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A method of estimating the vertical component of gusts in turbulence in the upper air

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ABSTRACT. It has been shown how the rate of rotation of the fan in the F-type radiosonde can be used to locate regions of turbulence in the upper air. A method of estimating the vertical component of the gusts from the radiosonde records is described in this paper. The mean rate of rotation of the fan at different heights has been obtained from a number of flights when no turbulence is present. This decreases uniformly with height due to the decrease in density of the air. Tests conducted in a wind tunnel give the rate of rotation of the fan for different speeds of wind in the direction of the axis of the fan. From these values, it has been shown how the vertical component of the gusts in regions of turbulence can be estimated.

Some radiosondes, *e.g.*, the British and Finnish, make use of a paper fan as a switching mechanism to telemeter the various meteorological elements like pressure, temperature and humidity, during the run of the balloon. They operate on the principle of the cup anemometer, but with its axis of rotation horizontal. As a result, the cup will rotate both during the rising and the falling of the balloon and also due to the horizontal winds. The F-type radiosonde of the India Meteorological Department (Venkiteshwaran *et al.* 1948) uses a paper fan (Fig. 1) which differs from the others. In the F-type instrument, the fan employed is of the simplest type and is made from a single square sheet of paper and it rotates about a vertical axis; its main feature is that it rotates only when it moves relative to the air along the axis of rotation in the upward direction and it is steady when moved in the opposite direction. Horizontal winds at any level have very little effect on the rotation of the fan and this was confirmed by tests in the wind tunnel. During a sounding, since the balloon moves horizontally with the speed of the wind, the effect of the wind will be negligible. Thus while in the case of all other types of radio-meteorographs, one can observe downward movement of the balloon only from the pressure and temperature data telemetered, it cannot be said whether they are due to downward vertical currents of air or due to the accumulation of the snow.

In the case of the F-type radiosonde, if the balloon develops a leak, the rate of ascent of the balloon will first decrease and later the balloon will descend. This will be reflected in the rate of rotation of the fan which will decrease at first and later stop when the balloon begins to descend. Again, if enough snow accumulates on the balloon, the balloon descends and the fan stops rotating, till the balloon has descended below freezing level when the accumulated snow melts and the balloon rises again and the fan starts working. Suryanarayana and Kachare (1951) have discussed such situations and Kachare *et al.* (1957) have also estimated the amount of water or snow deposited on the balloon, the levels at which snow deposits, melts etc. If on the other hand, the F-type radiosonde descends due to a strong downward current of air as in a thunderstorm, the fan will be rotating during the descent and will therefore telemeter continuously the meteorological elements during this stage; one can obtain from these data, the rate of descent and the strength of the downward currents (Venkiteshwaran and Tilakan 1952). It may, therefore, be stated that the F-type radiosonde of the India Meteorological Department has the unique feature to distinguish a downward movement of the balloon as to whether it is due to strong vertical currents of air or due to the accumulation of snow.

While the rotation of paper fan could distinguish between such major fluctuations relating to the movement of the balloon in view of the low inertia of the fan, certain characteristic fluctuations in the rate of rotation of the fan are observed which can be attributed to the regions of turbulence in the atmosphere. This will not be noticed from the rate of ascent of the balloon which has an appreciably larger inertia. With this technique, it is possible to identify regions of turbulence up to the highest level to which the balloon ascends, even in the stratosphere (Venkiteshwaran and Jayarajan 1952). The method of distinguishing regions of turbulence is described briefly below —

The paper fan in the meteorograph is geared to a 10-tooth contact wheel which makes and breaks the H.T. of the radiosonde signaller 960 times during one Olland cycle and the time for the 960 signals is about one minute (the rate of ascent of the balloon being 18 km/hr) in the lower layers of the atmosphere. These signals or impulses are automatically recorded during the flight on a paper

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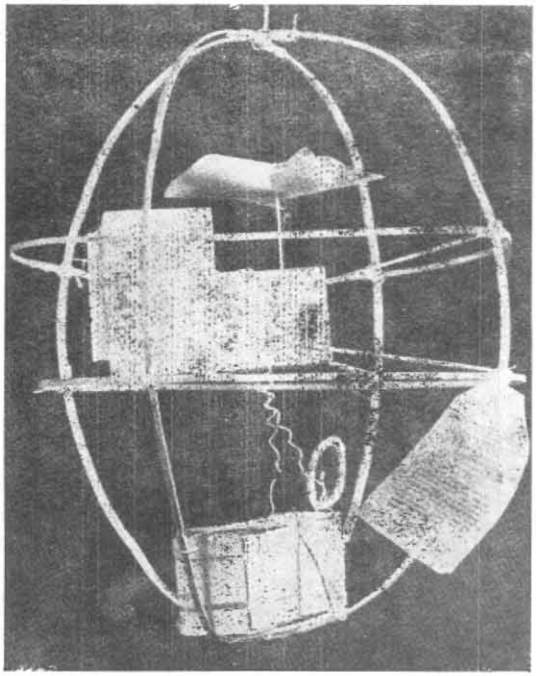

Fig. 1

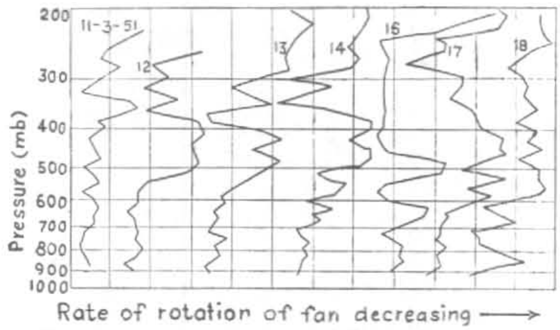

Fig. 2. Comparison of rate of rotation of fan at different heights on a few consecutive days at Poona

a pe moving at a constant speed. The length of the paper tape for one complete cycle of 960 impulses is taken as a measure of the rotation of the fan in the particular region of the atmosphere during the flight. This length will be constant, if the rate of rotation of the fan is uniform. However, it is observed that it is not constant and it varies during the flight. There are occasions when it suddenly increases in certain regions and some times,the rate of rotation is decreased. The length of the paper tape per Olland cycle will be less when the fan rotates faster since the cycle of signals is completed in a shorter time and *vice-versa.*

To test whether the changes in the rate of rotation of the fan are truly significant and represent the actual conditions existing in the atmosphere, two radiosondes were released with the same balloon and the records compared. The test was also repeated with two instruments attached to two different balloons but released simultaneously from the same place. It was observed that in all the cases, the curves showing the rate of rotation of the fan with height were very similar and showed the same feature in the simultaneous radiosonde ascents. This shows that the variations in the rate of rotation of fan are associated with the conditions prevailing in the atmosphere. There was no relation between this and horizontal winds at the level. Since the rotation of the fan can be affected only by the relative motion between the air and the radiometeorograph, fluctuations indicate regions of turbulence in the atmosphere.

Fig. 2 gives a series of curves showing the variations in the rates of rotation of the fan with height over Poona (Lat. 18° 32′ N, Long. 73° 51′ E). It will be observed from these that on some days, in some levels there were frequent and large increases in the rate of rotation of the fan. Their occurrence in a particular level, its persistence on a few days and absence later are significant. Examination of the daily record of the rate of rotation of the fan at Poona and elsewhere have shown that the region between 300 mb (about 10 km) and 200 mb (about 12 km) often appears to be one of turbulence. At Poona, it can be between 400 mb to 200 mb in winter. Anderson (1957) has also noticed with the gustsondes, a region of turbulence with its maximum at about 11 km. The type of persistence observed in the gustsonde ascents and their distribution with height over U. S. A. are similar to those observed with the F-type radiosonde over India. Anderson (1957) in working out the correlation between turbulence from the gustsonde and rawinsonde, is of the view that fairly persistent turbulence having "horizontal dimensions averaging at least 10 to 20 miles can exist". Simultaneous observations at Poona and Nagpur (Lat. 21°09′N, Long. 79°07′E) indicate the regions of turbulence to be of greater width. Interesting features like above normal turbulence above and below tropospheric inversions have also been observed (Jayarajan 1953).

An examination of the rate of rotation of the fan shows the existence of turbulence between 15—17 km (Venkiteshwaran and Huddar 1958) also, which is just below the region of lowest temperature in the tropopause.

Records of Dines meteorograph ascents made in India have often indicated blurs in the trace and it is sometimes also at the end of the trace at about the maximum height reached by the balloon. Sinha (1954) and Anna Mani *et al.* (1959) studied the blurs on the meteorograph records for Agra, Poona, Hyderabad, Bangalore and Madras. The cause of these blurs can be clearly attributed to turbulence, which cause violent vibrations to the instruments.

It is quite evident from the above that the rate of rotation of the fan in the F-type radiosonde of the India Meteorological Department shows the regions in the atmosphere where turbulence exists. The rate of rotation of the fan depends initially on the rate of ascent of the balloon. With a constant rate of ascent, and when turbulence is absent, the rate of rotation of the fan will gradually and steadily fall with height, due to a decrease in the density of the air. The analysis of a few ascents when no turbulence was observed, showed the following variations in rate of rotation of the fan at different heights at Poona. The rate of ascent of the balloon was about 18 km/hr.

Height	No. of impulses per sec
Near ground	22
8 km	18
12 km	15
16 km	9

For a constant rate of ascent (18 km/hr) the variation of rate of rotation is not proportional to the density of the air. While the number of impulses per second is 22 at the start, it is 18 at 8 km (about 400-mb level) where the density of the air is nearly halved.

Tests conducted in a wind tunnel showed the following approximate relation between wind and the rate of rotation of the fan in a radiometeorograph when the wind was blowing along the axis of rotation of the fan.

Speed of wind (km/hr)	No. of impulses per sec
30	33
24	27
18	22
12	13

It will be observed from Fig. 2 that at Poona, the rate of rotation of the fan at about 9 km (about 350 mb) increased suddenly from the usual value of 18 impulses per second at this level which will approximately correspond to 22 impulses per second near the ground. Due to turbulence the values at this level reach almost equal to or even slightly greater than 22 impulses per second which will correspond to at least $(22\times22)/18=27$ per second near the ground. This represents a relative wind of 24 km/hr or equivalent to a downward current of air of the order of 6 km/hr near the ground. Similarly there are vertical upward currents of this order at Poona in the 600—500 mb layer on 12 and 13 March 1951.

It can also be observed from Fig. 2 that the large scale turbulence observed between 400 and 300 mb is confined within a layer of approximately 2-km thickness.

It may be stated in this connection that the balloon itself lifting the radio-meteorograph is also subjected to the effects of the upward and downward currents associated with the turbulence. But since it takes place suddenly and duration is small the effects on the balloon with its large inertia are not easily observed on the ground. On the other hand, the fan with its very low inertia reacts immediately and this is observed and recorded on the ground.

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