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by

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Aero Flight Divn., R.A.E., Bedford

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ON LARGE AND RAPID WIND FLUCTUATIONS WHICH OCCUR WHEN THE WIND HAD PREVIOUSLY BEEN RELATIVELY LIGHT

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SUMMARY

Examination of anemometer records obtained at Bedford Airfield for the years 1962-66 shows that, on about 40 occasions per year, large and rapid changes in windspeed and direction occur in relatively light wind conditions. Such events are associated with convection and do not follow the usual relationship between the size of fluctuations and the mean windspeed.

*Replaces RAE Technical Report 69261 - ARC 32205

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1 INTRODUCTION

Variations of the speed and direction of the wind may significantly disturb an aircraft during take-off and landing[1,2]. In general, the size of these variations increases as the mean windspeed increases, as illustrated in Fig.1. However, recordings of windspeed and direction sometimes show fluctuations which are much larger than would be expected from the value of the mean windspeed before the fluctuation. Some examples of these, taken from routine Meteorological Office records made at Bedford Airfield, are given in Fig.2. From an aeronautical point of view, such events are of particular interest for two reasons. The first is that 'models' of atmospheric turbulence used in studies of take-off and landing, which generally assume the gusts to be members of a Gaussian random process which has an rms value dependent on mean windspeed, may well not predict their existence. Secondly, because they occur in conditions when the mean wind had previously been relatively light, a pilot encountering such an event may be taken by surprise. The present paper describes the results of an analysis of wind records from Bedford Airfield for the years 1962-66.

2 ANALYSIS OF ROUTINE RECORDS OF WINDSPEED AND DIRECTION MADE BY THE METEOROLOGICAL OFFICE AT BEDFORD AIRFIELD

2.1 Method of analysis

An examination has been made of routine recordings of windspeed and direction made by the Meteorological Office at Bedford Airfield, in an attempt to determine the size and frequency of the events described above. The recordings were made using standard Meteorological Office instruments mounted on a mast with an effective height of 10 m on which the instruments had reasonably good exposure. Continuous recordings were available for the whole of the years 1962 to 1965 and for 8 months (not consecutive) of 1966, and these have been used in the present study. Occasions were noted when the windspeed changed rapidly (within a few minutes) by more than 10 knots (5 m/sec) when changes of a comparable size did not occur during the preceding half hour. Fig.2 shows typical time-histories of such events. In practice, there was no difficulty in deciding whether a gust should be included in the present study or was associated with the general level of gustiness in conditions of relatively steady mean wind.

2.2 Results

Fig.3 shows the average number of events per year involving windspeed changes exceeding given values, and the percentage of these events in which changes in wind direction exceed given values. On average, 40 events involving windspeed increases exceeding 10 knots (5 m/sec) occurred; in 35 of these the mean windspeed for the preceding 10 minutes was below 15 knots (8 m/sec) and in 22 of them it was below 10 knots (5 m/sec). 5 events per year, on average, involved windspeed increases exceeding 20 knots (10 m/sec); on 3.5 of them the previous mean windspeed was below 15 knots (8 m/sec) and on 1.7, below 10 knots (5 m/sec). In 60% of the events the wind veered*. The change of wind direction exceeded 90^{o} in 10% of the events, about ¾ of these large changes being veers.

The way in which the occurrence of events was distributed throughout the year is shown in Fig.4. On average, more than half occurred in the 3 months of March, April and May, with a subsidiary peak later in the summer, the average distribution being reasonably typical of the actual distributions measured for 3 of the 4 years. In the other year, 1964, 75% of the events occurred in the period from June to October.

The distribution of events by hour of the day is shown in Fig.5, where it will be seen that most events occur in the early afternoon, with a small subsidiary peak in the early hours of the morning.

On 38% of the days on which events occurred, more than one large fluctuation in windspeed is shown on the record (e.g. Figs.2a, 2b and 2c). In the above analysis, each large fluctuation has been considered as a separate event when, if taken singly, it would have been so counted. The probability of occurrence of more than one event on a given day is shown in detail in Fig.6, the times between consecutive events being given in Fig.7.

2.3 Weather conditions associated with the events

The fluctuations in wind which occur in the events studied might well be termed 'squally' and we have been tempted to describe the events as 'squalls'. There is, however, an official World Meteorological Organisation definition of a squall[3] as 'a sudden increase of windspeed by at least 16 knots, the speed rising to 22 knots or more and lasting for at least one minute'. About a half of the events described here are squalls by the WMO definition, the remainder being similar in form but of rather smaller size. These latter are of some interest from an aeronautical point of view and since to include them and use

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*The wind is said to veer when the angular direction from which it blows increases. In changes in the opposite direction, the wind is said to back.

1 INTRODUCTION

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the term squall would be potentially confusing, we have preferred to use the term 'event', which might perhaps be thought of as 'squall-like event'.

Squalls usually seem to be associated with thunderstorms or other strong convection. The events described above were selected only on the basis of the wind records. The log maintained by the Bedford Meteorological Office has been examined to see if any association could be found between the events and the type of cloud reported. The results obtained are given in Table 1. No cloud reports were made on 57 of the 135 days on which events occurred. Of the remaining 78 days, cumulonimbus (thunderstorm) clouds were reported on 37, cumulus on 34 and other cloud types on 7 days. The latter comprised 5 days with reported stratus, and one day each with reported altostratus and strato-cumulus. There were 50 days on which cumulonimbus cloud was reported but no events occurred.

3 COMPARISON OF THE FREQUENCY OF OCCURRENCE OF THE EVENTS DESCRIBED ABOVE WITH THAT OF GUSTS OF SIMILAR SIZE WHICH OCCUR IN OTHER CONDITIONS

To judge the practical importance of gusts which occur as the type of event described above, it is necessary to relate their frequency of occurrence to that of gusts of similar size which occur in other conditions. As mentioned in the Introduction, the level of gustiness is usually fairly closely related to the mean windspeed, the events considered here being the exception to this general rule. The relationship between the rms windspeed fluctuations and the mean windspeed is fairly well established for the general case. Unfortunately, however, the rms and other quantities which can be readily obtained from it do not directly give a good measure of the frequency of occurrence of gusts, and particularly large gusts, of importance to an aircraft. To obtain the latter a number of somewhat questionable assumptions would have to be made. Rather than make these, it was thought better to attempt to assess this frequency directly.

A five hour record of windspeed obtained from a standard Meteorological Office anemometer mounted at the top of a 100 ft mast at Bedford airfield during a period with a fairly steady mean wind of about 27 knots (14 m/sec) has therefore been analysed. The recording speed used was 12 in per hour, which is adequate to resolve the most rapid fluctuations present. Increases in windspeed which took place in less than 1 minute and which persisted for at least 10 sec were selected by eye. These represent periods of about 15 sec and 2.5 sec respectively to an aircraft flying at 120 knots (62 m/sec) and cover the range of greatest importance to current jet transports during take-off and landing. From examination of records of events showing the detail of the wind fluctuations, e.g. Fig.8, such increases are thought to be comparable, from the aircraft point of view, to the events described above which are of similar size. The results are shown in Fig.9 in terms of the number of windspeed increases per hour, as fractions of the mean windspeed, which exceed given values.

Assuming that the curve given in Fig.9 applies to all windspeeds, and extrapolating it as shown, the number of windspeed increases per year exceeding a given size can be obtained if the annual distribution of mean windspeeds is known. The Meteorological Office has recently published[4] data giving this distribution for a large number of sites in the U.K. That for Cardington is shown in Fig.10 and may be taken as representative of conditions at Bedford Airfield, the distance between the two sites being about 8 miles (13 km). The data given in Figs.9 and 10 have been used to produce Fig.11, which shows the number of windspeed increases per year likely to exceed given values. Curves are also given which apply to cases when only windspeeds less than given values are considered, corresponding to likely operational experience when an upper limit to operating windspeeds is imposed. Data from Fig.3 are also shown for comparison.

As shown in Fig.11, the number of windspeed increases per year exceeding given values is much greater, when all mean windspeeds are considered, than those which occur as the events described in earlier sections; the number of 10 knots (5 m/sec) increases are about 250 times greater and the number of 25 knots (13 m/sec) increases about 10 times greater. When only windspeeds less than 21 knots (11 m/sec) are considered, as would be the case if such a speed was imposed as an operational wind limit, the number of 10 knots (5 m/sec) increases is still much larger, but the number of 20 knots (10 m/sec) increases is about the same. If windspeed limits much lower than 21 knots (11 m/sec) are considered, the number of large windspeed increases which occur as the events described above is much greater than would be expected on the basis of the mean windspeeds.

It is felt that the data given in Fig.11 give a reasonable indication of the relative importance, for aviation purposes, of the events described here. Further data are needed of the type shown in Fig.8, which allows the gusts to be resolved in detail and measurements are also needed at heights above those described here. Some work on this is now in hand, and it is worth remarking that, from preliminary results, although the initial large gust usually occurs almost simultaneously at heights of 30 ft and 100 ft, one record so far obtained shows a large wind change at 100 ft when a similar change did not occur at 30 ft for almost a minute.

4 CONCLUSIONS

Variations in the speed and direction of the wind may significantly disturb an aircraft during take-off and landing. In general, the size of these variations increases as the mean windspeed increases. However, recordings of windspeed and direction sometimes show fluctuations which are much larger than would be expected from the value of the mean windspeed. An analysis has been made of such fluctuations shown on routine Meteorological Office wind records made at Bedford Airfield for the years 1962-66.

These fluctuations are squall-like in character and the larger of them meet the internationally accepted meteorological definition of a squall. On average, 40 such events, involving increases of windspeed greater than 10 knots (5 m/sec), occurred per year during the period of study, these being most likely to take place in the early afternoon during the months of March, April and May. It appears that these events are associated with convection.

Taking the year as a whole, the number of windspeed increases which occur at Bedford in these squall-like events is much smaller than the number of changes of comparable size which take place in other conditions, which are primarily those in which the mean wind is strong. The mean windspeed before the occurrence of these events is almost always less than 20 knots (10 m/sec) and frequently less than 15 knots (8 m/sec). If only windspeeds of these and lower strength are considered, corresponding in practice to the imposition of an upper windspeed limit to operations, large increases in windspeed are most likely to occur as squalls and the imposition of a mean windspeed limit lower than about 20 knots (10 m/sec) gives only a small reduction in the probability of encountering large gusts during take-off and landing.

Table 1

ASSOCIATION OF EVENTS WITH CLOUD TYPE FOR BEDFORD ROUTINE DATA 1962-66

	1962	1963	1964	1965	1966+	Total
Days with events	19	34	23	28	31	135
Days with events and cumulonimbus	8	10	4	7	8	37
Days with events and cumulus	2	10	8	7	7	34
Days with events and other types of cloud*	0	1	2	1	3	7
Days with events but no cloud report available	9	13	9	13	13	57
Days with cumulonimbus and no events	11	12	11	10	6	50

\+ Data for 8 months only, since anemometer data not available for January, February, August and September.

* The other types of cloud reported were, stratus 5 times, and altocumulus and stratocumulus once each.

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No.	Author	Title, etc.
1	F. O'Hara J. Burnham	The atmospheric environment and aircraft. Now and the future. J. Roy Aero Soc. (1968)
2	J. Burnham	A note on turbulence problems associated with take-off and landing. R.A.E. Technical Report 67240 (A.R.C. 29520) (1967)
3		World Meteorological Organisation Commission for Synoptic Meteorology. Abridged final report of the Third Session, Washington, U.S.A., 26 March to 19 April 1962, p.56, WMO 122, RP 50
4		Tables of surface windspeed and direction over the United Kingdom. HMSO London (1968)

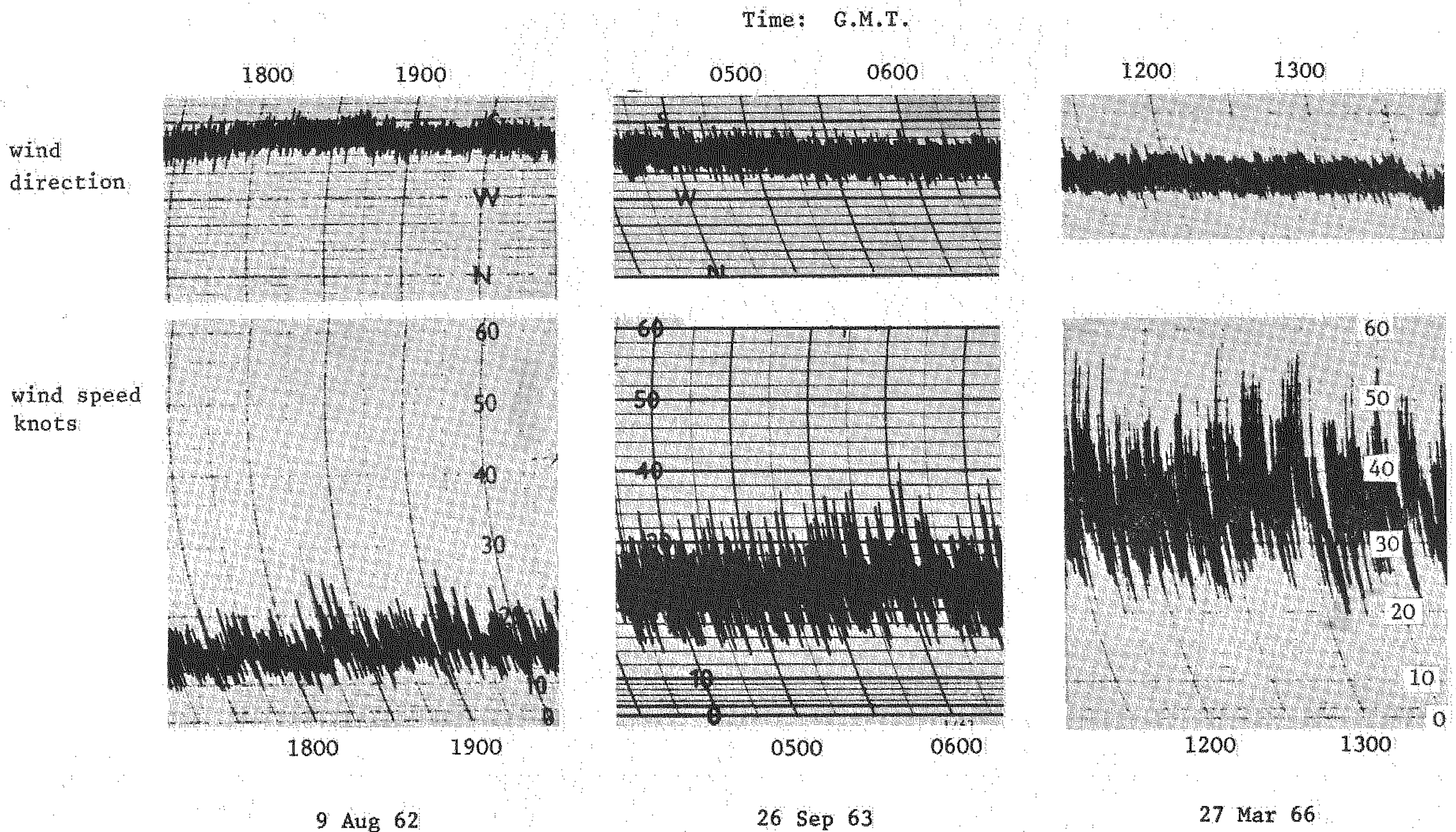

Fig 1. Examples of anemograph records taken in conditions in which the mean windspeed is relatively steady

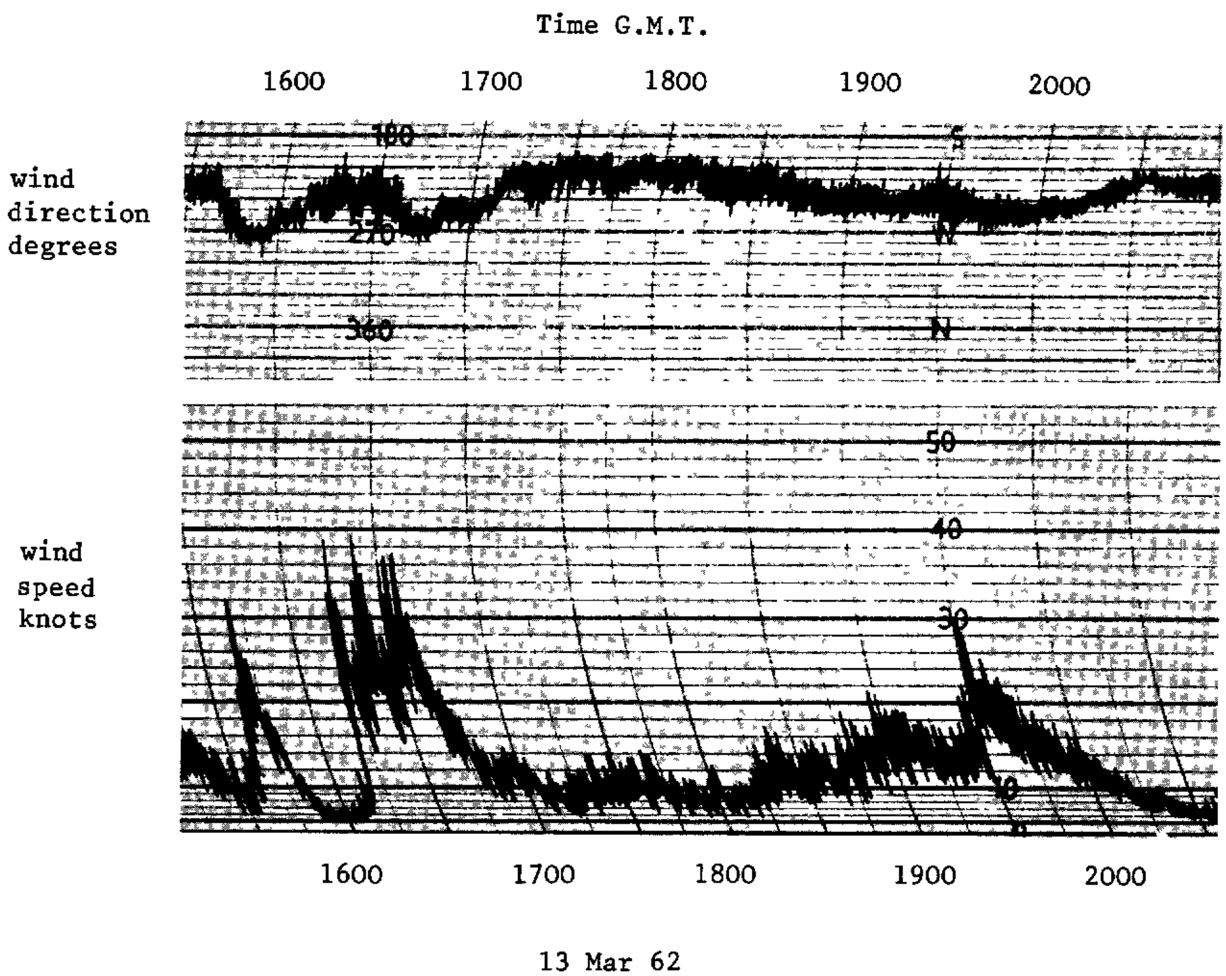

Fig 2a. Examples of events

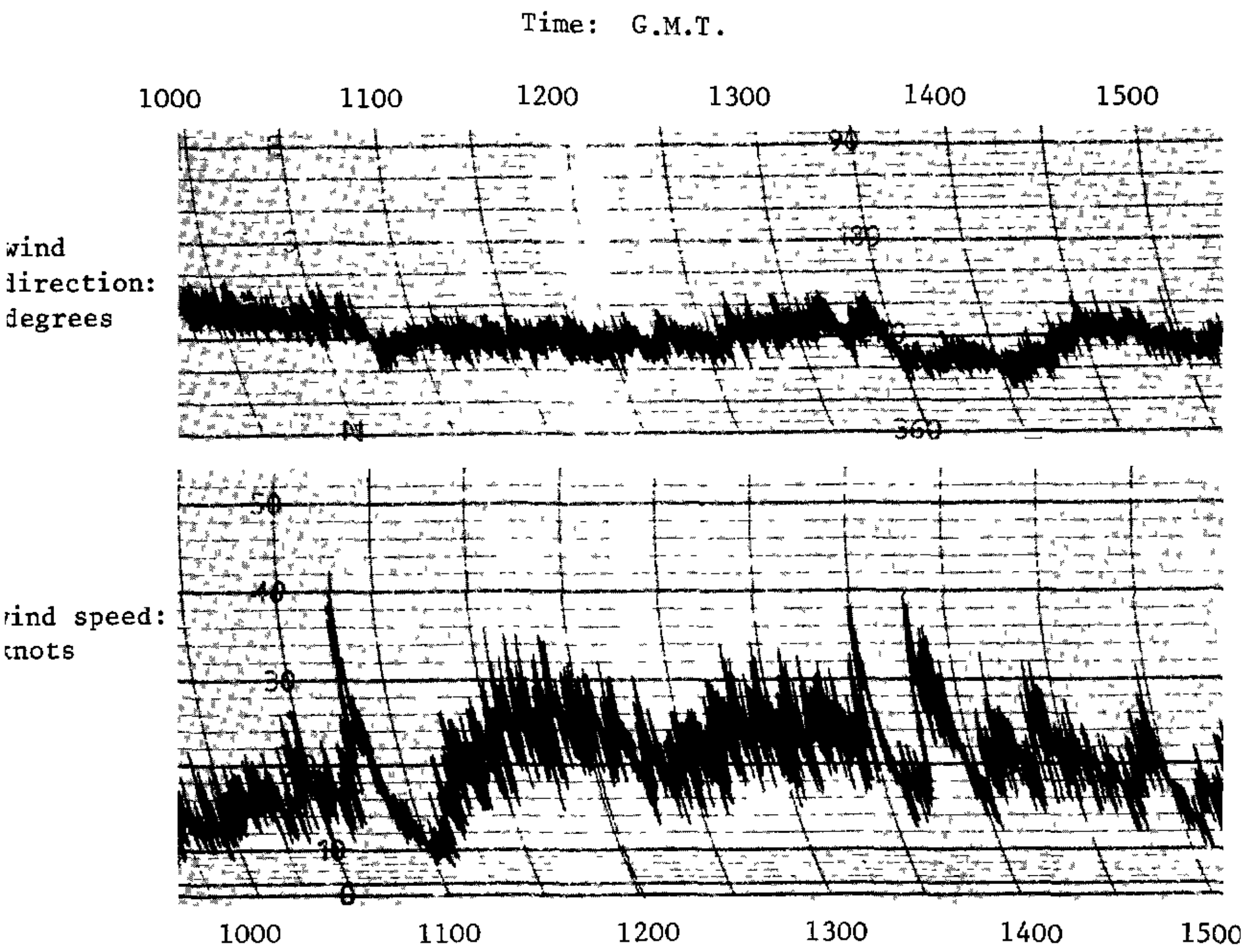

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Fig 2b.

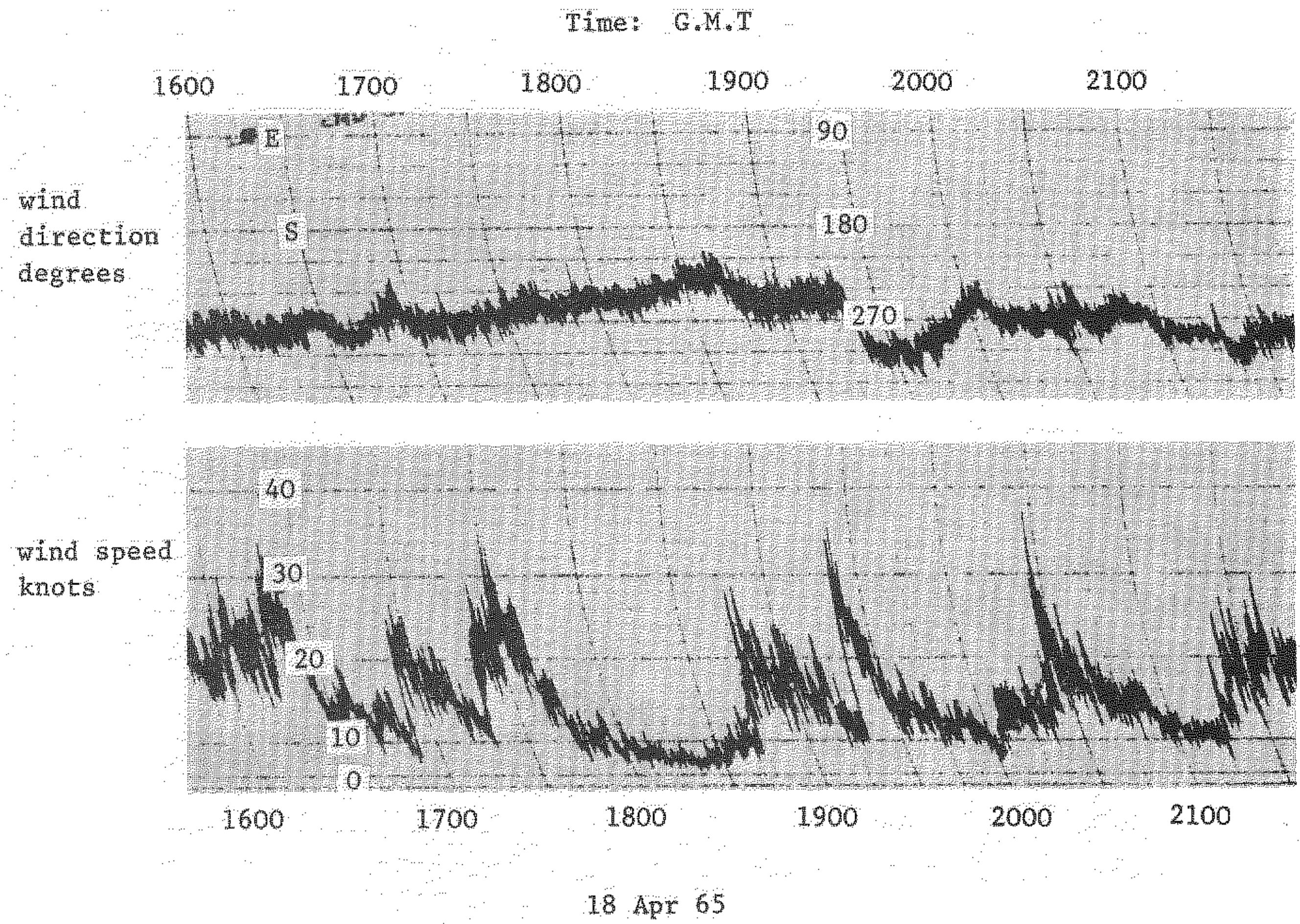
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Fig 2c.

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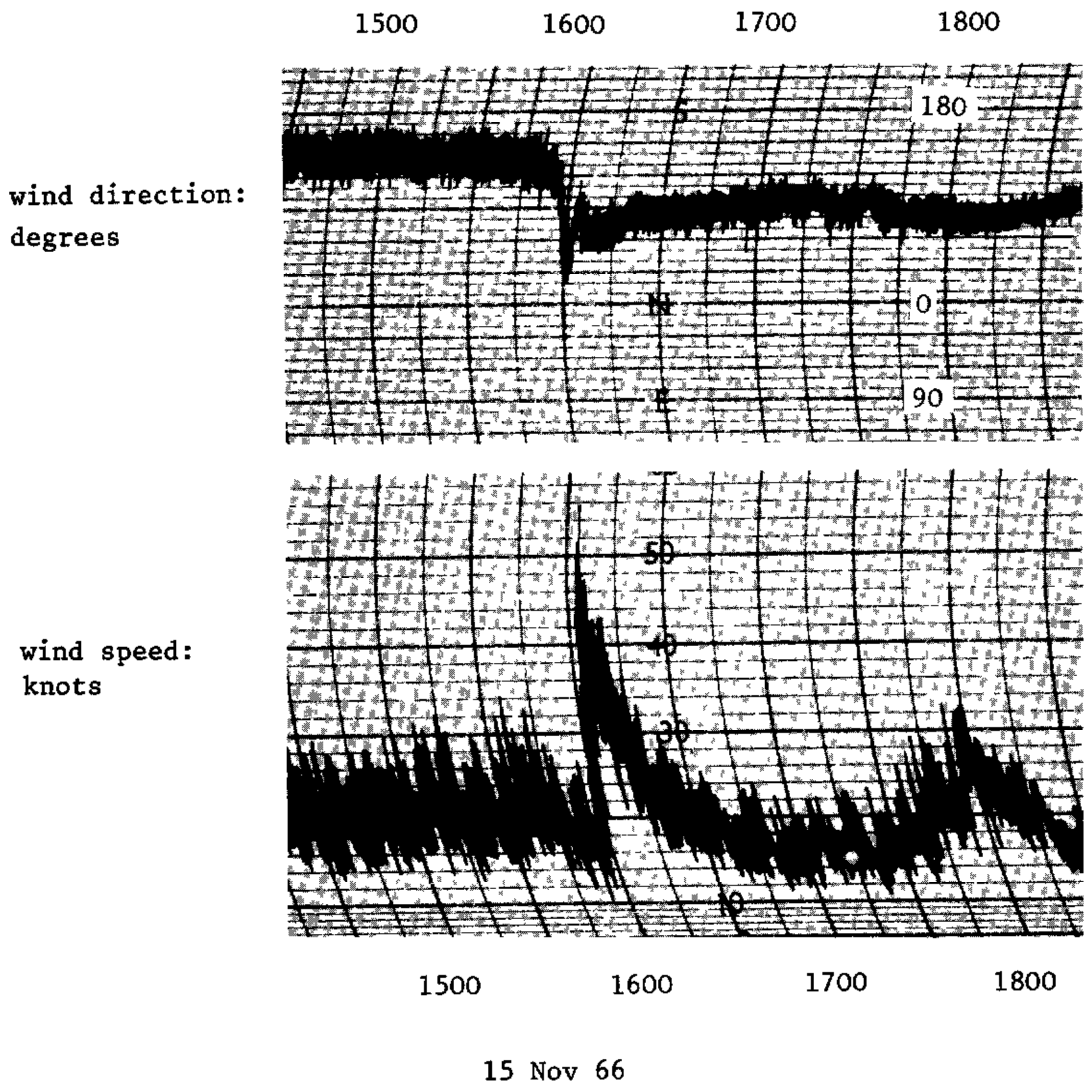

Fig 2d.

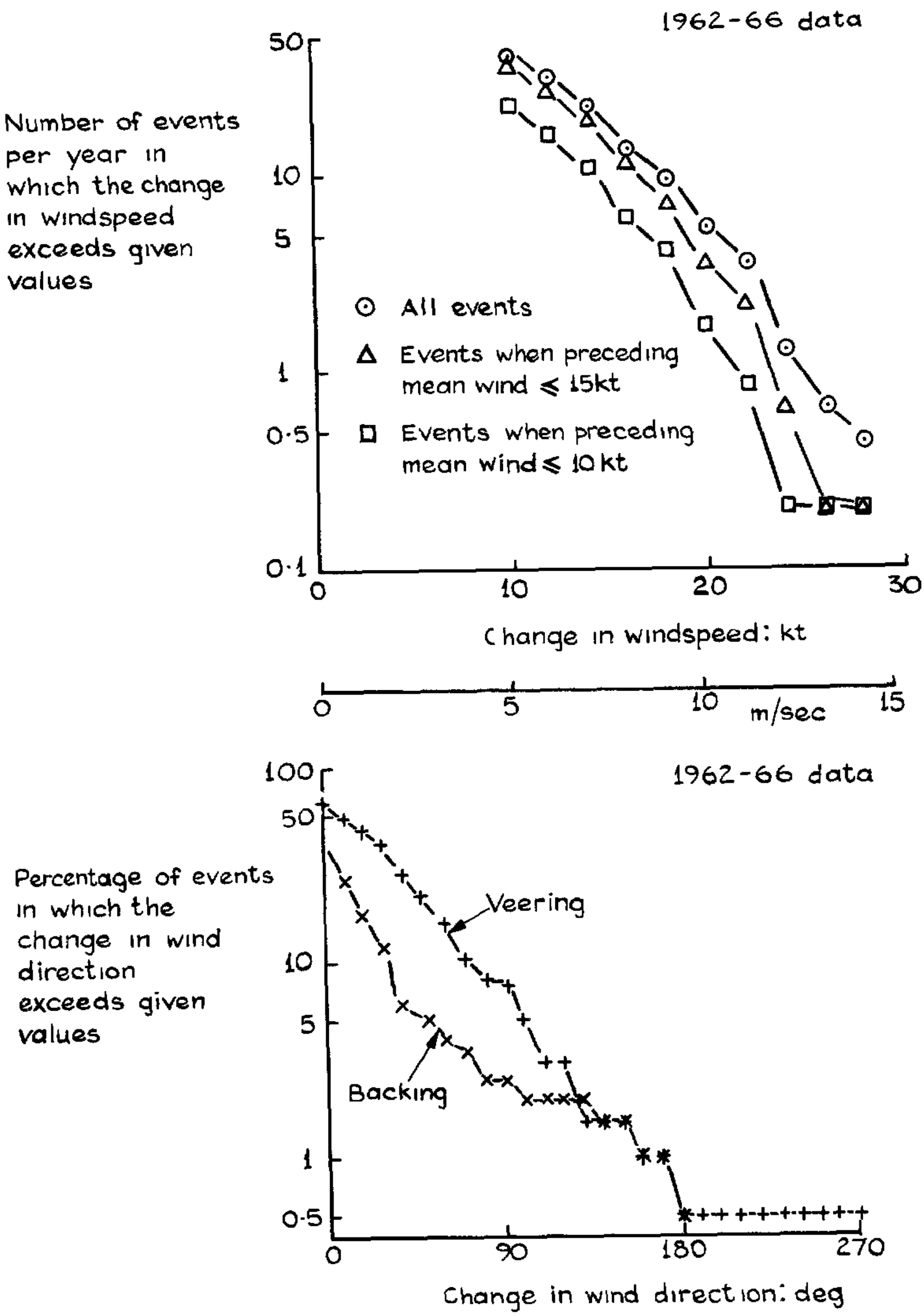

Fig. 3 Changes in windspeed and direction during events

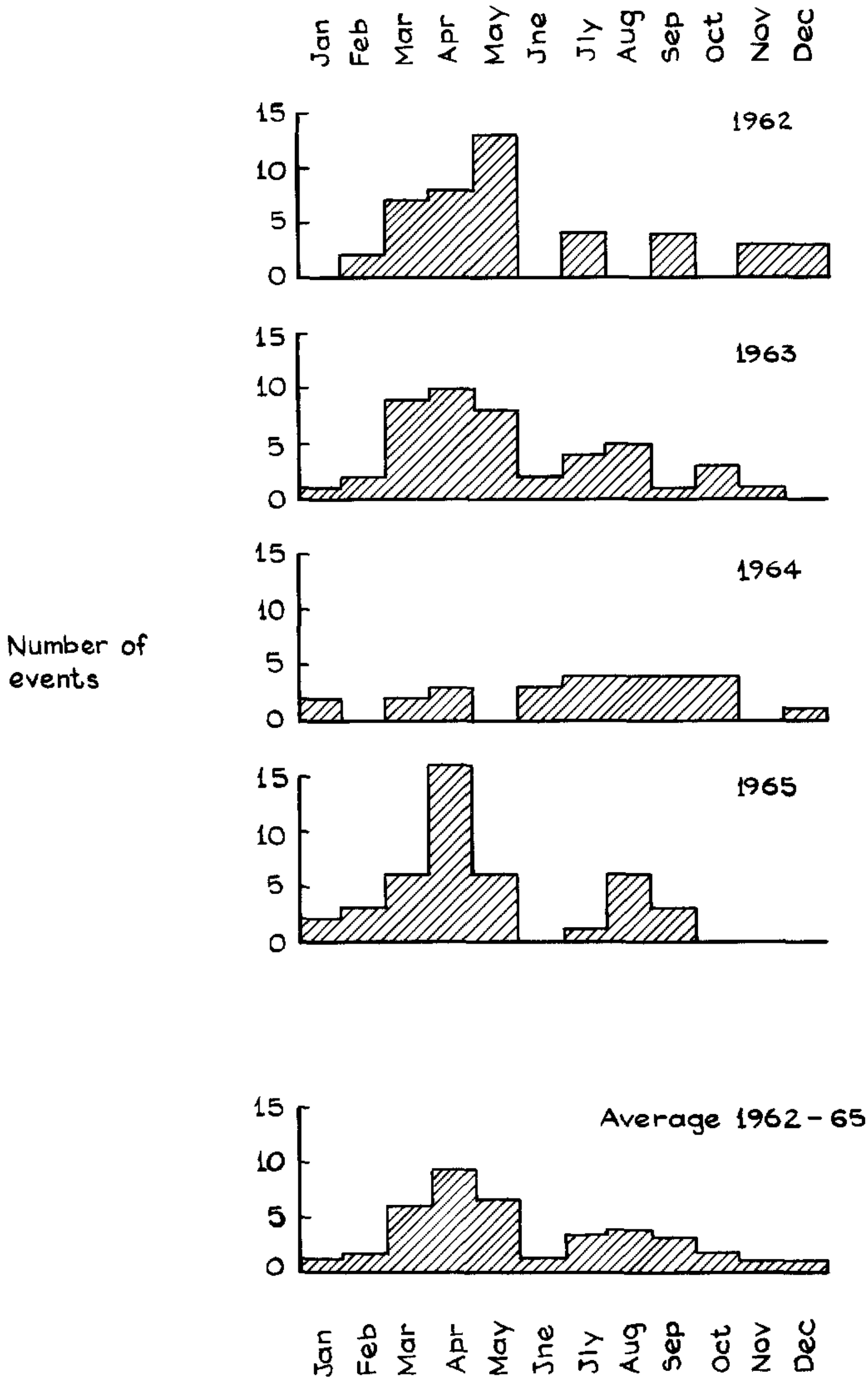

Fig. 4 Distribution of events throughout the year

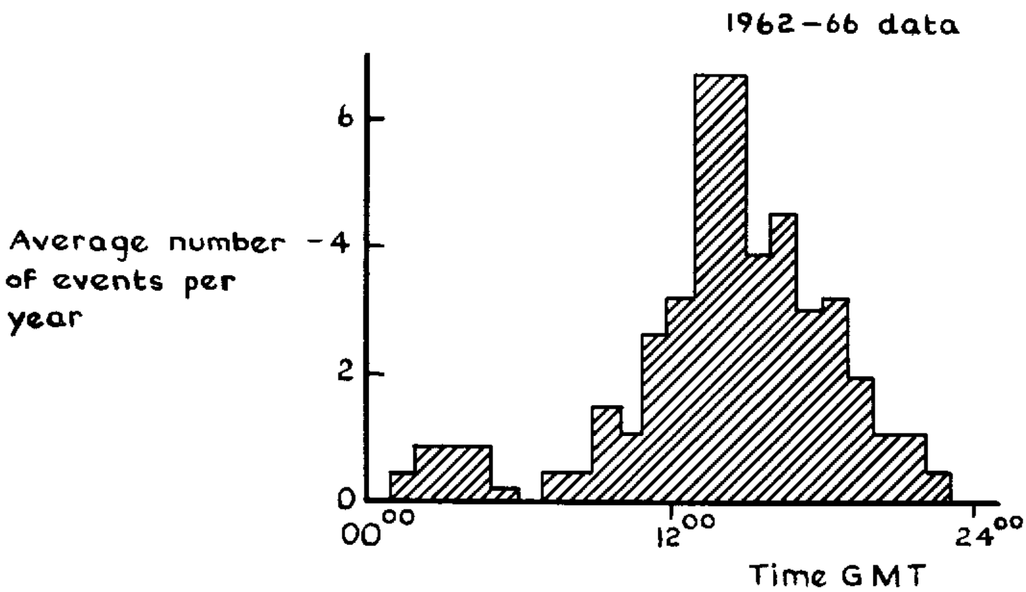

Fig. 5 Average number of events per year which take place between given hours

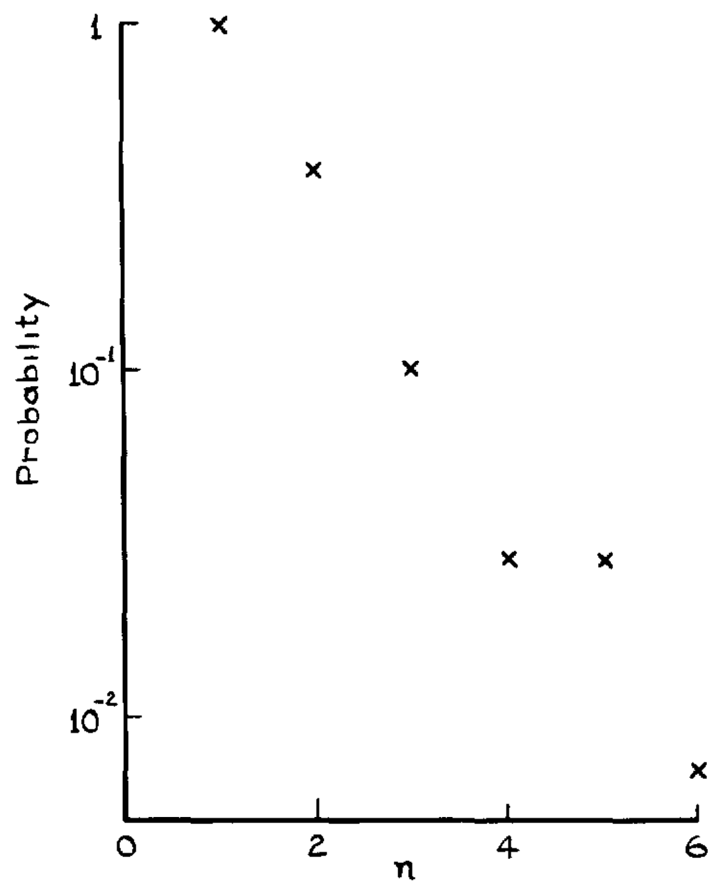

Fig. 6 Probability of getting at least n events per day for days on which events occurred

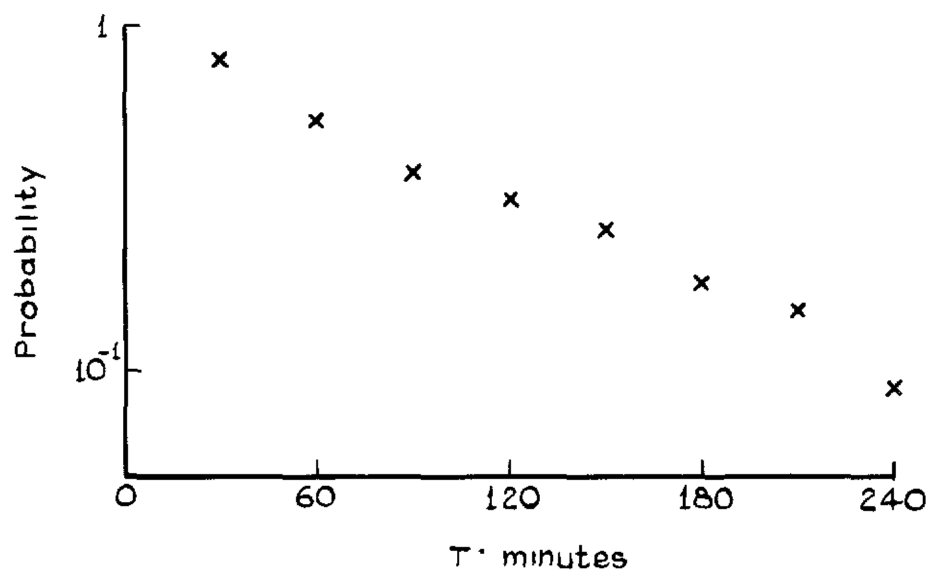

Fig. 7 Probability of the time between two consecutive events on the same day being greater than T

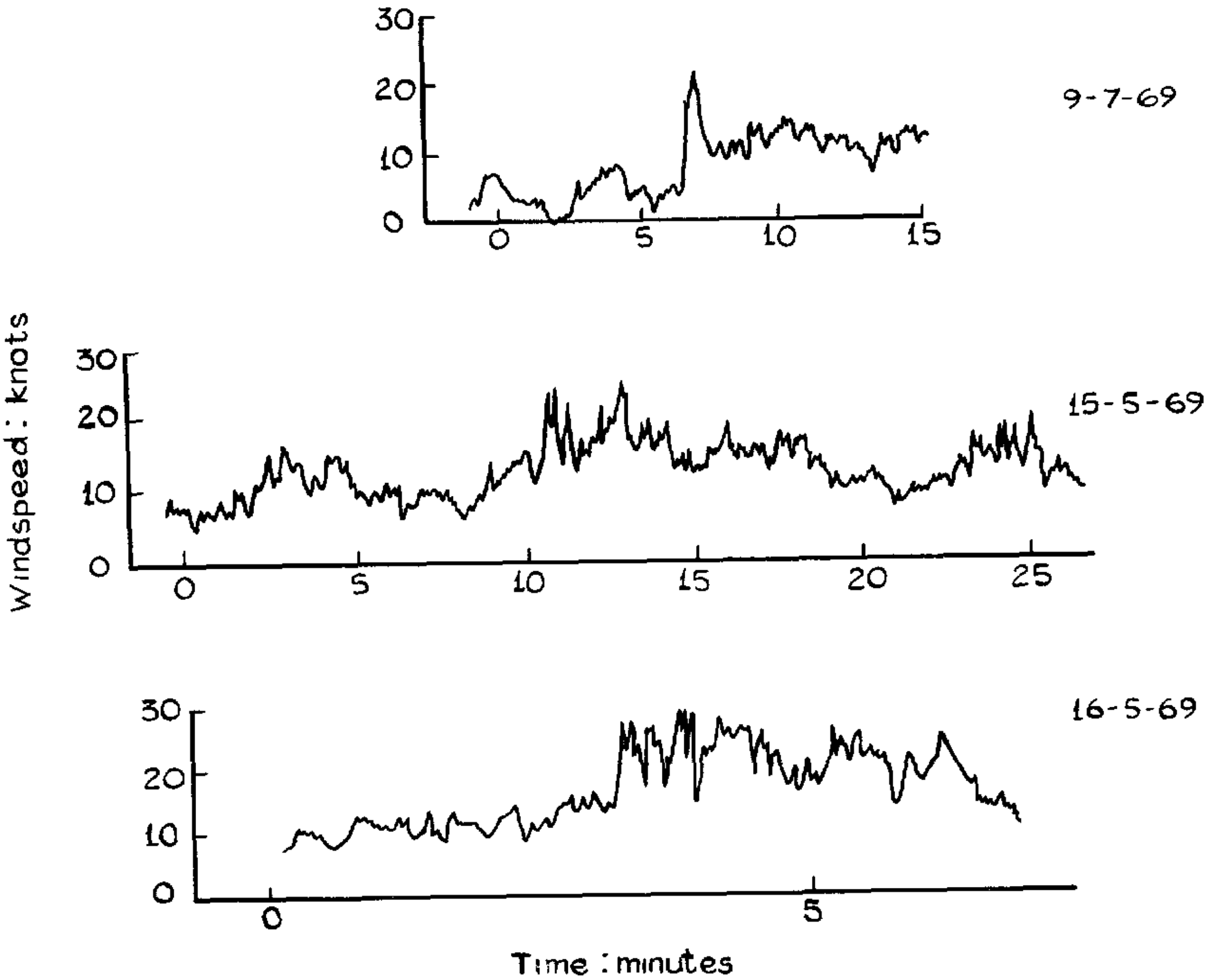

Fig. 8 Time histories of events recorded on faster timescales showing the wind fluctuations in detail, recorded at RAE Bedford at a height of 30ft

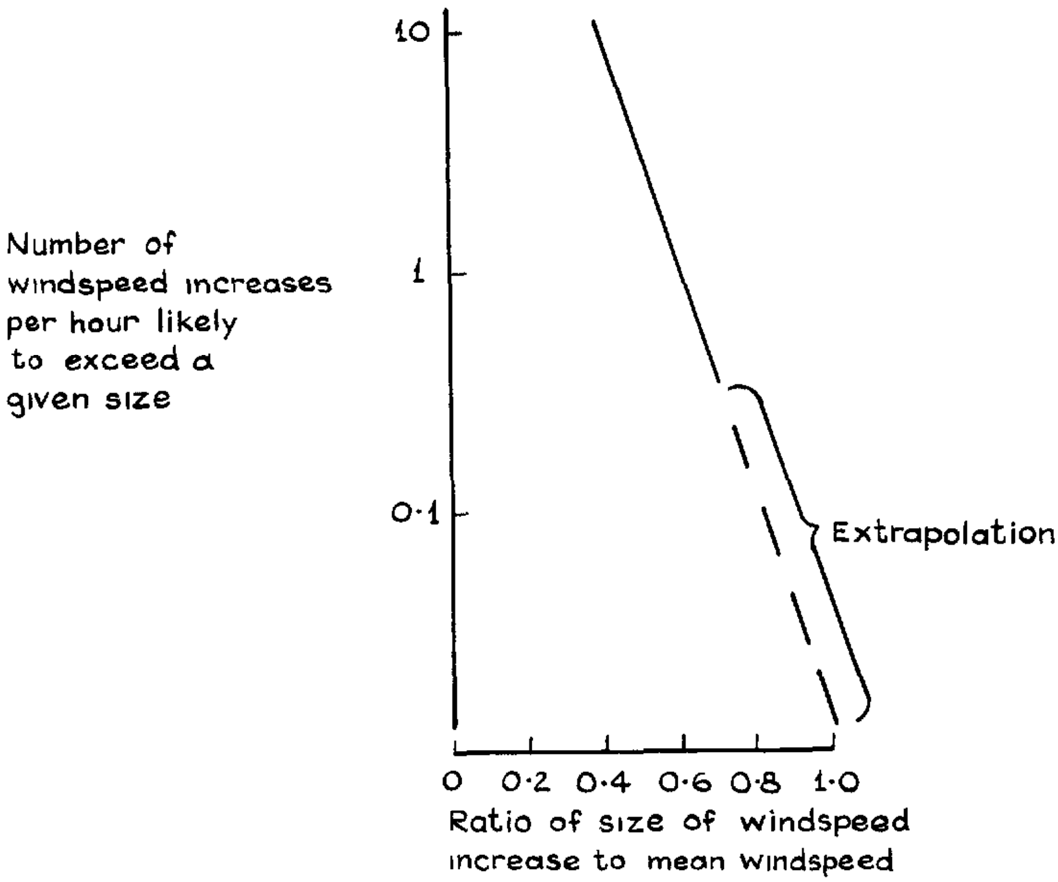

Fig. 9 Number of windspeed increases per hour (which take place in less than 1 minute and persist for at least 10 sec) in conditions of steady mean wind, based on analysis of 5 hr wind record of a 27 knot wind

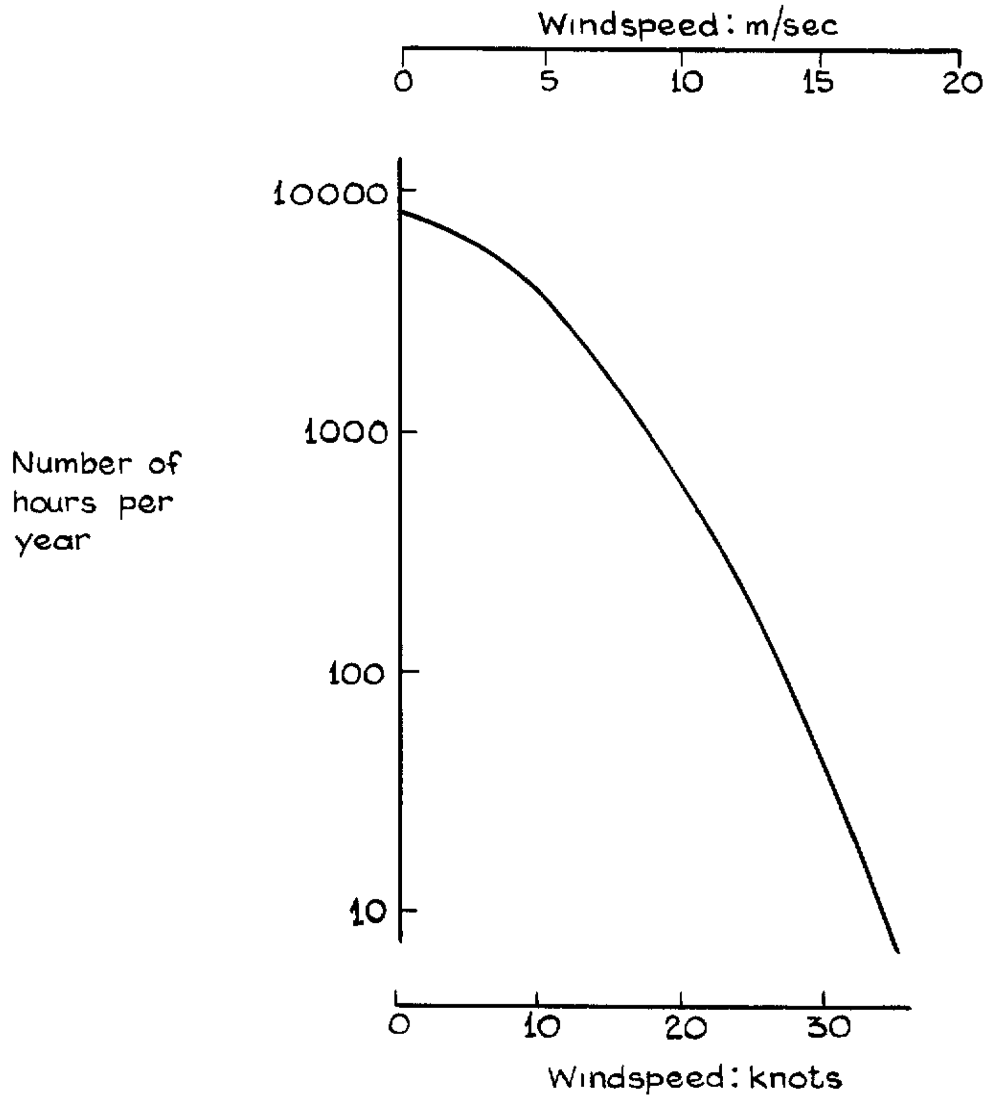

Fig.10 Number of hours per year that windspeed at Cardington exceeds given values (from data in Ref 4)

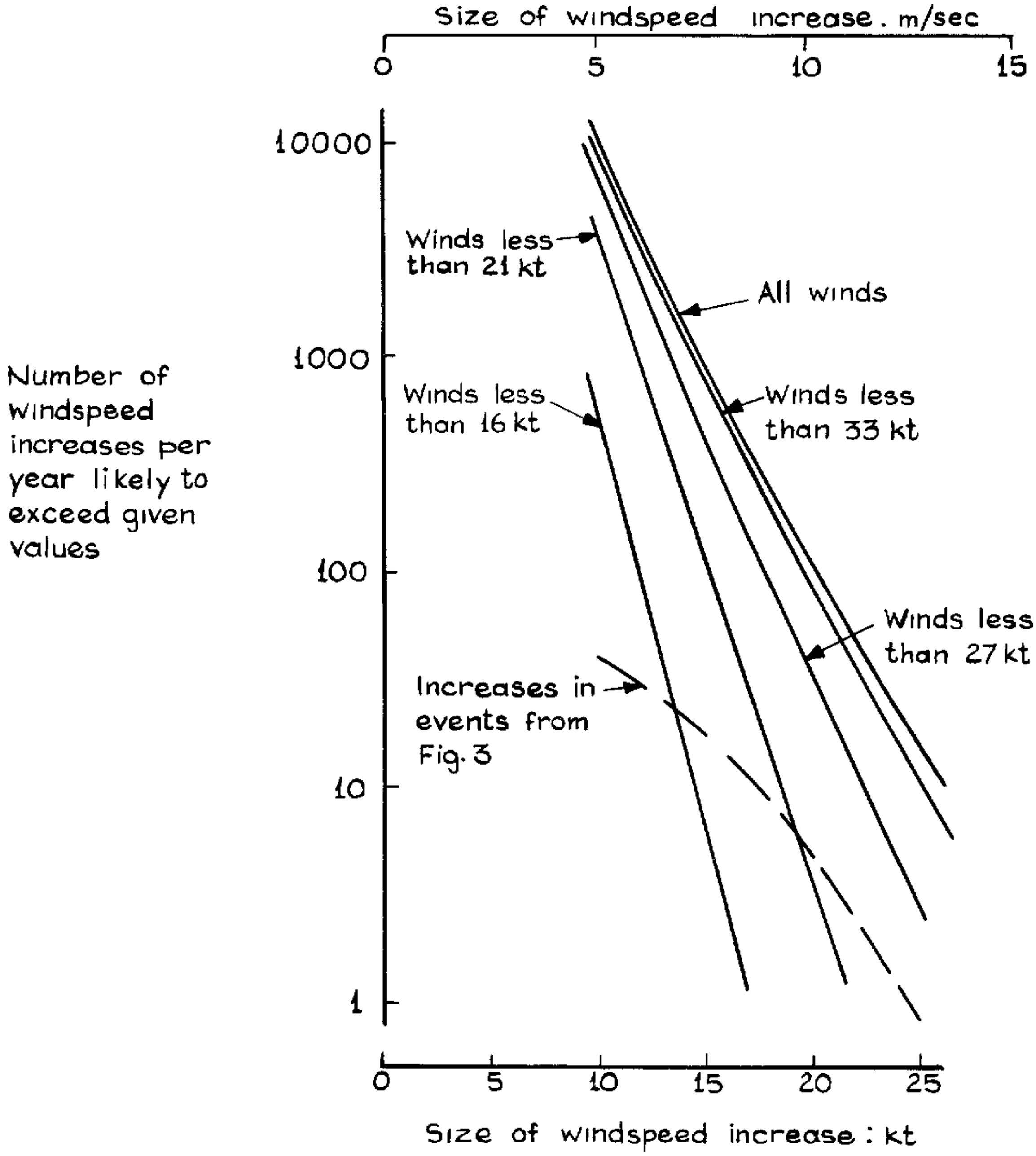

Fig.11 Number of windspeed increases per year likely to exceed given values for steady mean winds and the events considered here

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