WIND DATA FOR WIND DRIVEN PLANT

Arthur H. Stodhart

Electric Research Association
Surrey, England

To obtain the best performance with any type of machine, it is essential to have a good understanding of the fuel used. It is also necessary, for the broader view, to know where that fuel can most readily be found, the rate at which it can be extracted and used, and the magnitude of the resource. This is as true with wind as with any other fuel, except that this resource does not reduce with use.

What data do we have on wind? We know that of the 1.5×10^{18} kilowatt-hours (kW-hr) of solar energy falling on the Earth annually some 26000×10^{12} kW-hr are converted to air in motion and that a small fraction of what is accessible in the first 100 meters or so above the Earth's surface should provide a resource at least equivalent to the world water power reserves.

Wind is not distributed evenly over the globe, being on the average more plentiful in the temperate and polar latitudes and, almost everywhere, higher in coastal areas than inland for the same type of terrain. (See fig. 1) This same picture is shown in a more local context by the "isovent" map of the British Isles. (fig. 2) This type of map is produced from standard MO (Meteorological Office) data, based on standard MO anemometers, supplemented by spot readings in some sites and by visual observations reported on the Beaufort scale. It relates to open situations in level country at 10 meters above ground. Its use for wind power purposes is to indicate areas that are worthy of further exploration.

Why do we need to explore further? Simply because, if wind regimes much better than those indicated by the isovent map cannot be found, there is no economic case for wind power use at present day fuel prices. What must be found are sites where the specific output of wind-driven plant rated at wind speeds of around 15 meters per second (30 to 35 mph) is between 3500 and 4500 kW-hr/kW. Typical velocity-duration and power duration curves for such sites are shown in figure 3. Analysis of a large number of curves of this type shows that their shape does not differ widely and that there is, for any given rated wind speed, a roughly linear relationship between specific output and mean annual wind speed (fig. 4). It is not, therefore, necessary to use elaborate recorder equipment at each and every potential wind power site.

An adequate, and economic procedure in any geographical area is to make comprehensive measurements, including hourly mean values, at one site and obtain only weekly or monthly integrations of wind at a series of others.

The type of anemometer used is not of particular importance, but it is preferable to use identical types for all the general wind survey work.

How should we choose these sites? All past experience indicates that smooth-shaped hills with all-round exposure provide mean wind speeds well above the average for the surrounding countryside. In temperate and northern latitudes, hills below the normal winter snowline are preferable. It may be that studies of the ecological evidence, as suggested by Putnam, will help in the initial choice of site, but such evidence is not always available. Typical hill sites in the British Isles show average annual wind speeds 35 to 50 percent higher than at lowland measuring stations. Characteristic of the best sites is a slope of about 1 in 3½ (16°) in the final few hundred meters approach to the summit and the absence of a flat top to the hill. Conical shaped hills are preferred to ridges. Another advantage with such hills is the reduction in the vertical wind gradient. In level country of average roughness, and with neutral stability, the exponent of the gradient is about 0.17 (i.e., $\overline{V} \sim h^{0.17}$ where $\overline{V}$ is the mean hourly wind speed and h the height above ground). This is undesirable for aerogenerator operation since it imposes additional cyclic loads on the wind rotor. On ideal sites, because of the compression of the streamlines over the summit, this gradient is reduced, certainly in the first 50 meters, to give values of the exponent of 0.05 or less. For slopes of 1 in 6 the exponent is around 0.10 and for very shallow slopes, it approaches the value for level country.

All of this information can be obtained from hourly mean wind speed data.

To obtain useful data for structural design purposes requires, in the first instance, more detailed information, such as can be provided by sensitive anemometers installed in vertical and horizontal arrays on one or more typical wind power sites. Since the earlier wind power work was undertaken, considerable advances have been made in the collection and analysis of short-term wind data and its use for structural design purposes. The aerogenerator designer can benefit from these advances.

Associated with the period of 1 hour over which means are generally taken, there is a continuous random signal comprising the fluctuations of the wind about that value. These "gusts" need to be described, and to do this the methods developed in communications and control engineering, based on probability theory and statistical techniques, can be applied. By separating the gust vector from the mean, the rms gust speed and intensity of turbulence can be calculated. This leads to the important conclusions that the former is virtually independent of height and that the latter decreases with height (figs. 5 and 6).

Next, for a dynamical approach to wind loading, it is necessary to describe the evolution of gust velocity in time and its variation in space. The time structure of random signals (in this case gusts) can be described by the auto-covariance function, or by a normalised version known as the auto-correlation function. The latter is a measure of the information a gust component at one instant of time gives about the value at a later time. Gust properties can also be described by means of power spectra, an extension of Fourier analysis principles to non-periodic random signals. The power spectrum of a signal can be defined in terms of the contribution to the total variance coming from simple harmonic components in a defined band width of the continuous spectrum centred about a given frequency. It has been shown that the power spectrum of the longitudinal gust component can be fitted into a simple expression having as parameters the hourly mean wind speed at 10 meters and the surface drag coefficient. Typical gust spectra are shown in figure 7.

Results so far obtained confirm that the power spectrum provides a description of the evolution with time of the random gust velocity adequate for many structural loading problems.

Also important are the space average properties of gusts, and these can be obtained from cross-correlations for zero-time lag, which provide a measure of the relationship between simultaneous values of gust components at different points. These can be combined with the time relationships to show correlations at different points for different time lags (see fig. 8). Application of these methods to aerogenerator design could overcome past difficulties of relating wind behaviour to structural performance.

Finally, it is useful to accumulate data on extreme wind speeds in order to assess the likely probability, or return period, of any given value that may be relevant to the machine or tower design. However, because present techniques require the collection of maximum values of wind speed over many years, it will initially be necessary to learn what we can from less windy sites where such information is at present available. The technique is straightforward; the highest values for each year of the period are ranked in order from lowest to highest, a plotting position is calculated, as is the reduced variate (see fig. 9). The results can then be plotted (fig. 9(a)) and confidence limits drawn in. The hourly mean values are immediately meaningful; the gust values are so only if the term "gust" is defined. What may be more useful is to derive the probable values of short-term means from the hourly mean values. For level country inland the following relationships are typical.

	60 min mean	10 min mean	1 min mean	20 s mean	5 s mean	0.5 s mean
V_{max}/V_{mean}	1.0	1.06	1.33	1.36	1.47	1.59

For good wind power sites the ratios of the shorter term means to the hourly means will probably be less than these; a full examination of wind data from such sites is lacking.

The relative importance of extreme wind speeds to wind driven plant has not been established. Under these conditions the plant will be shut down and loading on the rotor and the tower could well be less than under full power conditions. Extreme data for low level sites in the UK are shown in figures 10 and 11.

Summarizing, the use of simple, averaged data will provide information on energy availability, facilitate site selection and enable appropriate operating ranges to be established for wind-driven plant. It will also provide a basis for the prediction of extreme speeds. For structural design purposes the more detailed shorter-term data are required, and more sophisticated methods of analysis must be utilized and applied.

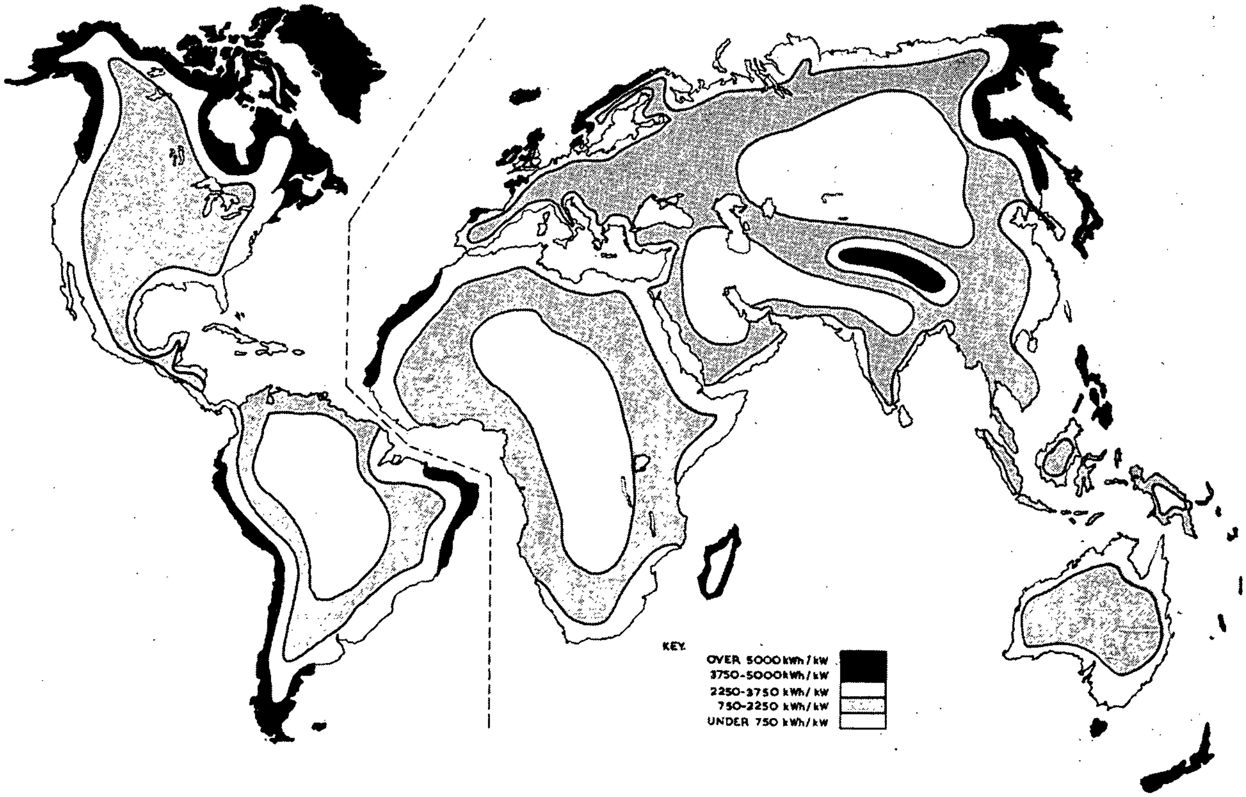


Fig. 1.—**Availability of wind energy**
Annual specific output of windmills rated at 25mile/h

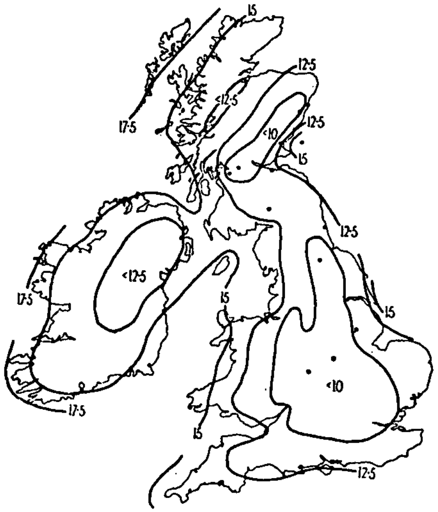


Fig. 2.—Isovent map of the British Isles. Annual mean wind speed given in mph.

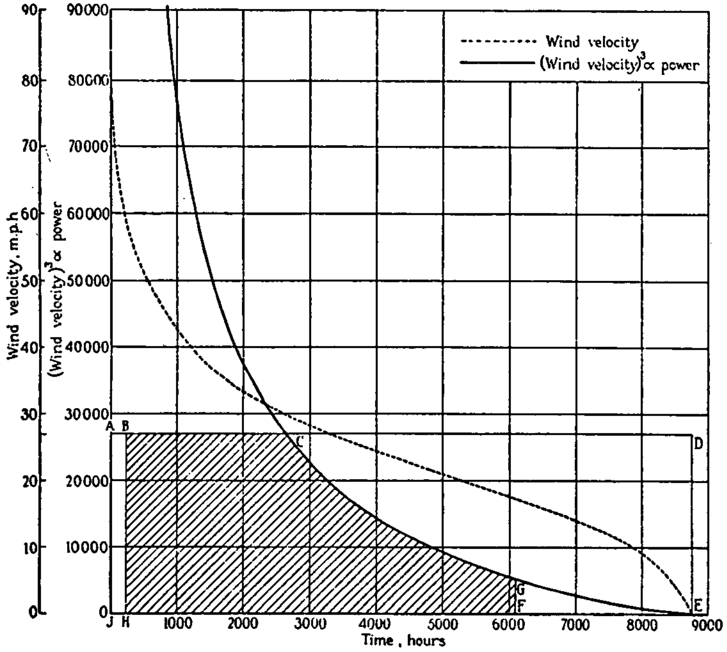
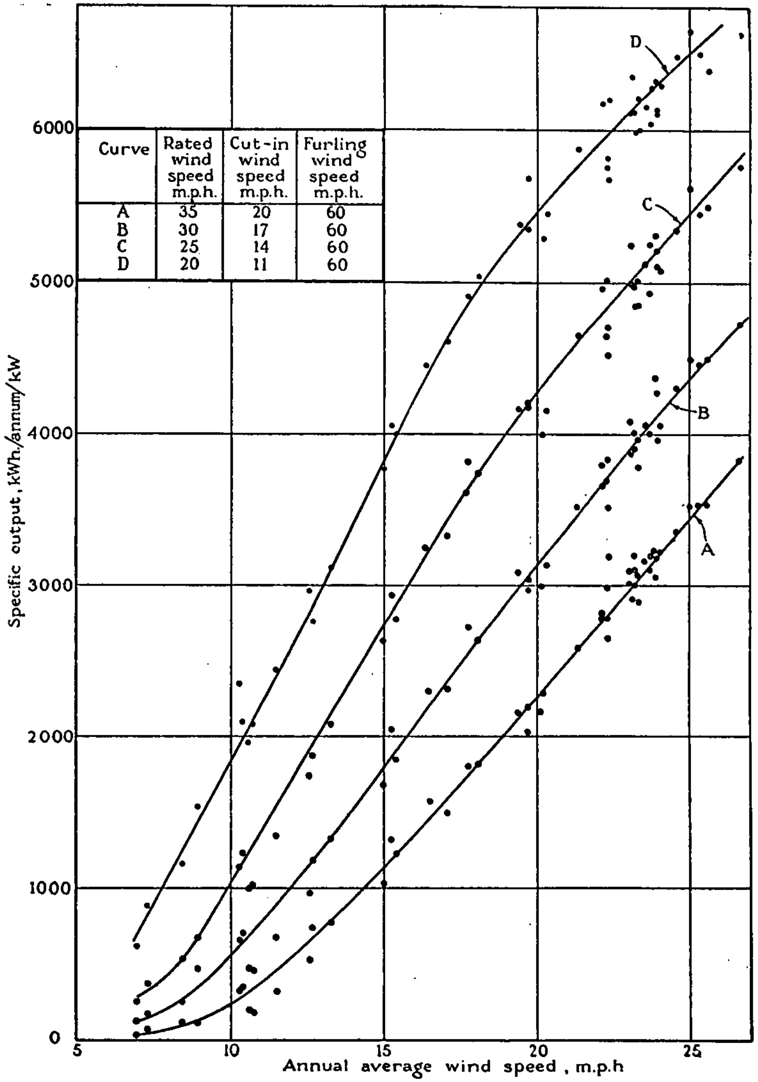


Fig. 3.—Velocity- and power-duration curves typical of an excellent site.



Curve	Rated wind speed m.p.h.	Cut-in wind speed m.p.h.	Furling wind speed m.p.h.
A	35	20	60
B	30	17	60
C	25	14	60
D	20	11	60

Fig. 4.—Relationship between the specific output and annual average wind speed at sites in the British Isles.

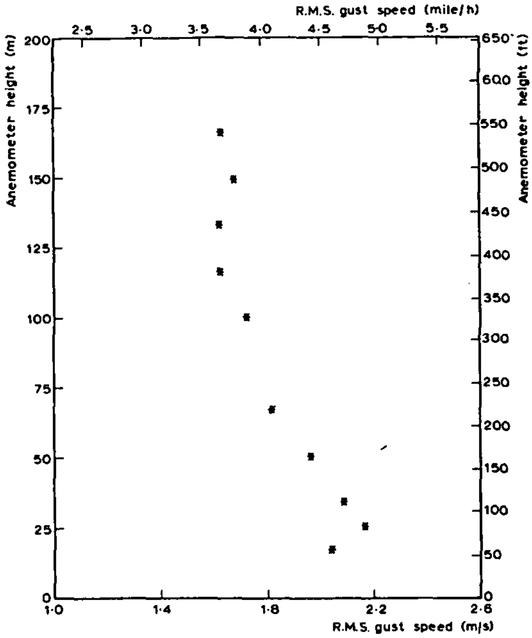


Figure 5 R.M.S. gust speed measured at Rugby

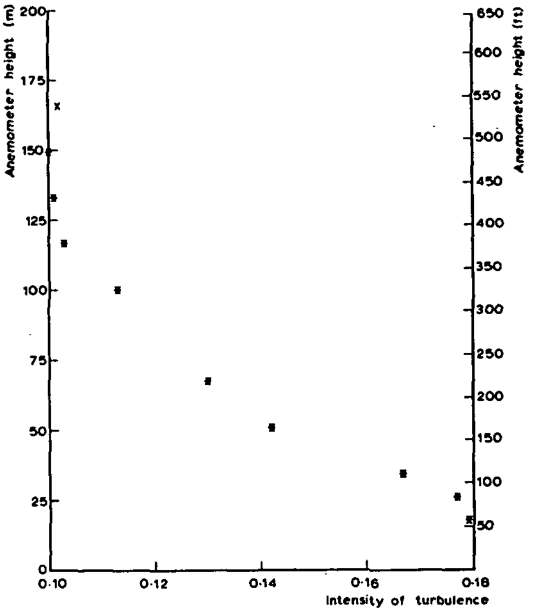


Figure 6 Intensity of turbulence measured at Rugby

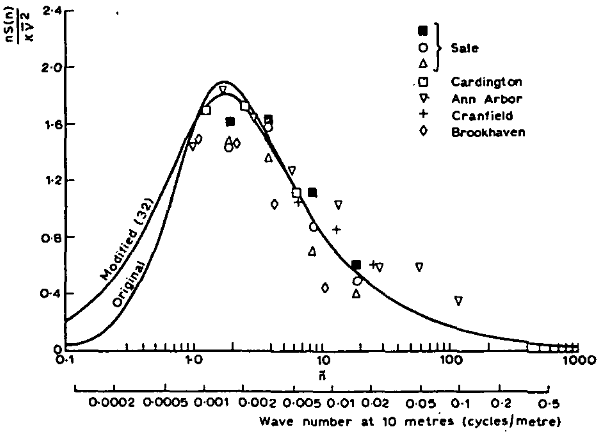


Figure 7 Comparison of the original and modified gust spectra

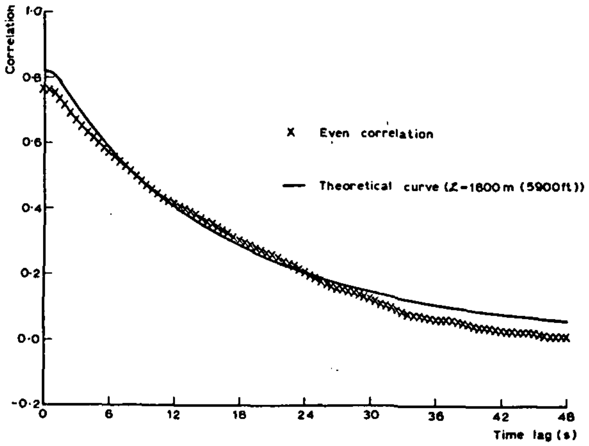


Figure 8 Cross correlation between long. component at 116·4 m (382 ft) and long. component at 100·0 m (328 ft)

ANNUAL MAXIMUM WIND SPEEDS (GUSTS) AT CARDINGTON, 1932–54

RANK m	HIGHEST GUST x m.p.h.	YEAR	PLOTTING POSITION $p = \frac{m}{N+1}$	REDUCED VARIATE $y = -\log_e(-\log_e p)$
1	55	1953	0·042	−1·16
2	59	1950	0·083	−0·91
3	60	1941	0·125	−0·73
4	61	1951	0·167	−0·58
5	62	1952	0·208	−0·45
6	63	1937	0·250	−0·33
7	63	1939	0·292	−0·21
8	64	1942	0·333	−0·09
9	65	1933	0·375	0·02
10	67	1949	0·417	0·13
11	68	1948	0·458	0·25
12	69	1945	0·500	0·37
13	71	1940	0·542	0·49
14	72	1934	0·583	0·62
15	72	1944	0·625	0·75
16	76	1954	0·667	0·90
17	78	1943	0·708	1·06
18	78	1946	0·750	1·25
19	81	1932	0·792	1·46
20	82	1936	0·833	1·70
21	86	1938	0·875	2·01
22	88	1935	0·917	2·44
23	93	1947	0·958	3·15

Figure 9

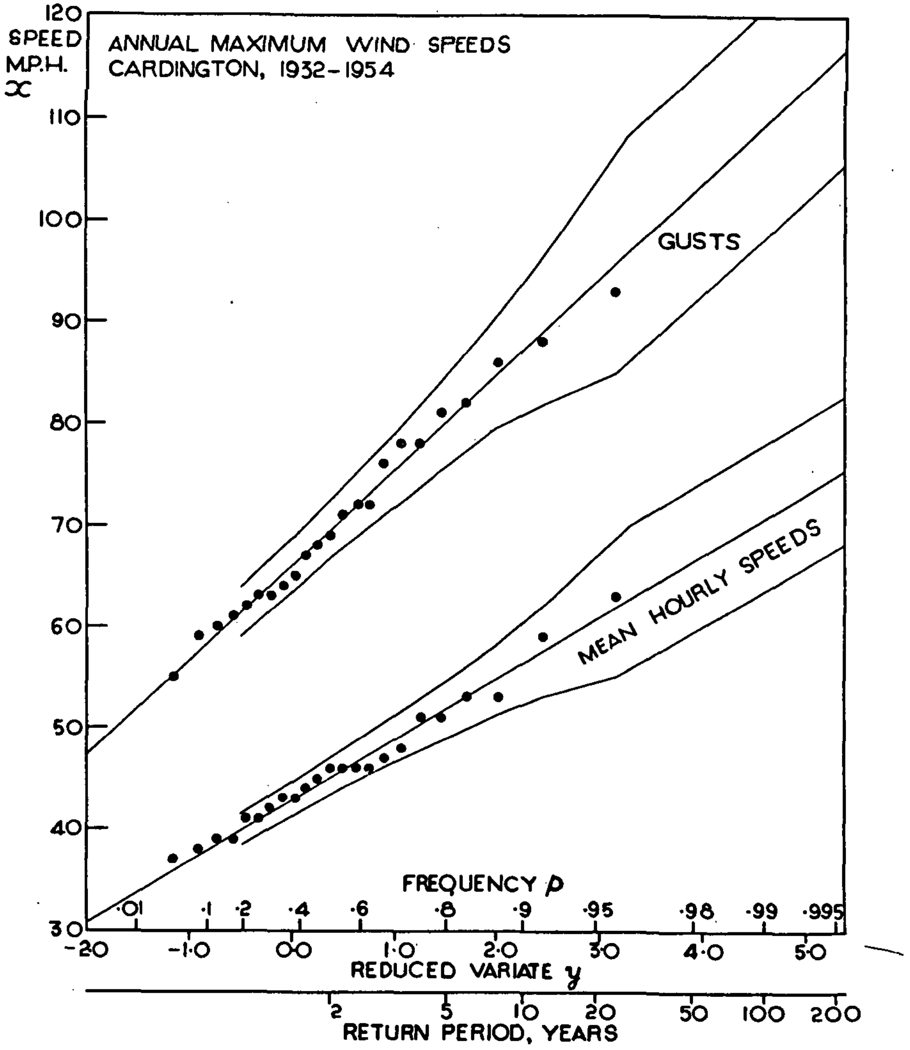


Figure 9(a)

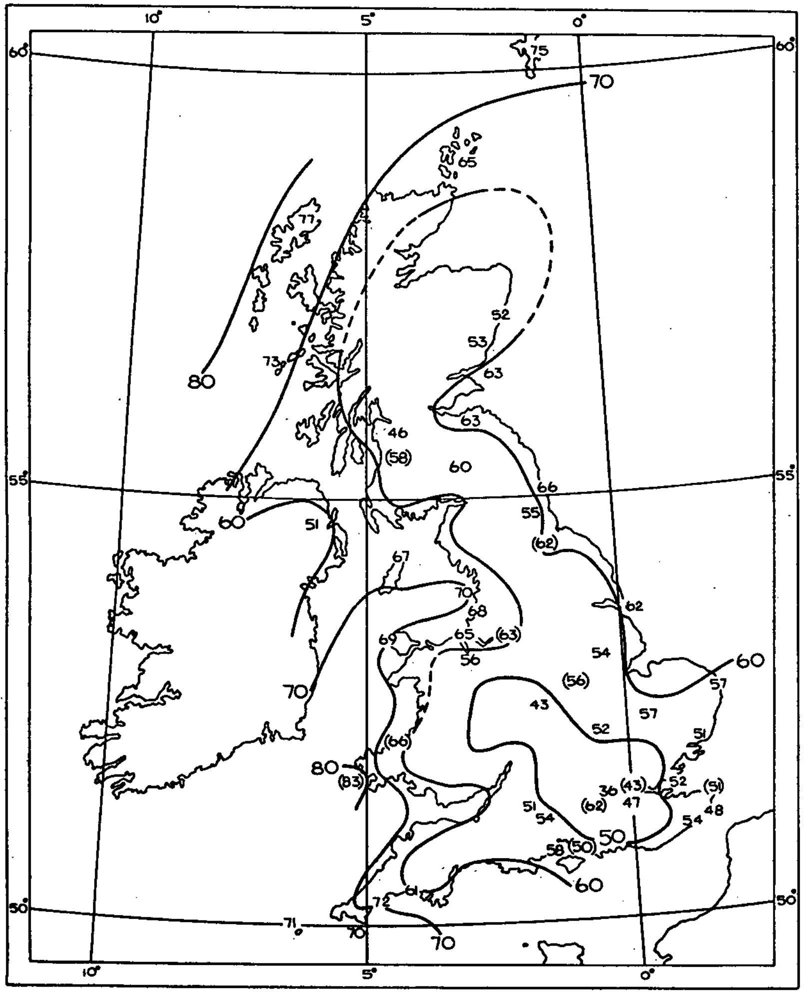


Fig. 10 HIGHEST MEAN HOURLY WIND SPEED AT 33 ft. LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS M.P.H.
(VALUES BASED ON LESS THAN 15 YEARS OF RECORD BRACKETED)

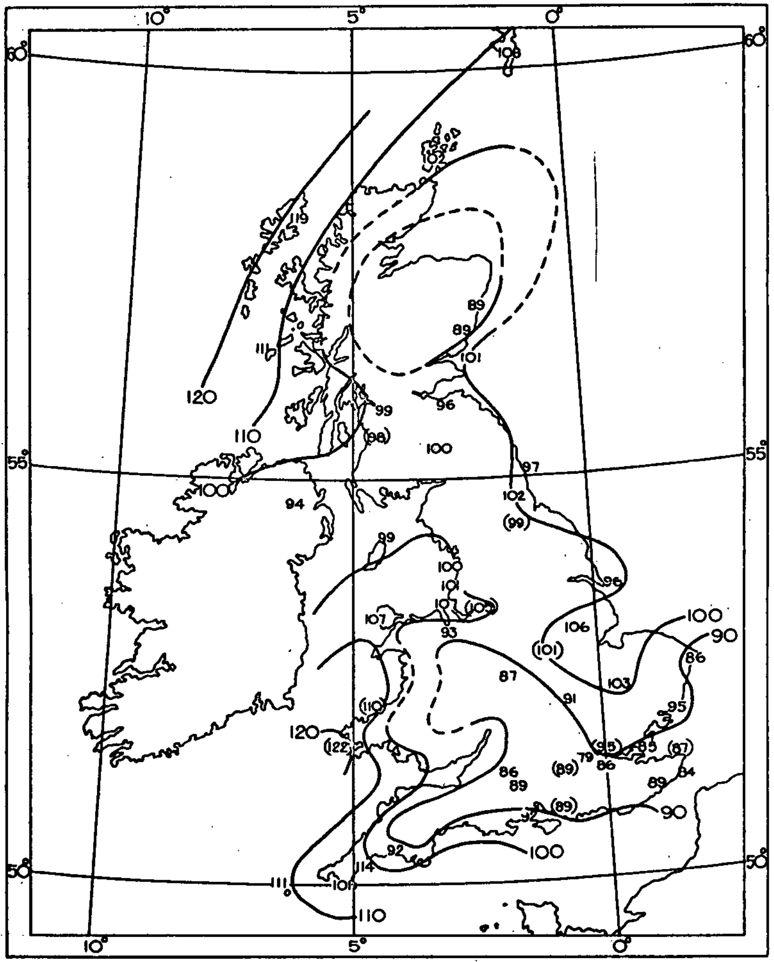


Fig. 11 HIGHEST GUST SPEED AT 33 Ft. LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS M.P.H.
(VALUES BASED ON LESS THAN 15 YEARS OF RECORD BRACKETED)