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Observations of turbulence in the upper air with the F-type Radiosonde

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ABSTRACT. The paper indicates how regions of turbulence in the upper air can be located by an examination of the rate of rotation of the fan in the F-type radiosonde developed and used in the India Meteorological Department.

1. The characteristics of the paper-fan in the F-type radiosonde

The main characteristics of the paper-fan in the F-type radio-meteorograph[1] are that it rotates only when it moves relative to the air along the axis of rotation in the forward direction and is steady when moved in the opposite direction ; and horizontal winds at any level have very little effect on the rotation of the fan. The rate of rotation of the fan was tested in a wind tunnel. The effect of the wind (*i*) at right angles to the axis of rotation, and in a direction along it and (*ii*) from in front of it is shown in Fig. 1. In an actual balloon ascent, the balloon moves horizontally with the speed of the wind and, therefore, the effect of the horizontal wind must be even much less. The Vaisala and British type of radio-meteorographs, on the other hand, operate on the principle of the cup anemometer, with its axis of rotation horizontal. As a result, the cup will rotate both during the rising and the falling of the balloon. Fig. 2 shows the rate of rotation of the fan in the F-type radio-meteorograph at different heights and the wind speed at that level. It appears from these curves that the rate of rotation of the fan is almost independent of the wind in that level.

As the fan in the F-type radio-meteorograph operates mainly during the upward motion along the axis of rotation, and is not appreciably affected by horizontal winds, the rate of rotation of the fan serves as a very useful indication of the existence of vertical currents in the atmosphere. If the balloon develops a leak, the rate of ascent will first decrease, and later the balloon will descend. This will be reflected in the rate of rotation of the fan, which will begin to slow and stop when the balloon begins to descend. On the other hand, if snow accumulates on the balloon, the rate of rotation will decrease gradually and the rotation will stop as soon as the accumulation is sufficiently large to exceed the free lift of the balloon and the balloon descends. However, in a case like this, when the balloon descends, the accumulated snow will melt below the freezing level, and the balloon will rise again, when the fan will restart working. Suryanarayana and Kachare[2] had occasion to observe this phenomenon on two days, when F-type radiosonde ascents were made during rain. On these occasions, the balloon came down and went up a number of times due to the accumulation of snow during ascent and melting during descent.

The F-type radio-meteorograph ascents have also indicated the existence of vertical currents in thunderstorms. In a paper[3] analysing a radiosonde ascent during a thunderstorm at Poona on 26 April 1950, Venkiteshwaran and Tilakan have shown that the balloon descended due to a strong downward current of air, and even estimated the rate of descent of the vertical current. As described in the previous paragraph, if the balloon descends due to the leakage of gas or due to the accummulation of snow, the fan will not rotate and no signals will be received from the radio-meteorograph. If however, the balloon descends due to strong downward vertical current of air, the fan will continue to rotate and the rate of descent will be indicated by the increase in the pressure and temperature values.

2. Rate of rotation of the fan and wind characteristics

It was decided to test whether the observed fluctuations in the rate of rotation of the fan are true indications of certain characteristic wind features in the atmosphere, and if so, to what extent. The rates of rotation of the fans in two instruments tied to the same balloon were first examined. The rate of rotation of the fan in the radiosonde ascent is measured by the length of the paper tape record, between the fixed reference in consecutive cycles. As the signals are caused by the rotation of the fan, and the total number of signals in one complete cycle, *i.e.*, between the fixed reference signals in consecutive cycles is constant, and as the tape is moved uniformly with a motor, a longer tape between two consecutive signals of the same fixed reference will indicate a slower rate of rotation of the fan and *vice versa*. Fig. 3(a) shows the rate of rotation of the fans in two instruments attached to the same balloon. The instruments sent up with the balloon have been taken at random and are, therefore, not standardised and identical. Therefore, the speed of rotation of the fans in the two instruments are not the same, but they show similar variations. Fig. 3(b) shows the rate of rotation of the fans in two instruments let off simultaneously with two independent balloons.

If the changes in the rate of rotation of the fan represents characteristic wind properties in the air mass, it should be indicated from two simultaneous ascents from different places in the same air mass. Fig. 4 shows the variation in the rate of rotation of the fan at Poona (18° 32′N 73° 51′E) and Nagpur (21° 09′N 79° 07′E). The ascents show a degree of agreement which confirms the view that the rate of rotation of the fan represents specific property of the air mass.

From the above, it is quite evident that the variation in the rate of rotation of the fan observed in the F-type radio-meteorograph records are due to the variations in the relative motion of the air in the vertical direction due to turbulence. In clear weather, when accumulation of snow or rain on the balloon cannot occur, the variations in the rate of rotation of the fan occur due to eddies which have large dimensions at higher levels ; they can also be due to the changes in the rate of ascent of the balloon caused by the temperature distribution in the atmosphere.

3. Temperature distribution in the atmosphere and rate of rotation of the fan

Fig. 5 shows the daily variation of the rate of rotation of the fan at various heights and the corresponding temperature distribution during the period 11 to 15 May 1950. The variation in the rate of rotation of the fan at different levels is indicated on the T-ϕ gram by distances from a line normal to the 1000 mb isobar. It is interesting to note from these observations that the large decrease in the rate of rotation of the fan is in the regions of low lapse rates. This is a common feature observed in all flights. As the performance of a hydrogen filled balloon can be considered in terms of a hot or lighter gas, it should naturally be expected to rise at a lower rate through low lapse rates or inversions. In this connection, the curves showing the " height line " of pilot balloons observed by the " tail method " were also examined and a non-linearity in the height line noticed in the region of the inversions. It can also be observed from Fig. 5 that the rate of rotation though different in the two layers above and below the region of low lapse rates remains almost the same within the two layers.

Figs. 6(a) and (b) show a series of curve showing the variation of the rate of rotation of the fan at various levels over Poona from 11 to 14 March 1951. It will be observed from these that in the region between 400 and 300 mb there were frequent and large increase in the rate of rotation of the fan. The occurrence of the rapid fluctuation in the rate of rotation in a particular region, its persistence on a few days, and its absence later are significant. Figs. 7(a) and (b) show a similar feature at Trivandrum.

An increase in the rate of rotation of the fan can either be due to an increase in the rate of ascent of the balloon relative to the surrounding air or due to a downward current of air ; the rate of ascent of the balloon may increase suddenly when the balloon is sharply pushed up by a vertical upward current from below. When, however, the balloon meets with a downward current, the fan will be rotating at a faster rate than usual. On the other hand, if the balloon, instead of rising due to its own free lift in steady air, gets into a column of rising air, resulting in decrease in the relative vertical velocity between the balloon and the air it will be reflected as a decrease in the rate of rotation of the fan. One can, therefore, conclude that the observed rapid increase or decrease in the rate of rotation of the fan are mostly due to strong downward or upward currents due to turbulence occuring in these regions. As the variations in the rate of rotation of the fan are all of very short periods, and represent the effect of turbulence they cannot be observed from the rate of ascent of the balloon computed from the observations of pressure signals received from the radio-meteorographs. The balloon due to its inertia cannot respond immediately to such short period effects of turbulence and the variations in the rate of ascent of the balloon will be so small as not to be capable of detection with the methods of observations now available.

4. Clear air turbulence and F-type radiosonde

With the increase in the frequency of high level flying, the atmospheric phenomenon of clear air bumpiness has come to light. G. S. Hislop[4] of British European Airways who has made an attempt to study this phenomenon has reported that aircraft flying at all levels above Europe from 15,000 to 37,000 ft have encountered severe bumpiness. The gustiness was encountered sufficiently often for it to be a matter of concern to airline operators, for it reached more than 1/2 g at times. High level turbulence has also been recently reported from Canada[5]. An instance has been reported in which an aircraft reported that turbulence commenced at 23,000 ft and it was still present at 26,000 ft the maximum height of ascent of the aircraft. The maximum turbulence was experienced at 24,000 ft at which height an acceleration of 3 g was recorded at an indicated speed of 170 knots. Hislop states that " these bumpy regions are of the order of 50 miles wide, nobody knows how long, and 2000 to 3000 ft deep. They may be above or below the tropopause, in high or low pressure regions or in cols and are not associated with mountains. They seem to occur with large or small horizontal and vertical wind and temperature gradients, but it must be said that these gradients have really only been measured as mean values over much greater distances than the extent of the bumpiness. The motion of the air is unknown except in so far as aircraft flying at about 300 miles per hour find it very bumpy, and no satisfactory explanations are forthcoming as to why it should occur at all ". These aircraft reports definitely seem to confirm the view that the variations in the rate of rotation of the fan are direct indications of the regions of turbulence. From the preliminary examination of the observations from a number of F-type radiosonde stations in India, it appears that clear air turbulence occurs fairly frequently at high levels in the regions of 300 to 250 mb at Trivandrum (8°29′N 76°57′E) during March and April and is, therefore, not a phenomenon to be associated only with jet- streams. A detailed study of this phenomenon, *viz.*, their frequency of occurrence with reference to seasons and heights, depth, etc., at all the F-type radiosonde stations is on hand and it is hoped that valuable information may be forthcoming on this subject.

Dever Colson[6] has observed an instance of unusually large vertical motions from direct observations of the variation of the rate of ascents from the pressure data from radiosonde ascents. This occurred just below an inversion layer in the middle troposphere and he has tried to explain the observations as due to gravity waves caused in the layer. From Fig. 5 it is observed that on 11 May 1950 the rate of rotation of the fan fluctuated in the regions just below and above layers of very low lapse rates. This appears to be a frequent feature associated with regions of low lapse rates. Apparently this is a turbulent region.

The present attempt has been only to prove how the rate of rotation of the fan in the F-type radiosonde can be a simple tool for locating regions of turbulence at any height in the atmosphere. With standardised fans it may be possible not only to locate regions of turbulence, but to compare its intensity from day to day. A detailed analysis of the rate of rotation at different levels over different stations is on hand, to study the seasonal and other characteristics and it is hoped that useful results will be obtained.

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5. *Weather*, **6**, 5, pp. 152-153 (1951).
6. Dever Colson, *Bull. Amer. met. Soc.*, **31**, 10, (1950).

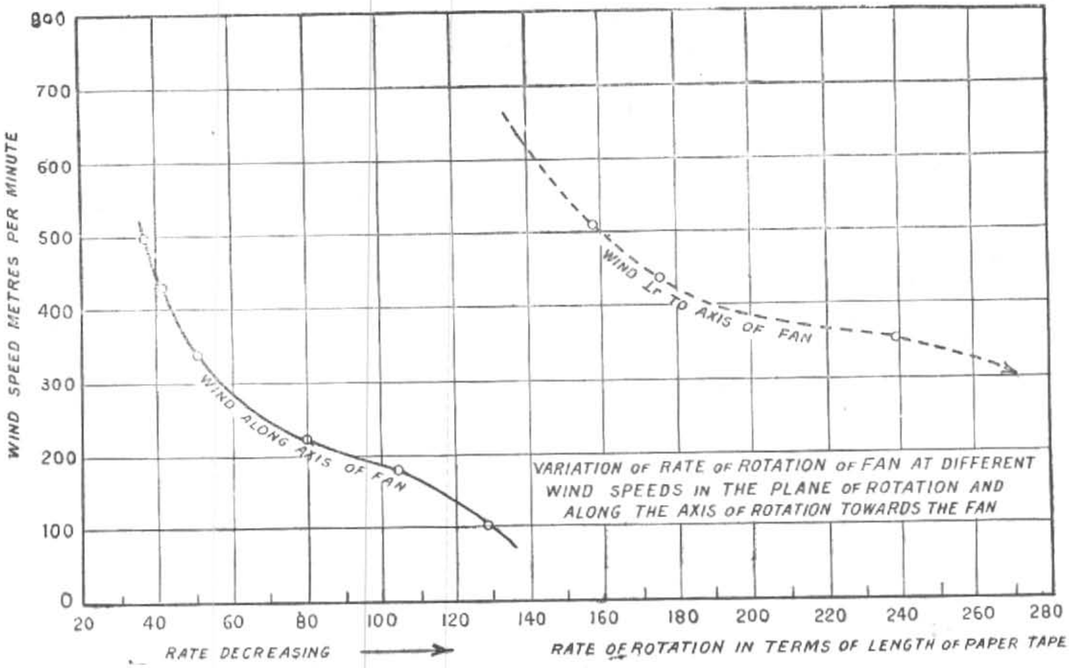
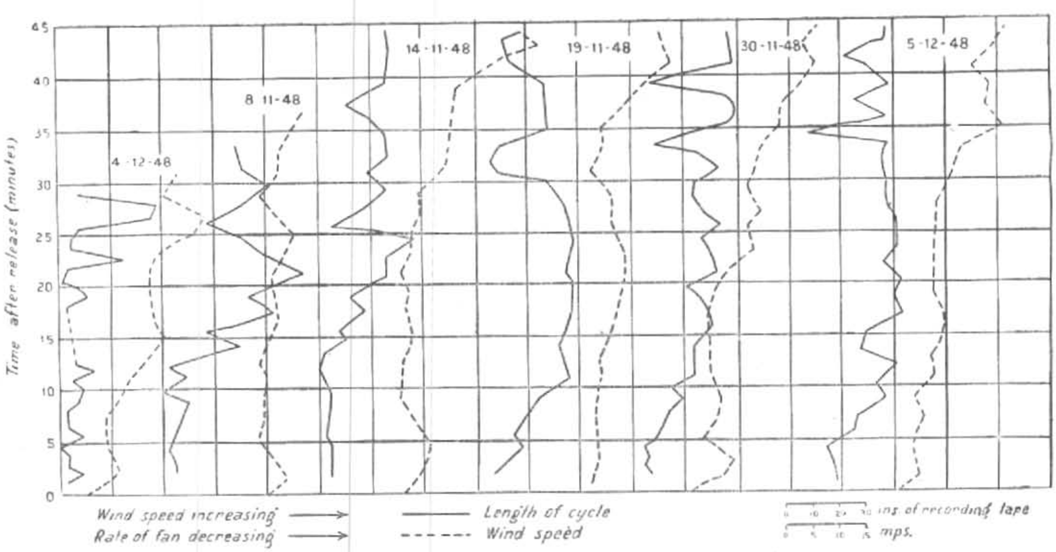
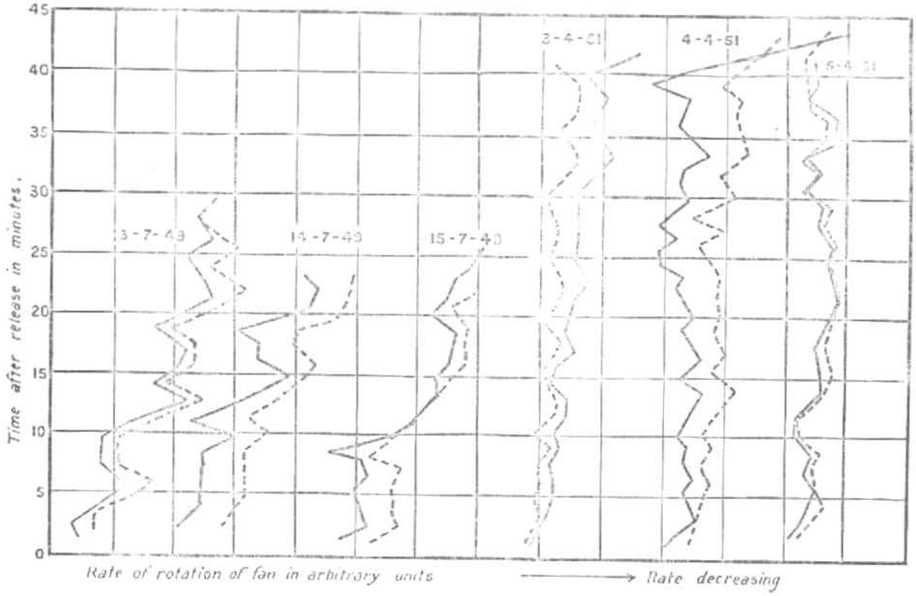


Fig. 1



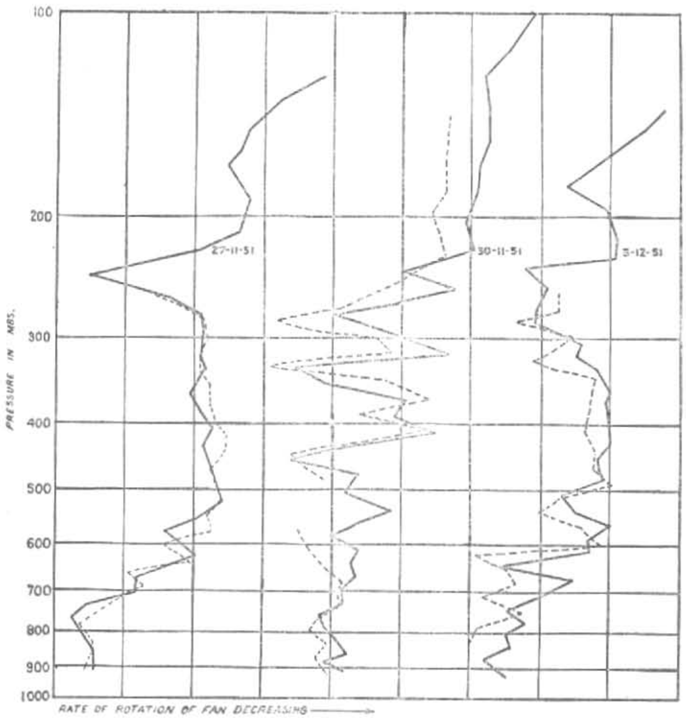
RATE OF ROTATION OF FAN AND WIND SPEED AT DIFFERENT LEVELS AT POONA

Fig. 2



COMPARISON OF RATE OF ROTATION OF FAN IN TWO INSTRUMENTS LET OFF WITH ONE BALLOON AT POONA.

Fig. 3(a)



COMPARISON OF RATE OF ROTATION OF FAN IN TWO INSTRUMENTS LET OFF SIMULTANEOUSLY WITH TWO INDEPENDENT BALLOONS AT POONA

Fig. 3(b)

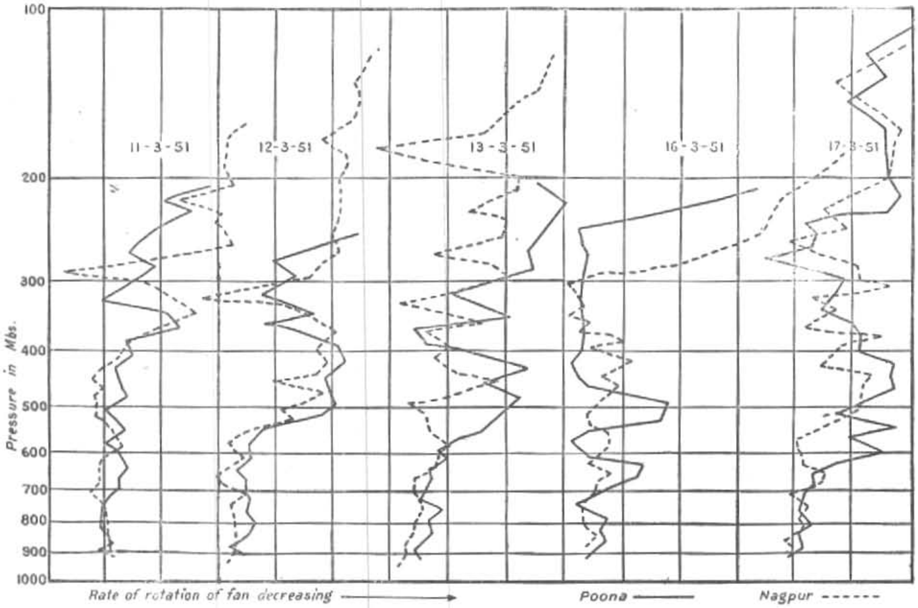


Fig. 4

COMPARISON OF RATE OF ROTATION OF FAN IN RADIO SONDES RELEASED AT ABOUT 1500 HRS. G.M.T. AT POONA AND NAGPUR.

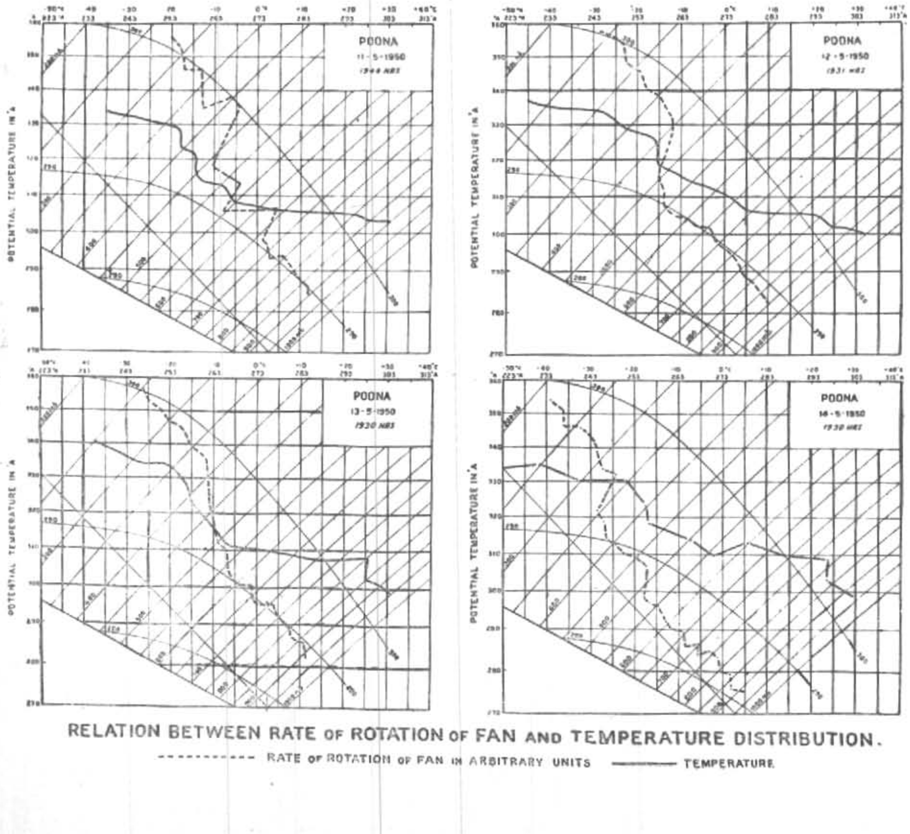


Fig. 5

RELATION BETWEEN RATE OF ROTATION OF FAN AND TEMPERATURE DISTRIBUTION.

----------- RATE OF ROTATION OF FAN IN ARBITRARY UNITS ——— TEMPERATURE

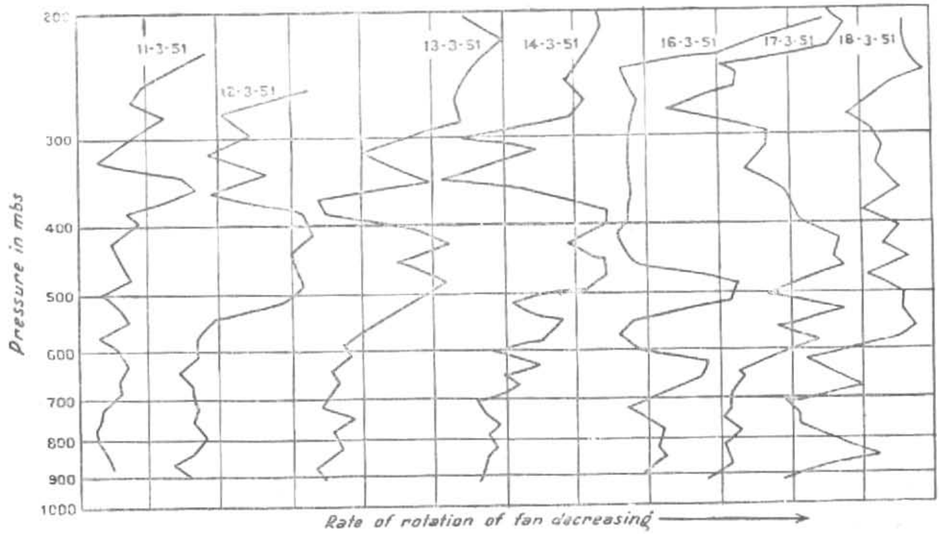


Fig. 6(a)

COMPARISON OF RATE OF ROTATION OF FAN AT DIFFERENT LEVELS ON A FEW CONSECUTIVE DAYS AT POONA

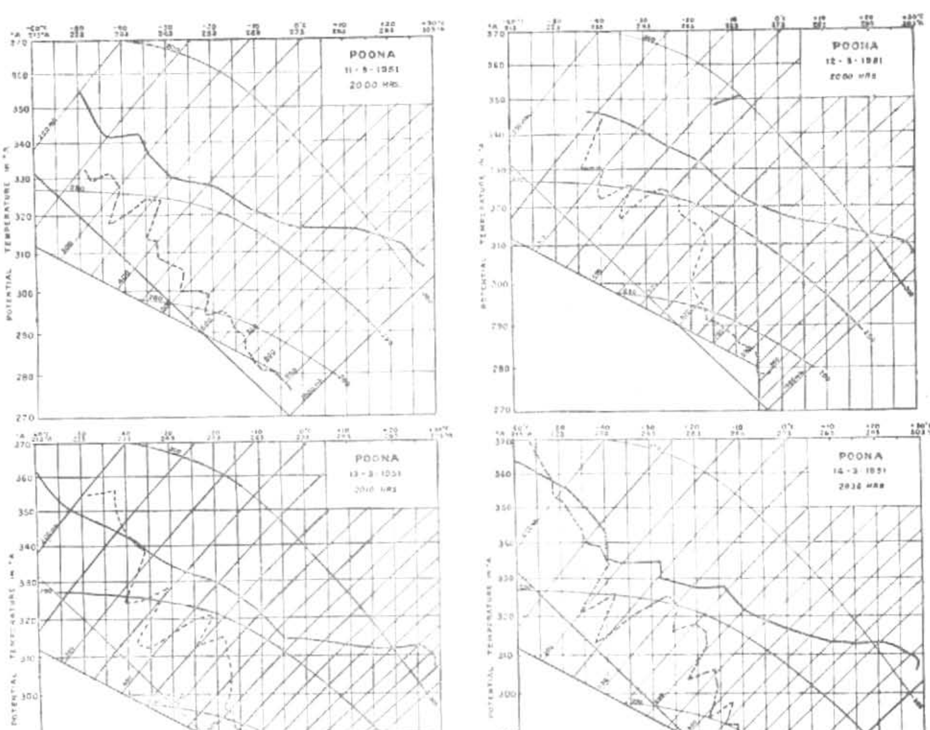


Fig. 6(b)

RELATION BETWEEN RATE OF ROTATION OF FAN AND TEMPERATURE DISTRIBUTION.

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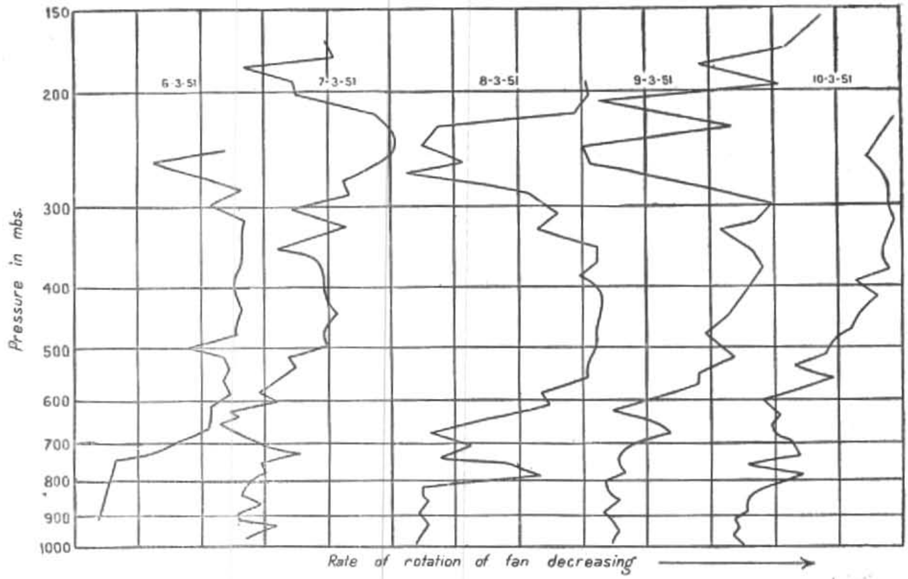

Fig. 7(a)

COMPARISON OF RATE OF ROTATION OF FAN AT DIFFERENT LEVELS ON A FEW CONSECUTIVE DAYS AT TRIVANDRUM.

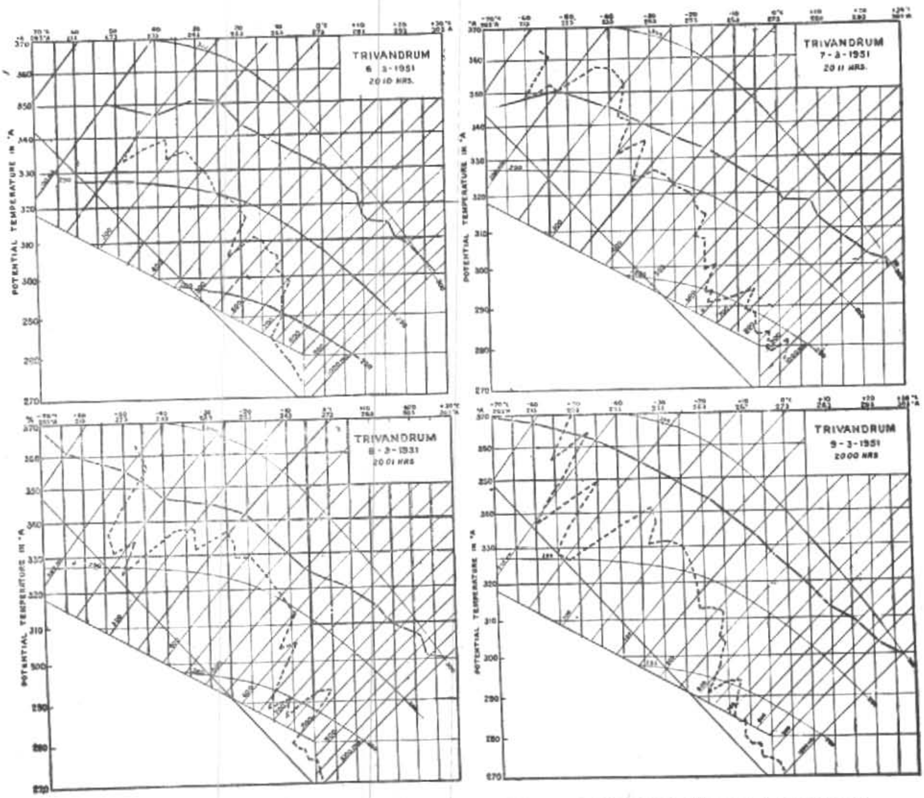

Fig. 7(b)

RELATION BETWEEN RATE OF ROTATION OF FAN AND TEMPERATURE DISTRIBUTION.

----------- RATE OF ROTATION OF FAN IN ARBITRARY UNITS ——— TEMPERATURE