 | 1327 | 7540 | 44000 | —60 | 090 | 85 | ,, | ,, | ,, | ,, | ,, | Do. |
| 1010 | 1300 | 7552 | 44000 | —60 | 090 | 88 | V. good | *Ac,Sc* | 8 | — | 25000 | Severe clear air turbulence |
| 1013 | 1233 | 7616 | 44000 | —60 | 093 | 85 | ,, | ,, | ,, | ,, | ,, | ,, |
| 1020 | 1200 | 7623 | ,, | —63 | 080 | 78 | Ground covered V. good | ,, | ,, | ,, | ,, | Drift fluctuating with 3-4 deg. |
| 1025 | 1139 | 7631 | ,, | ,, | 078 | 90 | ,, | ,, | ,, | ,, | ,, | — |
| 1035 | 1100 | 7643 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | — |
| 1045 | 0957 | 7715 | ,, | ,, | 080 | 85 | ,, | *Ac, As, Ci* | 6 | ,, | 25000<br>35000 | — |
| 1055 | 0820 | 7735 | ,, | —65 | 083 | 68 | ,, | ,, | 3 | ,, | ,, | Ground visible patch |
| 1058 | Over Cape Comorin | | ,, | ,, | 087 | 60 | ,, | — | — | — | — | — |

**TABLE 1** *(contd)*

| Time (IST) | Position | | Pressure Altitude (ft) | Temp. (°C) | Wind | | Visibility | Clouds | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lat. N (deg.& | Long. E min.) | | | Dir. (deg.) | Speed (kt) | | Type | Amt (octa) | Base (ft) | Top (ft) | |
| 1110 | 0830 | 7800 | 46000 | —66 | 083 | 60 | Ground covered V. good | — | — | — | — | — |
| 1120 | 1030<br>Trichi | 7845 | ,, | ,, | 090 | 55 | ,, | *Ac*<br>*Ci* | 2-3<br>1 | —<br>— | —<br>30000 | —<br>— |
| 1129 | 1110 | 7920 | ,, | —65 | 087 | 60 | ,, | ,, | ,, | ,, | ,, | — |
| 1147 | 1230 | 7829 | 47000 | ,, | 075 | 90 | ,, | *Ac*<br>*Ci* | 3<br>2 | — | 25000<br>35000 | Slight clear air turbulence |
| 1210 | 1325 | 7715 | ,, | ,, | 083 | 87 | ,, | ,, | ,, | ,, | ,, | Do. |
| 1220 | 1425 | 7640 | ,, | —67 | 080 | 82 | ,, | ,, | ,, | | ,, | |
| 1228 | 1535 | 7600 | ,, | ,, | 090 | 82 | ,, | *Cu*<br>*Ac* | 4<br>3 | —<br>— | 2500<br>20000 | |
| 1245 | Over Poona | | 22000 | —08 | 270 | 20 | In clouds | Could not get descent winds as C/SATIN was unlocking | | | | |

**TABLE 2**

| Lat. (°N) | Temp. (°C) 43 th. feet |
|---|---|
| 1505 | —60 |
| 1430 | —60 |
| 1355 | —60 |
| 1327 | —60 |
| 1300 | —60 |
| 1233 | —60 |
| 1200 | —63 |
| 1139 | —63 |
| 1100 | —63 |
| 0957 | —63 |
| 0820 | —65 |
| 0805 | —65 |

**TABLE 3**

| Lat. (°N) | Temp. (°C) 46 th. feet |
|---|---|
| 0830 | —66 |
| 1030 | —66 |
| 1110 | —65 |
| 1230 | —63 |
| 1325 | —63 |
| 1425 | —65 |
| 1535 | —65 |

humps A and B is 78 knots and between B and C, it is 85 knots. There is another hump of 75 knots at Lat. 15° N.

The direction of wind at hump A is 078 deg. and at hump B is 090 deg. This 12° difference is a clear evidence of splitting up of a jet into two distinct streams. Between humps B and C, there is a difference of only 3 degrees. Such fine structure could be revealed only by met. reconnaissance flights where wind readings are taken at short intervals and not possible by normal methods in the existing network of Pibal Stations. The Doppler Navigator ensures high accuracy of the observations and the high speed of the aircraft makes the wind observations almost synoptic. Similar fine structure in polar jet streams also exists as revealed by the work of Endlich (1954), Landers (1955) and Riehl (1955).

In the return flight, unfortunately there are only 8 readings. Fig. 9 reveals only one maximum of 90 knots at Lat. 12°30′ N.

### 11.2. *Temperature*

Temperatures are reduced to the same pressure altitude of 43,000 feet for the outward flight by assuming a lapse rate of 2°C

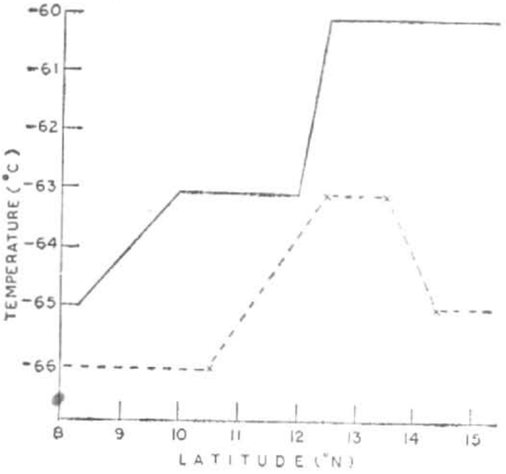

Fig. 12

per thousand feet (Table 2). The temperature remains steady at —60°C from Lat. 15°N to 12°33′N. Then there is a sharp fall of 3°C. It remains steady at —63°C till Lat. 09° 57′ N after which it again falls by 2°C. The gradient of temperature is from north to south as is required for easterly jet stream below the core. The highest baroclinity is seen at 12°N Lat. which is roughly the core of the jet.

For the return flight, the temperatures are reduced to 46,000 ft pressure altitude (Table 3). The temperature is —65°C at 15°N Lat. and remains the same till 14°25′N. It rises to —63°C till 12°30′ Lat. Thereafter again it falls to —66°C. Temperature is maximum over the jet stream and decreases on either side by 2 to 3 degrees (Fig. 12).

### 11.3. *Clear Air Turbulence*

Severe clear air turbulence was experienced at Lat. 14°N at the entrance to the jet stream core where there was a strong wind shear of 20 knots in about 40 miles. The turbulence lasted for about 100 n. miles from 14°N to 12°30′ N Lat. In the return flight again clear air turbulence was experienced at 12°N at the entrance to the jet core where the wind shear was 30 knots in 60 n. miles.

### 11.4. *Clouds*

There was 8/8 clouds between 14°N and 10°35′ N latitudes, just below the jet stream in the outward flight only. The medium cloud tops were estimated to be 25,000 ft. There were also patches of Cirrus, base 41,000 ft, tops 43,000 ft at the jet stream latitude. During the return flight, which was slightly to the east, there were only broken medium clouds and Cirrus tops extended upto 30—35,000 ft.

## 12. Further study

Detailed case study of some more jet streams and analysis of met. reconnaissance reports are on hand.

## 13. Acknowledgement

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