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WIND SPEEDS OVER SHORT PERIODS OF TIME

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With the use of lighter and lighter materials in building construction, engineers are being forced to consider the wind structure in greater detail and its effect on the individual members of their buildings. Indeed the engineering of modern buildings is involving aerodynamics in a manner undreamed of till lately. In particular, since the aerodynamic pressure on a plate is proportional to the square of the velocity of the wind passing over it, economy demands that the probable maximum speed of the wind affecting any member of a building should be assessed with some accuracy. Moreover the duration of the passage of a high-speed parcel of air is intimately associated in its pressure effect with the dimensions of the member on which it is operating; hence it is a matter of considerable interest to engineers to know the wind speeds which are likely to operate over short time-intervals. The published records are mainly hourly mean values and maximum gusts: the former is far too long an interval for the engineers' requirements; the latter, if made by a Dines pressure tube anemograph, refers probably to an interval of two to three seconds; with the new electrical cup anemograph the maximum gust will refer to a still shorter interval. However, between two seconds and 60 minutes there is a gamut of intervals which are uncatered for except by the research work done with open-scale Dines recorders, as at Cardington,[1] and pressure plates, as at Ann Arbor, Michigan[2, 3] and the very fine-scale work done by Scrase.[4]

In what follows an attempt is made to use the data of these researches to make a statistical assessment of the wind speeds likely to occur in shorter intervals of time when the mean hourly wind speed falls in certain ranges.

To do this we suppose that the wind F at any time t can be represented by

$$F = V + v + x,$$

where V is the mean wind over, say, the hour, $V + v$ is the mean wind over, say, the 10 min interval and $V + v + x$ is the mean wind over the particular short period (perhaps 5 sec) in which we are interested.

Thus $$[F]_{600} = V + v \text{ and } [F]_{3600} = V,$$

where square brackets denote mean values averaged over intervals of 10 and 60 minutes respectively.

Moreover the mean square of F is

$$[F^2]_{3600} = [V^2] + [v^2] + [x^2].$$

Hence we can look on the mean square of the velocity as being made up of the mean square of the hourly wind, plus the mean squares of the departures of the 10 min means from the hourly means, plus the mean squares of the departures of the 5 sec mean winds from the 10 min means.

Moreover if the frequencies of the short-period means follow the normal Gaussian distribution, it is possible from tables of frequencies such as those quoted by Brooks and Carruthers[5] to estimate the maximum gust over a given short period likely to occur during an hour when the mean wind is of a given speed.

The distribution of the short-period winds about the 10 min means was examined in the data for Cardington given in *The structure of wind over level country*.[1] The frequencies of speed, during 5 sec periods, from the "ultra quick runs" were plotted on probability paper for a number of the records and in only one case was there a marked divergence from the Gaussian frequency; that was the case of the "ultra quick run 361" in which at one anemometer the wind speed rose from 43 m.p.h. to 69 m.p.h. in 5 sec and remained between 66 and 73 m.p.h. for 20 sec before it dropped back to 46 m.p.h. The three other anemometers of the layout, which were within 700 feet of this one and were in operation at the same time, showed nothing of this surge of high air speed. Apart from this surge no 5 sec speed at any of the four anemometers was greater than 54 m.p.h.

Provided the possibility of such rare occurrences is borne in mind it is legitimate to assume that winds follow closely a Gaussian distribution.

If we consider an anemogram in which there is no general change of wind direction or speed during the period T and if we measure the values of the wind in each small interval of time t, we then have a number T/t of wind measurements from which we can form a frequency distribution, or we can take a mean value M of the wind over the period T and derive the departures from the mean of the wind measured over each interval t. If we call these departures $m(Tt)$ we can derive the standard deviation $\sigma\,(Tt)$ where

$$\sigma\,(Tt) = \sqrt{\frac{\Sigma\{m(Tt)\}^2}{(T/t)-1}},$$

which is so written to imply that the standard deviation is of winds measured over the short interval t about the mean measured over the period T. Similarly $M(T)$ indicates the mean over time T.

In *The structure of wind over level country*[1] there are set out the values of wind speed over 5 sec intervals during periods of about 10 min. Occasions were chosen when there were no obvious general changes in wind direction or speed and calculations were made from seven occasions of the mean wind speed over 10 min and the standard deviations of mean winds averaged over 5, 10, 15, 20, 25, 30, 40, 50 and 60 sec. These standard deviations are set out in Table I.

When the values of the standard deviations for the 5 sec means in Table I are plotted against the mean speed it is seen that they are nearly proportional, with a ratio of about 0·145, whereas the ratio of the standard deviations for

TABLE I—MEAN SPEED M (10 MIN) AND STANDARD DEVIATION σ (10 MIN, t) FOR SEVEN CASES OF 10 MIN RECORDS

Run no.	Mean speed	Period t in seconds 5	10	15	20	25	30	40	50	60
		miles per hour								
314	22·9	3·5	3·3	3·2	3·0	2·9	2·7	2·7	2·5	2·2
361	41·2	7·6	7·0	6·7	6·6	6·9	6·3	5·1	5·5	5·0
401	11·3	1·4	1·3	1·3	1·2	1·2	1·1	1·1	0·9	0·9
391	34·3	4·5	4·1	4·0	3·7	3·6	3·4	3·1	2·8	2·8
393	27·2	4·4	3·9	3·7	3·7	3·4	3·4	3·3	3·2	3·1
97	42·1	5·1	4·7	4·4	4·0	4·0	3·8	3·5	3·1	3·2
147	12·1	1·7	1·6	1·5	1·5	1·4	1·4	1·4	1·2	1·1

60 sec means to M (10 min) is about 0·095. Indeed on average the ratios of these standard deviations to the mean 10 min winds are as follows in Table II.

TABLE II—AVERAGE RATIO OF STANDARD DEVIATION OF SHORT-PERIOD MEANS TO MEAN VALUE OF WIND OVER 10 MINUTES (SEVEN CASES)

Period in seconds (t)	5	10	15	20	25	30	40	50	60
Ratio $\frac{\sigma\ (10\ \text{min},\ t)}{M\ (10\ \text{min})}$	0·145	0·135	0·128	0·124	0·120	0·115	0·107	0·098	0·095

To confirm how closely the standard deviation is related to the mean wind a further nine cases were calculated of the standard deviation of 5 sec mean winds about the 10 min means. The sixteen cases are shown in Table III.

TABLE III—10 MIN MEAN WINDS AND STANDARD DEVIATIONS OF 5 SEC MEAN WINDS ABOUT THE 10 MIN MEAN WINDS

Run no.	Wind speed over 10 min M (10 min) *m.p.h.*	Standard deviation of 5 sec mean wind speeds σ (10 min, 5 sec) *m.p.h.*	Run no.	Wind speed over 10 min M (10 min) *m.p.h.*	Standard deviation of 5 sec mean wind speeds σ (10 min, 5 sec) *m.p.h.*
97	42	5·1	371	28	2·0
147	12	1·7	389	31	3·5
314	23	3·5	391	34	4·5
344	19	2·2	392	30	3·1
351	20	3·7	393	27	4·4
357	28	3·3	401	11	1·4
361	41	7·6	402	10	1·1
368	32	3·6	427	23	2·9

The relationship of these is shown in Figure I.

The correlation coefficient is 0·87 and the consequent regression equation is

$$\sigma\ (10\ \text{min},\ 5\ \text{sec}) = -0{\cdot}2 + 0{\cdot}14\ M\ (10\ \text{min}).$$

The standard error is 0·75 m.p.h.

To a close approximation we can say

$$\frac{\sigma\ (10\ \text{min},\ 5\ \text{sec})}{M\ (10\ \text{min})} = 0{\cdot}14.$$

In the seven cases where the standard deviation of 60 sec mean values had been worked out the correlation coefficient was about 0·9 and the ratio

$$\frac{\sigma\ (10\ \text{min},\ 1\ \text{min})}{M\ (10\ \text{min})} = 0{\cdot}10.$$

Further, as there were in existence tabulations of the Cardington 50 ft anemograms giving the mean hourly winds and also the mean wind speeds over the 10 min interval before each hour, it was possible to obtain a relationship between the mean wind over 10 min and the hourly mean. Forty-four days were

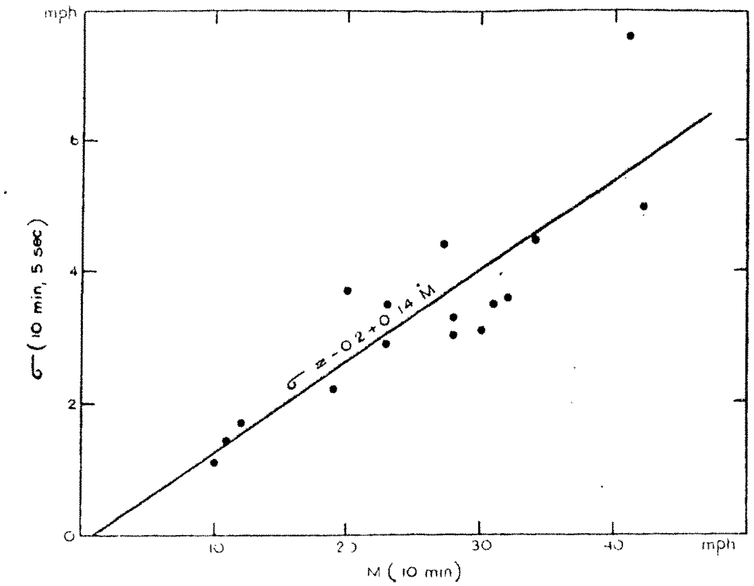

FIGURE I—GRAPH OF $\sigma = -0{\cdot}2 + 0{\cdot}14M$

picked out from the period September 1928 to May 1929 when there were no significant changes of wind in speed or direction. These 44 days were classified into three groups according to the general level of the wind speed: namely, light winds with an average of 13 m.p.h. (25 cases), moderate winds with an average of 20 m.p.h. (15 cases) and four cases of strong winds with an average of 28 m.p.h. Each speed group was arrayed as departures from the mean wind speed of the day, and then standard deviations were formed of these departures for each group. A correction was made to allow for diurnal variation of the mean wind of the group as a whole. These standard deviations were formed for both the hourly means and the 10 min means, that is, there were calculated σ (24 hr, 1 hr) and σ (24 hr, 10 min) as is shown in Table IV.

TABLE IV—MEANS AND STANDARD DEVIATIONS FOR VARIOUS TIME INTERVALS

Characteristic grouping	No. of days	Mean speed *m.p.h.*	σ (24 hr, 1 hr) *m.p.h.*	σ (24 hr, 10 min) *m.p.h.*	σ (1 hr, 10 min) *m.p.h.*
Light winds	25	13	2·20	2·35	0·82
Moderate winds	15	20	2·66	2·84	1·07
Strong winds	4	28	3·95	4·44	2·02
All winds	44	17	2·62	2·83	1·06

Values were originally taken to a further place of decimals and were then rounded off.

In this table σ (1 hr, 10 min) has been obtained from the formula

$$\{\sigma\ (1\ \text{hr},\ 10\ \text{min})\}^2 = \{\sigma\ (24\ \text{hr},\ 10\ \text{min})\}^2 - \{\sigma\ (24\ \text{hr},\ 1\ \text{hr})\}^2.$$

The mean wind speeds M (10 min) and M (24 hr) are the same provided the means are made up of a sufficiently large number of randomly chosen values.

The ratios of the standard deviations to the mean wind speed are on the whole somewhat greater for light winds than for moderate and strong winds. For all winds combined the ratio σ (24 hr, 1 hr)/M is 0·158 and σ (24 hr, 10 min)/M is 0·170. σ (1 hr, 10 min)/M is 0·064 for all winds combined and is 0·07 for the four cases of stronger winds.

We are now in a position to make an estimate of the magnitude of winds measured over short periods of time at sites over level country. The ratio σ (1 hr, 10 min)/M lies somewhere between 0·055 and 0·075; the ratios of the standard deviations over shorter periods σ (10 min, t)/M are those given in Table II; we can combine these and expect the standard deviations about an hourly mean wind to be

$$\sqrt{\{\sigma\,(1\text{ hr}, 10\text{ min})/M\}^2 + \{\sigma\,(10\text{ min}, t)/M\}^2}.$$

These are given in Table V.

TABLE V—VALUES OF σ (1 HR, t)/M FOR VARIOUS VALUES OF t

t	10 min	1 min	30 sec	20 sec	10 sec	5 sec
	0·055	0·110	0·127	0·136	0·146	0·155
σ (1 hr, t)/M	0·065	0·115	0·132	0·140	0·150	0·159
	0·075	0·121	0·137	0·145	0·154	0·163

The difference between the three lines of this table is not great. Using the middle line we obtain in Table VI values of σ (1 hr, t) for various values of the mean hourly wind M.

TABLE VI—VALUES OF σ (1 HR, t) FOR VARIOUS VALUES OF t AND VARIOUS MEAN HOURLY WIND SPEEDS

Mean hourly wind speed	Period t: 10 min	1 min	30 sec	20 sec	10 sec	5 sec	½ sec
			miles per hour				
20	1·3	2·3	2·6	2·8	3·0	3·2	—
30	2·1	3·5	4·0	4·3	4·5	4·8	—
40	2·6	4·6	5·3	5·6	6·0	6·4	(7)
50	3·3	5·7	6·6	7·0	7·5	8·0	(9)
60	3·9	6·9	7·9	8·4	9·0	9·6	(10)
70	4·5	8·0	9·2	9·8	10·5	11·2	(11½)
80	5·2	9·2	10·6	11·2	12·0	12·7	—

For shorter intervals than 5 sec, calculations made from the data of Sherlock and Stout[2,3] show that in two sets of observations (Run 330, 340 to 384 sec and Run 330, 138 to 157 sec with four stations used in each case) the standard deviations of ½ sec mean winds about 5 sec means, that is, σ (5 sec, ½ sec), were 3·0 m.p.h. for a mean wind of about 40 m.p.h. If such a standard deviation is added to the 5 sec means in Table V we get a value of σ (1 hr, ½ sec) of about 7 m.p.h. for a mean speed of 40 m.p.h. and probably up to 11½ m.p.h. for a mean speed of 70 m.p.h. These figures have been added in the last column of Table VI.

Now if we assume that the distribution of, say, a 5 sec mean wind about the hourly mean is Gaussian, we can get the probable maximum gust, over that duration of time, from tables of the probability integral, for example those quoted in Appendix II of the *Handbook of statistical methods in meteorology*.[5] Thus we can make up Table VII.

TABLE VII—FACTORS BY WHICH σ (1 HR, t) HAS TO BE MULTIPLIED TO PRODUCE THE MAXIMUM GUST IN ONE HOUR

t	10 min	1 min	30 sec	20 sec	10 sec	5 sec	½ sec
t/1 hr	0·167	0·017	0·0085	0·0056	0·0028	0·0014	0·00014
Factor	0·9	2·1	2·4	2·55	2·8	3·0	3·6

Finally we get estimates of the maximum gust, averaged over short periods, likely to occur once in an hour as follows in Table VIII.

TABLE VIII—PROBABLE VALUES OF THE MAXIMUM WIND SPEED, AVERAGED OVER SHORT PERIODS OF TIME t, WHEN MEAN HOURLY WIND SPEED HAS VARIOUS VALUES

Mean hourly wind speed	Period t: 10 min	1 min	30 sec	20 sec	10 sec	5 sec	½ sec
			miles per hour				
20	21	25	26	27	28	30	—
30	32	37	40	41	43	44	—
40	43	50	53	54	57	59	(65)
50	53	62	66	68	71	74	(82)
60	64	74	79	81	85	89	(96)
70	74	87	92	95	99	104	(111)
80	85	99	106	109	114	118	—

If values of σ (1 hr, t)/M of 0·055 or 0·075 had been used instead of 0·065 the probable values of the maximum wind speed, averaged over short periods of time, would have been altered by only about one mile per hour.

It has been pointed out to me that according to Graph 4.2.2(3) of Gumbel's *Statistics of Extremes*[6] a more appropriate value for the factor in Table VII for 10 min would be 1·2 instead of the 0·9 given by the assumption of a Gaussian distribution. This, however, makes little difference to the values of the 10 min column of Table VIII, the values up to 64 being increased by 1 m.p.h. and the two highest by 2 m.p.h.

It must, however, be noted that the figures in Table VIII strictly refer only to a site in which the wind has an unobstructed field and the topography is flat. Data do not appear to be available for any other type of exposure. However, it is believed that the values given in Table VIII can be reasonably applied to sites where the countryside is undulating but slopes are not steep. The figures must not be applied to sites where the wind arriving at the anemometer has recently travelled over obstructions such as houses or trees which are but little lower than the anemometer itself. They do not apply to winds blowing immediately off the sea on to the site.

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