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Some measurements on atmospheric gusts during southwest monsoon season in the vicinity of the ground

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ABSTRACT. During the southwest monsoon of 1976 wind velocities were measured near the vicinity of the ground using an instrumented gust sphere. Certain definite trends were observed in the amplitude, duration and frequency of the gusts. An order of magnitude on the period of the gusts suggested that the gusts have the same characteristic of the eruptions observed in turbulent boundary layer flows.

1. Introduction

This report describes some of the observations made recently on atmospheric gusts near the vicinity of the ground in the months of June, July and August 1976, when the southwest monsoon was active. During this monsoon season, high wind velocities prevail associated with large gustiness. There are certain indications that the frequency of gusts over India is large compared to that of Europe (Ranganayakamma 1974). Most of the information available today in open literature on the topic of gusts in India are the results of the analysis made on flight response of aircraft. Only recently surface gusts have gained importance in our studies in view of their varied applications. In addition the gusts occurring near the surface might influence the structure of the earth's boundary layer in which a large amount of mass and energy transfer occurs. Recent experiments (Kline 1967; Corino 1969; Laufer and Badri Narayanan 1971; Stickland *et al.* 1974) in laboratory turbulent boundary layers indicate that a kind of recycling process exists between the inner and outerpart of the boundary layer. Eruptions in the wall region occur periodically, as a part of the recycling process, involving transfer of fluid from the wall to the outer region. In the author's opinion the atmospheric gusts are somewhat similar to the eruptions and gusts occurring over the ocean surface might influence the upward convection of moisture towards cloud formation thus playing a major role in air sea interaction.

The measurements reported in this paper were made in an open flat terrain practically free of obstructions at the aircraft landing strip of the Indian Institute of Science, Bangalore and the velocities were measured using a gust sphere mounted at two different heights, namely 6 ft and 25 ft from the ground. Rainy days were avoided. Experiments were conducted during May, June, July and August 1976.

2. Instrumentation

2.1. *Gust sphere*

A gust sphere is an anemometer used in atmospheric research (Hopley and Tunstall 1971). It is a rugged instrument with no rotating parts and it can be used in severe weather conditions. Basically it is a drag measuring device consisting of a perforated hollow sphere with a force measuring element incorporated at the centre. The perforations are so tailored that the drag coefficient (C_D) of the unit is constant, independent of Reynolds number.

$$\text{Drag} = \tfrac{1}{2} \rho U^2 C_D, \quad C_D \text{ being constant}$$

$$\text{Drag} \simeq U^2$$

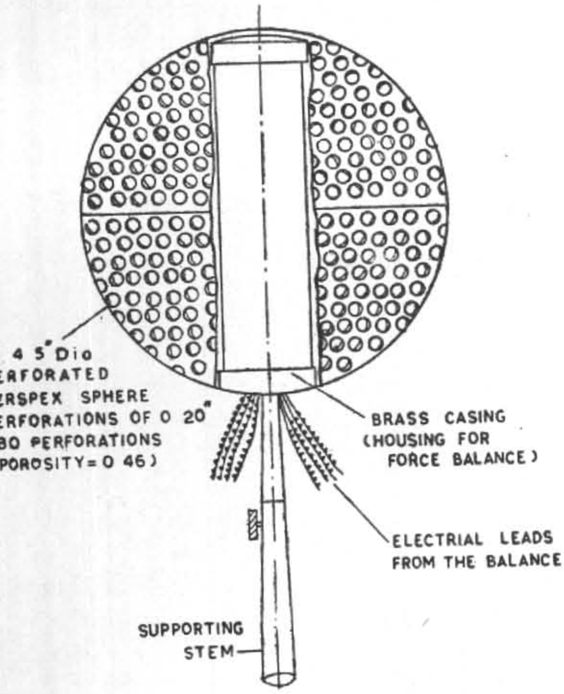

Fig. 1. Some details regarding the gust sphere

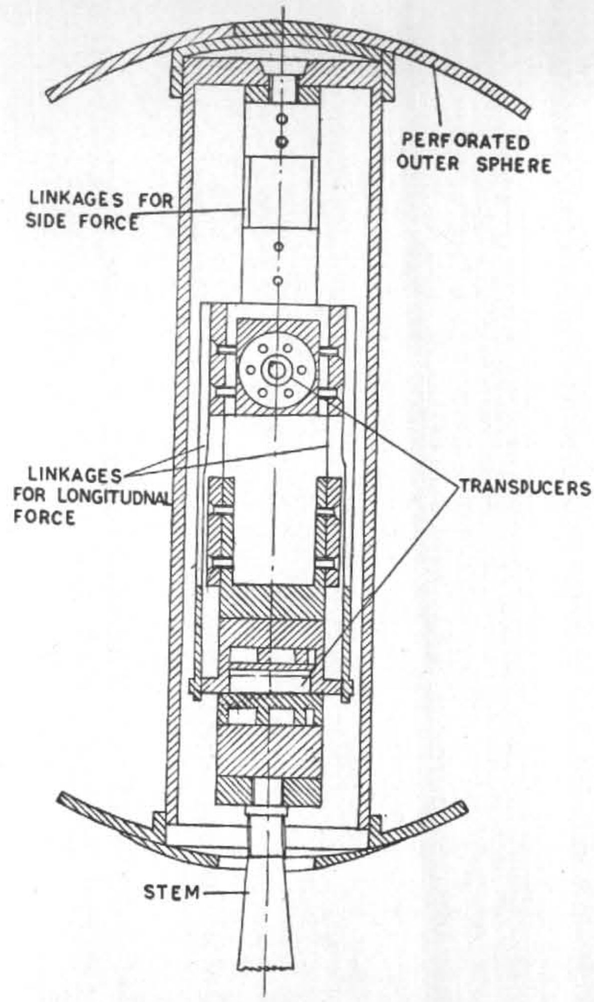

Fig. 2. Cut-out view of the gust sphere

Fig. 3. Variation of drag coefficient with Reynold's number

where ρ is the the density of the fluid medium (air in the present case) and U is the wind velocity.

Carefully designed gust spheres can have a frequency response upto 5 cycles per second which is more than ample for atmospheric research and well suited for gust measurements. In addition, the instrument is not very sensitive to temperature fluctuations, often encountered in the atmospheric flow and hence its superiority over hot wire anemometry, even though frequency response of the latter is orders of magnitude higher.

A 4·5 inches diameter sphere was fabricated from 1/8 inches thick perspex sheet and 980 holes of 0·20 inch diameter were drilled on its spherical surface, amounting to a porosity of 0·46. The force balance was of a two component type, capable of measuring the longitudinal and also the transverse drag components in the horizontal direction. Thin flexible lead springs were used to measure the forces and the deflections were transmitted to linear voltage differential transformer type transducers which converted the movement into electrical signals. The movements of the springs were restricted to 1·0 mm to ensure linearity of the system. The drag balance was assembled in a 1·5 inches diameter thin brass cage to which the perforated sphere was attached. The gusts sphere unit, as a whole, was mounted on a 5 ft tall slender conical stand. Some details regarding the gust sphere and its assembly are shown in Figs. 1 and 2.

The calibration of the gust sphere was carried out in a low turbulence wind tunnel whose speed could be varied from 5 ft to 70 ft/sec. Drag tests were made in the velocity region 0 to 65 ft/sec the upper velocity corresponding to a Reynolds number of 2×10^5 (Reynolds number based on free stream velocity and the diameter of the sphere) and C_D was found to be a constant equal to 0·68 in this Reynold number range (Fig. 3).

The electrical output from the transducers was amplified and fed to a strip chart recorder with a chart speed of 1·0 mm per second. In the present investigation only one of the force elements was used and the experiments were confined to the longitudinal velocity only.

2.2. *Vane anemometer*

Apart from the gust sphere a rotating vane anemometer was designed and fabricated to measure the wind velocities. This instrument was mainly meant to cross check some of the results obtained by the gust sphere. Eight inclined blades were used and they were shrouded inside an 8 inches diameter ring to increase its efficiency for protection. The rotor was mounted on two fine ball bearings enclosed in a dust proof casing and this casing was again mounted on a freely rotating vertical shaft. An eight segment commutator in series with a 1·5 volts torch cell produced an electrical output whose frequency was later converted into voltage. The anemometer was repeatedly calibrated at regular intervals and its R.P.M. was found to be linearly proportional to the flow velocity in the range 2 to 80 ft/sec. A cut-out view of the instrument is shown in Fig. 4. The blades were set at an angle of 45°. A milli voltmeter connected at the output of the frequency to voltage converter was directly calibrated in terms of wind velocity.

3. Experimental results

The data was processed for seven sample records (called seven experiments hereafter in this report) obtained on seven different days. To get reasonably large sample points records of long duration of the order of an hour were used. All the experiments were conducted on high gust days except experiment 7 which was performed during a reasonably quiet period in the monsoon season.

For analysis purposes, the following basic quantities were estimated from the velocity records.

(*a*) The mean velocity ($\overline{U}$)

(*b*) The peak velocity ($\overline{U}_{max}$)

(*c*) The duration of the gusts (T)

(*d*) The interval between gusts (I).

(*i.e.*, time interval between the beginning of one gust to the beginning of the next gust).

Definition of gust and evaluation of the gust parameters

It was noticed that during the monsoon season the wind velocities were high and large fluctuations occurred almost continuously. There was rarely a quiet period. The fluctuations reached a minimum periodically and this minimum U_{min} remained constant for a period of 4 to 5 hours in each experiment. In this report, any fluctuation above this minimum is identified as a gust however small in magnitude. The values of U_{min} were 15, 20, 0, 15, 25, 15, 0 and the number of gusts as

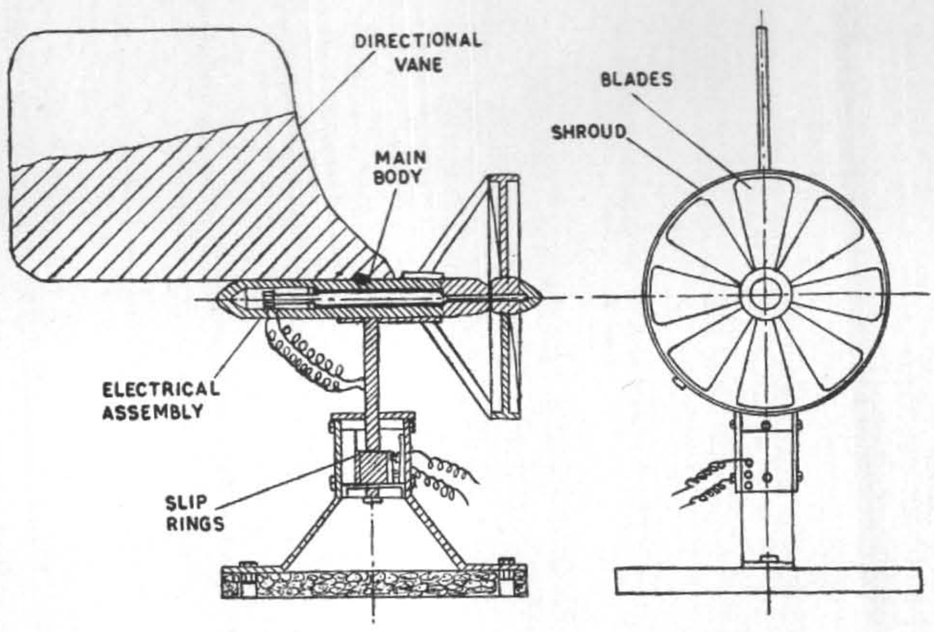

Fig. 4. Details of the Vane anemometer

measured using the above definition were 257, 200, 83, 97, 35, 95 and 146 per hour for experiments 1 to 7 respectively.

The mean velocity ($\bar{U}$) was obtained by averaging many velocity readings taken at every thirtieth second over a period of thirty minutes. $\bar{U}$ remained constant for a period of 3 to 4 hours continuously in each experiment even though it varied from day to day. Measurements from the gust sphere as well as from the vane anemometer were used in this averaging process and both yielded the same result. The values of $\bar{U}$ were 31·5, 24, 0, 24, 5, 19·8, 27·3, 31·0 and 12·5 ft/sec for experiments 1 to 7 respectively.

The maximum velocities of the gusts (U_{max}) veried appreciably, the highest recorded value of U_{max} being 1·6 times $\bar{U}$. During the monsoon season most of the gusts were strong with velocities above $\bar{U}$ and low intensity gusts were rare. Using U_{min} as the base, the duration of gusts (T) was measured and from this data an average duration of the gusts ($\bar{T}$) was estimated using samples taken over a period of two hours. The values of $\bar{T}$ thus obtained were 14, 18, 43·5, 37·0, 102·0, 38·0, 4·0 seconds for experiments 1 to 7 respectively. The longest gust had a period of 4 $\bar{T}$ while the shortest was 0·1 $\bar{T}$.

TABLE 1

Experiment No.	$\bar{U}$ (ft/sec)	$\bar{U}_{max}$ (ft/sec)	G	$\bar{U}_{max}/\bar{U}_{min}$
1	31·5	34·0	1·08	2·26
2	24·0	27·0	2·13	1·35
3	24·5	27·0	1·35	1·80
4	19·8	23·0	1·16	1·53
5	27·3	37·6	1·37	1·58
6	31·0	33·5	1·08	2·24
7	12·5	26·55	2·12	—

Estimation was also made on the interval (I) between two consecutive gusts (beginning of a gust to the beginning of the next gust). Since the gusts were continuous in all the experiments from 1 to 6, the period of a gust was practically the same as that of the interval between two gusts.

4. Discussions

Intensity of the gusts

The intensity of the gusts is usually defined in terms of a gust factor (Wieringa 1973)

$$G = \bar{U}_{max}/\bar{U}$$

where $\bar{U}_{max}$ is the average of the peak value of the gusts (U_{max}) and $\bar{U}$ is the average wind velocity. The values of G obtained from the seven experiments are given in Table 1.

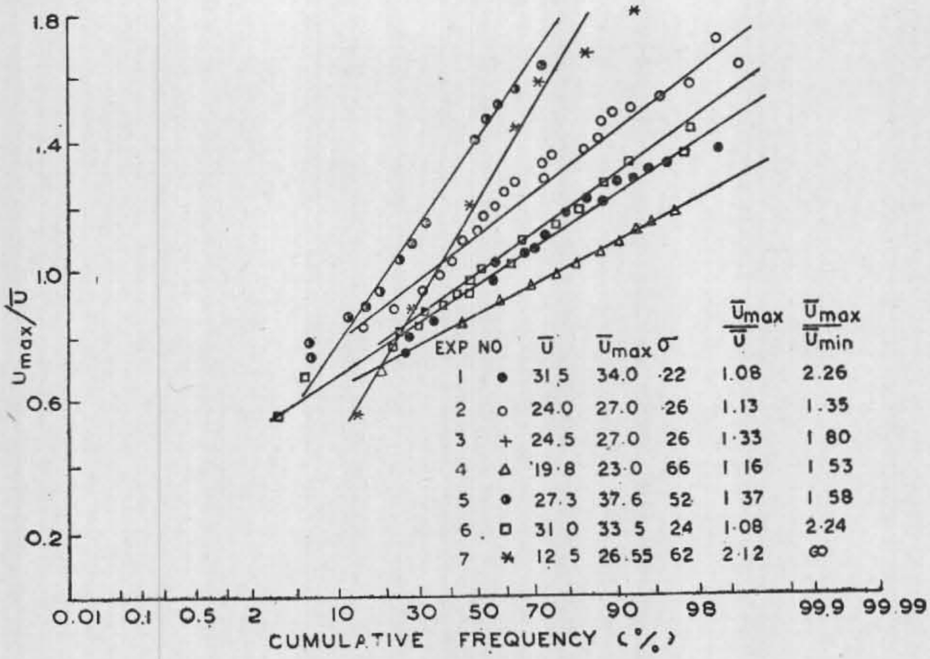

Fig. 5. Distribution of peak velocities in gusts

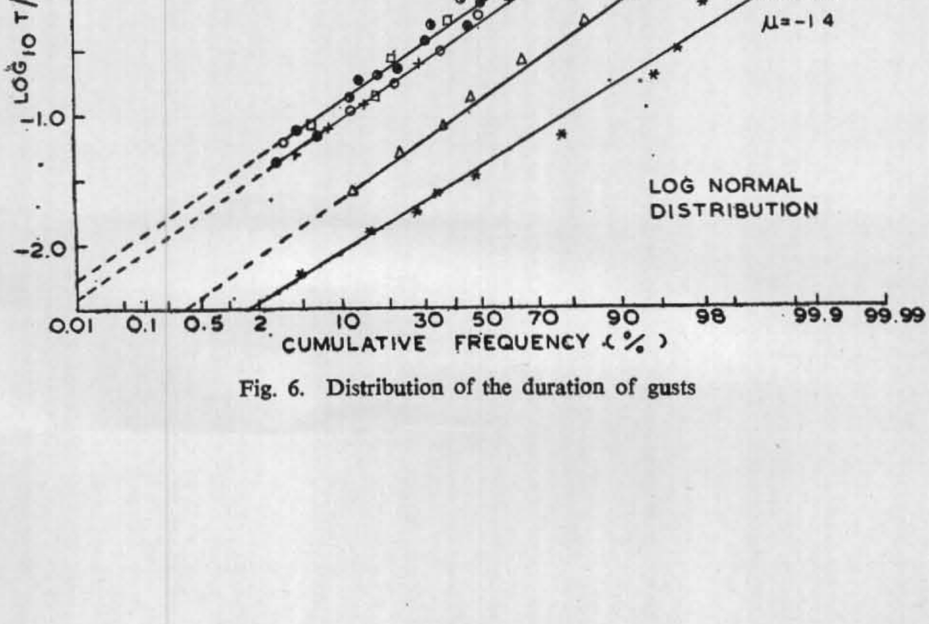

Fig. 6. Distribution of the duration of gusts

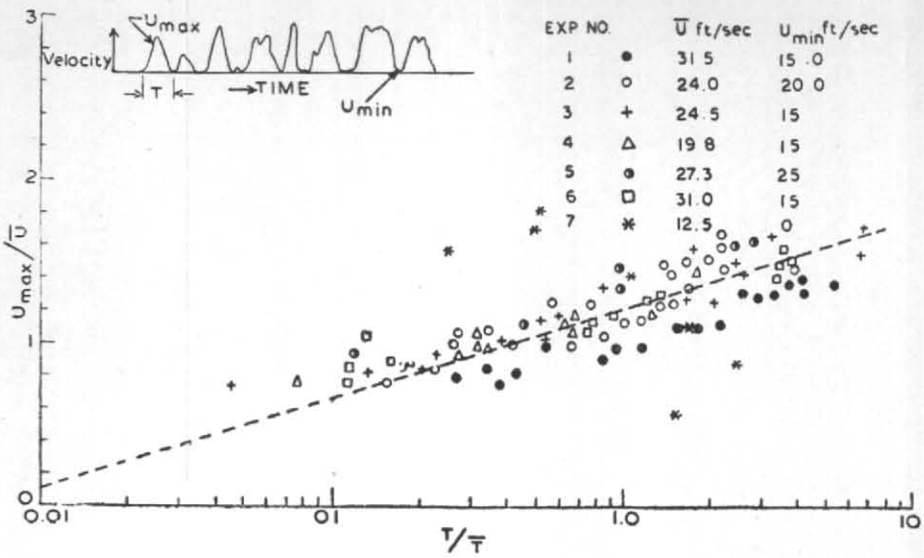

Fig. 7. Relation between gust velocity and duration

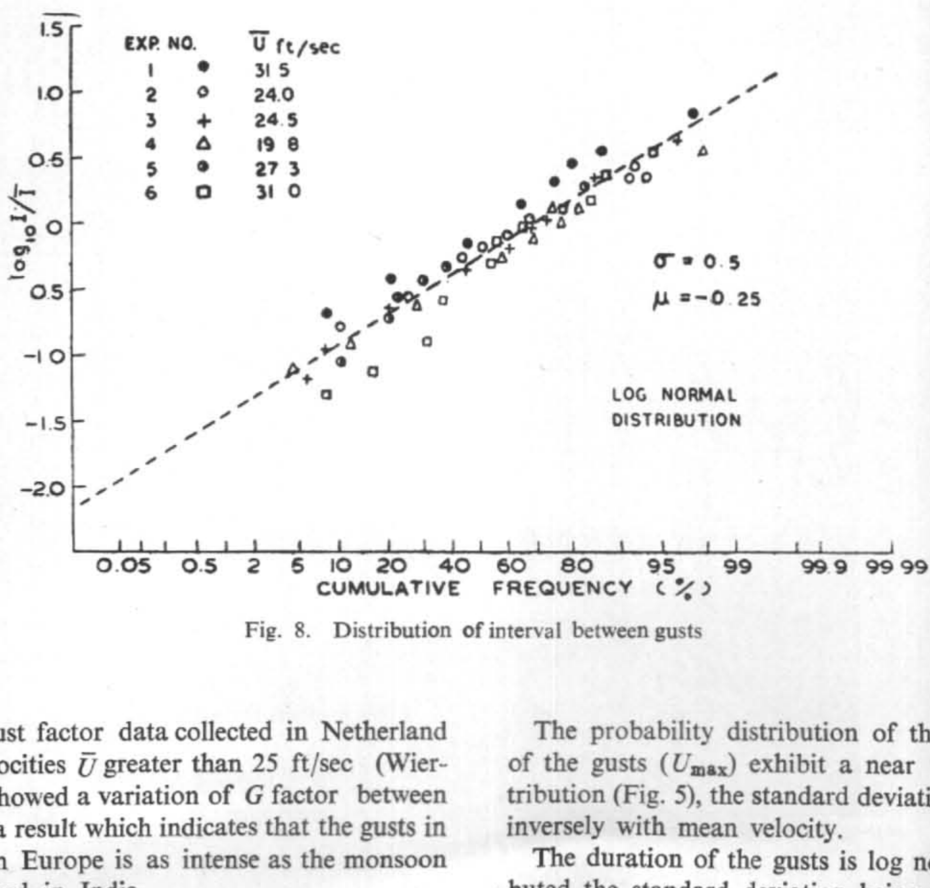

Fig. 8. Distribution of interval between gusts

Median gust factor data collected in Netherland for wind velocities $\overline{U}$ greater than 25 ft/sec (Wieringa 1973) showed a variation of G factor between *1·0* and 2·0 a result which indicates that the gusts in the northern Europe is as intense as the monsoon gusts observed in India.

The probability distribution of the peak values of the gusts (U_{max}) exhibit a near Gaussian distribution (Fig. 5), the standard deviation (σ) varying inversely with mean velocity.

The duration of the gusts is log normally distributed the standard deviation being the same and equal to 0·5 in all the seven experiments; however the mean value (μ) increase with $\overline{U}$ (Fig. 6). Since U_{max} and T of the gusts exhibit certain definite patterns and belong to the same phenomenon it is natural to expect some relation between these two quantities. The results plotted in the semi logarithmic form with $U_{max}/\overline{U}$ and $T/\overline{T}$ as the variables (Fig. 7), definitely indicate a reasonably unique trend except for experiment 7. A close observation suggests that the point of each experiment to be on different straight lines but all of them parallel to each other. Since the scatter is somewhat appreciable identifying these lines individually is rather difficult and hence a single mean straightline has been drawn to represent all the points. This line gives the relation in the form

$$\frac{U_{max}}{\overline{U}} = 0{\cdot}6 \log_{10} (T/\overline{T}) + 1.2$$

The interval between the gusts also exhibit a log normal distribution with $\sigma = 0{\cdot}5$ and $\mu = -0{\cdot}25$ (Fig. 8). Since the gusts were almost continuous the interval is nearly equal to duration.

The data obtained in the present investigation indicates beyond doubt that there exist certain well defined patterns in the monsoon gusts. These gusts can be considered as disturbances occurring in the earth's turbulent boundary layer and an attempt is made in this report to compare the gusty motions in the atmosphere to the large scale disturbances observed in a laboratory turbulent boundary layer on which some information is already available. It is now well established that in the wall region of a turbulent boundary layer the flow is intermittent and eruptive in nature (termed as bursts). The bursts are large scale disturbances forming the nucleus of turbulent production and during the bursting process many distinct phases indicating that the production process is intermittent in nature (Kline 1967, Corino *et al.* 1969). Even though the birth of the bursts are observed near the wall region they are not classified as a wall phenomena since they are triggered by the outerflow during the cyclic process. The present day opinion is that the outer interface, which is responsible for entrainment, and the bursts form part of a cyclic process and this cyclic prosess is essential for the continuous production of turbulence. This process seems to be absent in free shear flows and hence decay of turbulence predominates in such cases. Recent investigations (Laufer and Badri Narayanan 1971, Stickland *et al.* 1974) on the bursting phenomena indicate that the period of the bursts (T_B) scale with the free stream velocity (U_∞) and the boundary layer thickness (δ) and the non-dimensional parameter $U\overline{T}_B/\delta$ ($\overline{T}_B$ is the time coverage of T_B) is a constant approximately equal to 5·0 at all Reynolds numbers (Corino 1969, Laufer and Badri Narayanan 1971). If the value of this parameter, in the case of atmospheric gusts with the gust period as the time scale, is also nearly equal to 5·0, then one can reasonably expect the gusts and the boundary layer burst are one and the same. In the present investigation the values of $\overline{T}$ and δ are not readily available for the above calculation. However assuming some realistic values, a rough calculation yields the following result.

The assumed values are

δ = 1000 ft for Prandtl's boundary layer

U_∞ = 100 ft/sec

$\overline{T}$ = 40 sec, an average value based on the present investigation

$$\frac{U_\infty \overline{T}}{\delta} = \frac{100 \times 40}{1000} = 4{\cdot}0$$

The above result suggests that atmospheric gusts of 40 sec period and the bursts observed in the laboratory turbulent boundary layer may be similar phenomenon. This conclusion is only tentative since the available data is not sufficient to warrant a firm statement.

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