Surface Gustiness and Wind Speed Range as a Function of Time Interval and Mean Wind Speed

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ABSTRACT

Approximately 100 hours of wind records with mean speeds of 20 to 100 kt (at 12 m) were obtained from the Mt. Washington Observatory. Analyses of these data indicate that the gust factor can be used to describe the relationship between mean wind speed and wind speed range for a specific interval of time.

Pooled data recorded at 14 airfields in the Northern Hemisphere were used to develop 50-, 75-, 90-, and 98-percentile gust factor curves for 5 min, 1 min, and 30 s average wind speeds. Also presented are nomograms of the 50-, 75-, 90-, and 98-percentile wind speed ranges for mean speeds of 20 to 100 kt. The results are considered applicable to most airport locations at a height of approximately 15 m above the runway.

1. Introduction

While there are many available studies on the relationship of gusts to the steady wind speed (e.g., Camp, 1968; Davis and Newstein, 1968; Durst, 1960; Sherlock, 1947; and others), the quantitative results have varied depending on the data and analytical methods used. Furthermore, none of these provides a realistic description of the wind speed range, defined as the difference between the maximum and minimum, as a function of time interval and mean wind speed.

In this paper, the gust factor is defined as the peak wind speed divided by the steady speed. There is no restriction as to the time average of the peak gust or the steady speed except that the peak gust is of shorter duration than the steady speed. Unless stated otherwise, however, the peak gust represents the highest value of the wind speed discernible on the recorder trace for a particular averaging period of the steady wind.

2. Data

Approximately 100 h of wind records with mean speeds of 20 to 100 kt (at 12 m) were obtained from the Mt. Washington Observatory, N. H. Wind speeds averaging more than 60 kt were measured using a pitot sensor and a Foxboro recorder. This system was designed to measure strong winds that frequently occur atop Mt. Washington and is inaccurate below approximately 30 kt. Records for winds averaging less than 40 kt were taken from a 3-cup anemometer (located $1\frac{1}{3}$ m from the pitot and $\frac{1}{3}$ m lower in altitude) and an Esterline Angus recorder. For speeds of 40 to 60 kt, data were obtained from both systems.

Using comparative runs from both recording systems, it was determined that the Foxboro recorder used with the pitot sensor is slightly more responsive than the 3-cup Esterline Angus system. Since the peak gust on the recorder chart for the 3-cup anemometer is assumed to represent a 2 s gust (Sissenwine *et al.*, 1973), the resolution of the pitot recorder is less than 2 s. Although the resolution cannot be determined from the comparative run, it has been subjectively estimated at between 1.5 and 2 s. The difference between the two systems was minimized by adding 1 kt to the wind speed range of the 3-cup data.

Individual wind gust and wind speed range observations were made at approximately 10 min intervals. Assuming that the most likely gust configuration is symmetrical (Camp, 1968), it was decided that the gust being measured should be in the center of the averaging period. This concept is shown graphically in Fig. 1. Since the resolution is approximately 2 s, the peak gusts and the lulls are considered to be 2 s wind speeds.

In Fig. 1 the peak gust is indicated by an arrow. The 5 min speed (average for 5 min) is 38 kt, the 1 min speed is 40 kt, the 30 s speed is 43 kt, and the peak (2 s) gust is 60 kt. The range (the difference between the 2 s peak and the 2 s lull) for three time intervals was also determined. The 5 min lull is 20 kt for a range of 40 kt. In the example, the 1 min and 30 s lull are the same, 25 kt, for a range of 35 kt.

A total of 615 such observations were made. The method used was to make observations centered on the highest peak gust at 10 to 15 min after the previous peak gust. On occasions when a higher gust fell within 2.5 min of the gust chosen, that gust then became the center of the observation.

Another source of data was that obtained by Sissenwine *et al.* (1973). For that study an almost identical procedure as the one discussed above was used to make

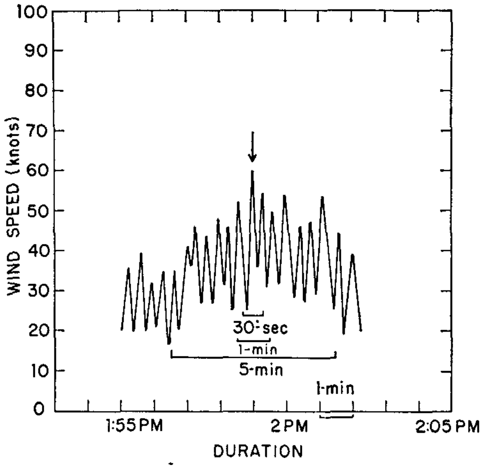

FIG. 1. Method used to determine wind speeds and wind speed range for differing durations. The peak gust in the center of the averaging period is indicated by an arrow. The mean wind speed and the range (difference between the peak and lowest part of the trace) is calculated for each of the three bracketed time intervals.

548 observations of gustiness, but not wind speed range. Observations were made using original wind data from 14 airfields around the Northern Hemisphere between 14° and 77° latitude. Mean wind speeds were 20 to 80 kt and the average anemometer height was approximately 15 m.

3. Approach

One of the purposes of this study was to determine the wind speed range as a function of time and mean wind speed. The gust factor is, in effect, a partial measure of the range. The peak gust minus the steady speed is the amplitude of the wind speed fluctuation for the period of time over which the steady speed is averaged. If the wind fluctuates symmetrically about the mean, doubling the amplitude would then result in the wind speed range.

To explore this approach, the Mt. Washington data were used to calculate the 50-, 75-, 90- and 98-percentile wind speed range for each of seven 5 min mean wind speed classes (20 to 29 kt, 30 to 39 kt,...80 to 89 kt) and three time intervals (5 min, 1 min, and 30 s). For example, the 67 observations with a 5 min mean speed of 30 to 39 kt were grouped. The peak gust, in the center of this 5 min interval, minus the lull in the 5 min interval, is the 5 min range. The range for 1 min and 30 s intervals were also calculated as depicted in Fig. 1 and described in Section 2. This procedure results in 3 values for each 5 min mean speed: the 5 min range, the 1 min range and the 30 s range. All of the 5 min ranges were ordered and the cumulative frequencies were plotted on probability paper. This was also done for the 1 min and 30 s ranges. Each percentile represents the value that exceeds that percentage of other values in the distribution. That is, the 50-percentile wind speed range is in the middle of the distribution, the 75-percentile range exceeds 75% of the ranges in the distribution, etc.

The range values determined from the data, termed "actual" values, and the mid-class wind speeds were used to derive linear equations by the method of least squares. These equations (not given) were used to estimate the wind speed range, termed "fit to actual" in Table 1. Also shown in Table 1 is the range estimated using the gust factor (GF). This was accomplished by calculating the 2 s GF to the 5 min, 1 min and 30 s speed for each percentile and 5 min mean speed class. The range was then calculated using

$$R=2S(G-1), \tag{1}$$

where

R = range for a specific time interval (5 min, 1 min, or 30 s) and percentile

G = the gust factor for the same time interval and percentile

S = the mid-class value of the 5 min mean speed.

An inspection of Table 1 shows that the values calculated using the GF overestimated the actual range in 24 of the 84 wind speed categories (approximately 29%). Two categories were identical leaving 58 categories (69%) which were underestimated. Despite this bias, the root-mean-square (rms) difference (indicated for each percentile and time interval group) is less than the rms difference between the "actual" and the "fit to actual" in 7 of the 12 groups. The rms differences tend to increase with increasing percentile level except for the 30 s interval range from the 75- to the 90-percentile.

On the basis of the values presented in Table 1, it is apparent that the wind does not usually fluctuate symmetrically about its mean speed, at least for time intervals up to a few minutes. There also seems to be a bias toward greater amplitude of the wind fluctuation below than above the mean speed, as indicated by the percentage of underestimates using Eq. (1). Despite this, the rms differences indicate greater reliability using Eq. (1) as an indicator of the wind speed range than the linear fit (a more complex fit is unwarranted by the data).

4. Gust factor relationships

The Mt. Washington data were used to develop a method for calculating the wind speed range as a function of time interval and mean wind speed. This source was chosen because of the availability of records on strong winds. The data used were recorded specifically for this study over the course of a one-year period (March 1972 to March 1973).

Mt. Washington is unique in many meteorological respects, mainly because of its exposure, as can be seen in Fig. 2. It is doubtful that wind speed fluctuations on this mountain peak are comparable to those of most airfield locations. This is borne out in Fig. 3, which

Table 1. Comparison of the actual wind speed range for Mt. Washington with the range estimated using a linear fit to the actual data and the range calculated using the gust factor (GF).

5 min mean speed (kt) (mid-class value)	Number of observations	5 min interval range			1 min interval range			30 s interval range		
		Actual	Fit to actual	GF*	Actual	Fit to actual	GF*	Actual	Fit to actual	GF*
a. 50-percentile values										
24.5	51	17.5	20.7	16.2	15.1	16.8	12.7	10.0	12.7	7.1
34.5	67	26.2	21.4	22.4	22.0	17.4	19.0	18.5	13.4	13.4
44.5	64	22.5	22.5	22.3	16.7	18.1	17.8	11.5	14.1	15.1
54.5	67	24.0	23.4	21.8	19.0	18.8	17.3	16.1	14.9	12.1
64.5	84	21.5	24.3	22.1	16.7	19.4	17.2	13.2	15.6	13.3
74.5	166	25.9	25.2	25.2	20.5	20.0	19.2	16.5	16.3	15.3
84.5	105	26.5	26.1	26.9	21.8	20.7	21.1	17.7	17.0	17.2
rms difference			2.40	1.77		2.23	1.74		2.61	3.05
b. 75-percentile values										
24.5	51	27.2	27.4	24.5	22.3	23.8	19.8	16.8	20.2	9.5
34.5	67	30.0	28.2	29.8	27.0	24.0	24.9	25.1	20.4	19.9
44.5	64	28.7	29.0	33.0	24.9	24.2	29.6	20.9	20.6	21.1
54.5	67	32.0	29.9	29.0	24.4	24.4	21.6	21.8	20.7	17.0
64.5	84	24.8	30.7	24.5	20.5	24.6	19.9	15.7	20.9	19.0
74.5	166	31.5	31.6	29.1	25.0	24.8	24.1	22.0	30.1	20.7
84.5	105	35.0	32.4	35.2	26.5	30.0	26.5	22.3	30.2	21.6
rms difference			2.66	2.41		2.42	2.44		5.21	4.08
c. 90-percentile values										
24.5	51	31.0	30.4	29.7	25.0	27.1	22.7	21.5	25.4	15.5
34.5	67	34.0	32.7	32.5	30.5	27.9	28.8	28.7	25.9	25.5
44.5	64	40.2	35.0	41.0	33.0	28.8	36.2	29.0	26.4	27.0
54.5	67	35.4	37.3	33.5	30.3	29.7	26.5	30.1	26.9	25.3
64.5	84	30.1	39.6	29.9	23.0	30.5	26.3	22.1	27.4	23.6
74.5	166	37.0	41.8	35.9	31.0	30.3	28.8	28.0	27.9	25.9
84.5	105	53.3	44.0	45.0	36.1	32.1	32.8	29.2	28.4	25.0
rms difference			5.76	3.35		3.82	2.91		3.13	3.73
d. 98-percentile values										
24.5	51	34.6	34.5	37.6	28.3	32.7	24.5	25.3	27.8	16.9
34.5	67	41.1	38.5	41.1	41.1	36.1	34.2	36.2	31.7	30.6
44.5	64	46.5	42.6	49.0	43.2	39.4	43.1	36.1	35.6	31.9
54.5	67	45.2	46.6	38.5	45.2	42.8	40.7	45.2	39.5	32.6
64.5	84	36.5	50.6	44.8	33.8	46.2	37.8	27.9	43.4	33.8
74.5	166	65.1	54.6	68.5	53.3	49.5	64.8	52.4	47.3	61.5
84.5	105	58.5	58.6	63.7	54.5	52.9	48.3	53.5	51.2	37.5
rms difference			6.90	4.89		5.80	6.20		8.79	9.65

* Estimated.

shows a comparison of the mean 2 s GF to the 5 min speed between Mt. Washington and the airfield data discussed in Section 2. The curves are a least squares fit of the data to

$$GF = 1 + Ae^{-BV}, \tag{2}$$

where A and B are constants and the speed of the steady wind, $V(\geqslant 20$ kt), is the 5 min average. This equation was used by Sissenwine *et al.* (1973) to fit GF curves.

Fig. 3 shows that Mt. Washington GF's are about 10% less than those for the airfield data. In a study on gust factors, Davis and Newstein (1968) conclude that the GF decreases with height. Although the anemometer at Mt Washington is 12 m (40 ft) above ground level, its exposure above the surrounding terrain is much

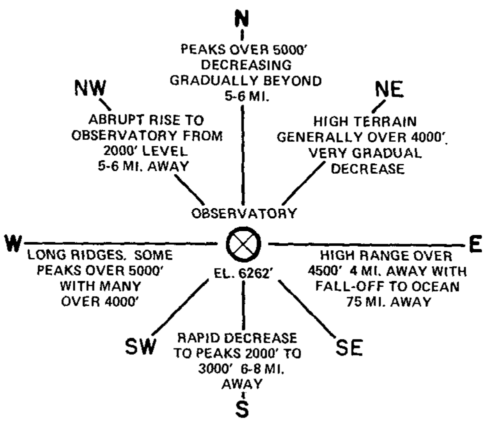

FIG. 2. Exposure of Mt. Washington Observatory.

higher (see Fig. 2). This is most likely the main cause for less gustiness. Since the airfield data are considered representative of most airport exposures, these data were used to develop gust factor and wind speed range statistics.

Gust factor curves were fitted to the airfield data using Eq. (2). These curves are shown in Figs. 4, 5 and 6. The value for V is the 5 min speed in Fig. 4, the 1 min speed in Fig. 5, and the 30 s speed in Fig. 6. The values for B in Eq. (2) were determined by a least squares fit of all the data to the 5 min, 1 min and 30 s speeds. Using these values of B, the value for A was determined for each percentile curve by a least squares fit to the mid-class values (e.g., 24.5 kt for $V=20$–29 kt) and weighted for the number of observations at each point.

5. Wind speed range relationships

The 5 min speed was used as a base for describing the wind speed range relationships. Fig. 7, which shows curves of the 30 s GF to the 5 min speed (30 s speed/5 min speed) and 1 min GF to the 5 min speed was used to estimate the 1 min and 30 s speed from the 5 m speed. As an example, for $V_{5\,\min}=20$ kt, the 1 min GF is

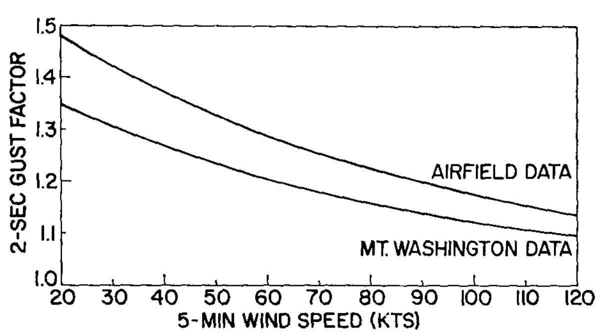

FIG. 3. Comparison of the mean 2 s GF to 5 min speed for Mt. Washington and the pooled airfield data. The curves are a least squares fit of the data to $GF=1+Ae^{-BV}$.

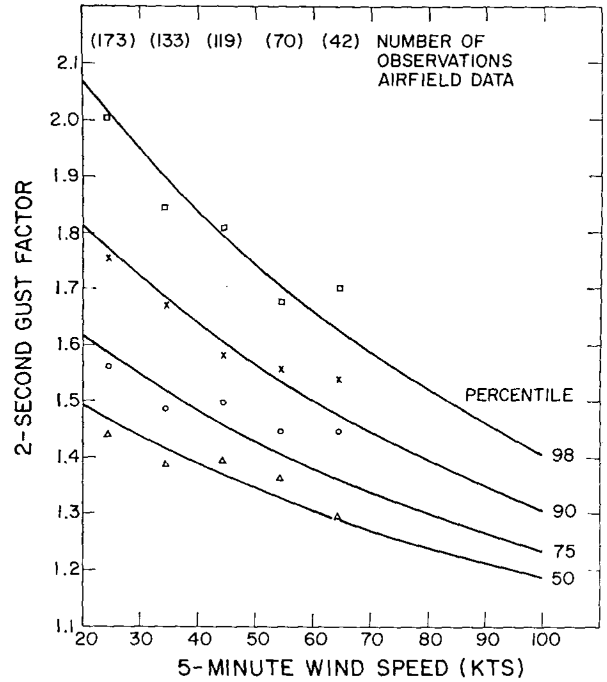

FIG. 4. Relationship between the 2 s GF and the 5 min wind speed at indicated percentiles for the airfield data. Data were fitted to $GF=1+Ae^{-BV}$ and weighted for the number of observations at each mid-class value.

1.108, which is multiplied by 20 kt to give $V_{1\,\min}=22.2$ kt. Table 2 gives values of $V_{1\,\min}$ and $V_{30\,s}$ for several values of $V_{5\,\min}$.

Eq. (1) was used to calculate the 50-, 75-, 90- and 98-percentile wind speed range in 5 min using $S=V_{5\,\min}$ and $G=$ the associated GF in Fig. 4. The range in 1 min

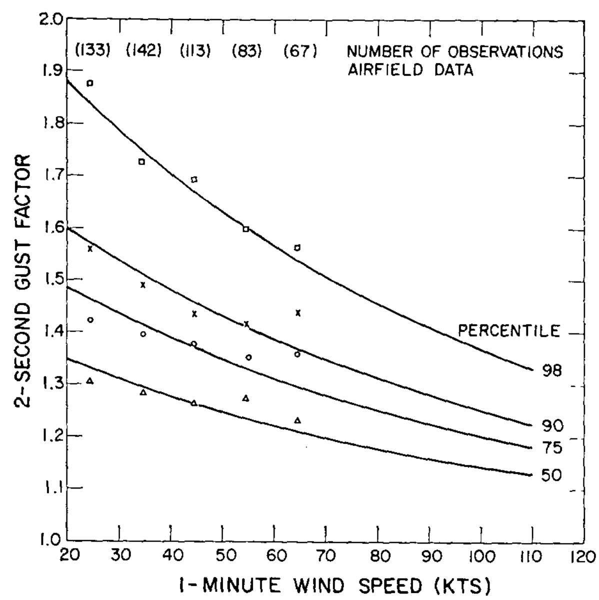

FIG. 5. As in Fig. 4 except for 1 min wind speed.

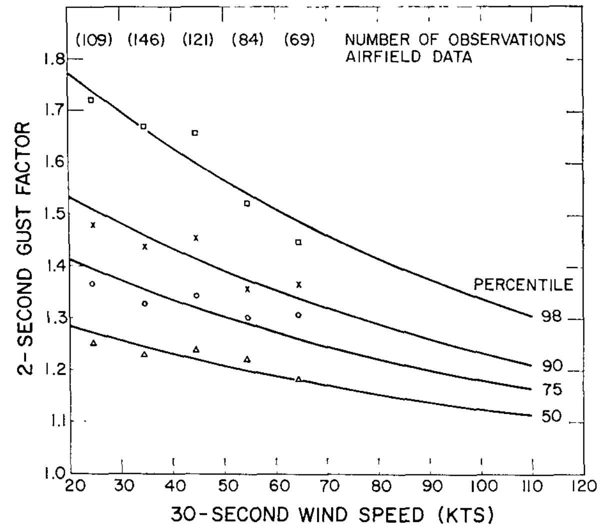

Fig. 6. As in Fig. 4 except for 30 s wind speed.

Table 2. Expected values of 1 min and 30 s speed corresponding to the 5 min speed estimated from Fig. 7.

$V_{5\,min}$	$V_{1\,min}$	$V_{30\,s}$
20	22.2	23.1
40	43.2	44.9
60	63.5	65.8
80	83.6	86.0
100	103.2	105.9

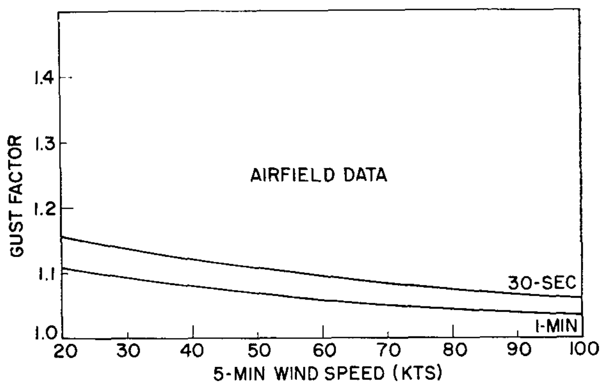

Fig. 7. Curves of the 30 s and 1 min GF to 5 min speed for the airfield data fitted to $GF=1+Ae^{-BV}$.

and 30 s was similarly calculated using Eq. (1) and Figs. 5 and 6. These values were used to draw nomographs of the 50-, 75-, 90- and 98-percentile wind speed range versus time interval and the 5 min speed (Figs. 8 through 11).

The lines were drawn to 3 points, for 300, 60 and 30 s determined by the data. A fourth point, representing zero wind speed range at 0.01 s (not shown on the

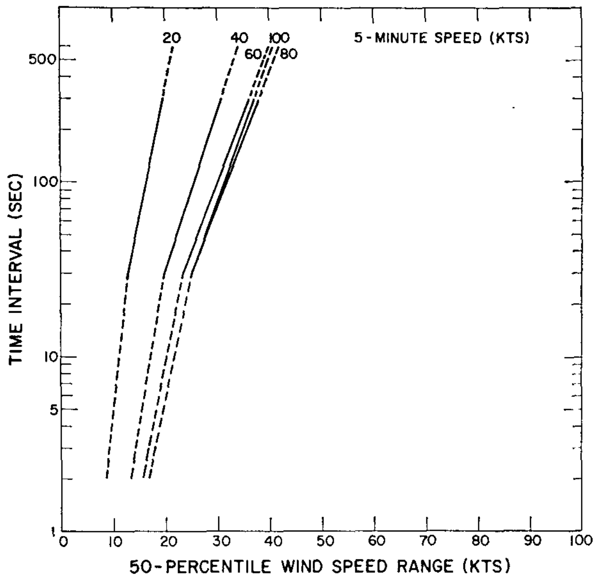

Fig. 8. Fifty percentile wind speed range versus time interval and 5 min speed.

nomogram) was used to extend the line down to 2 s (lower dashed lines). The upper dashed lines represent extrapolation of the 60 s to 300 s lines out to 600 s.

6. Results

The gust factor curves presented in this paper show that, in general, the gust factor decreases with increasing speed. This trend is apparent for both the Mt. Washington and airfield data.

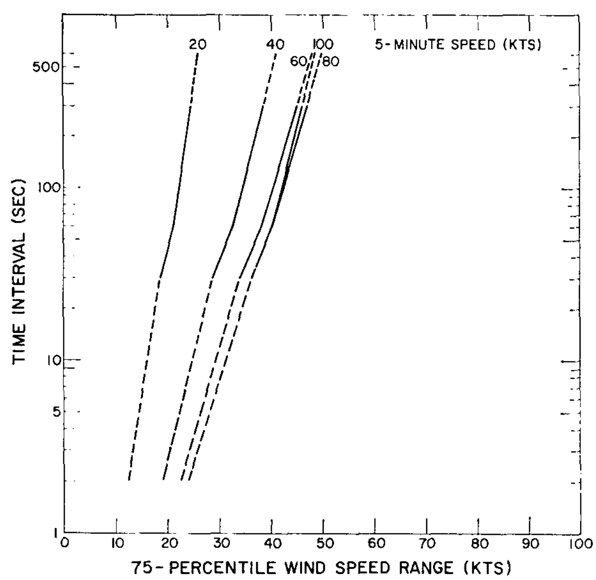

Fig. 9. Seventy-five percentile wind speed range versus time interval and 5 min speed.

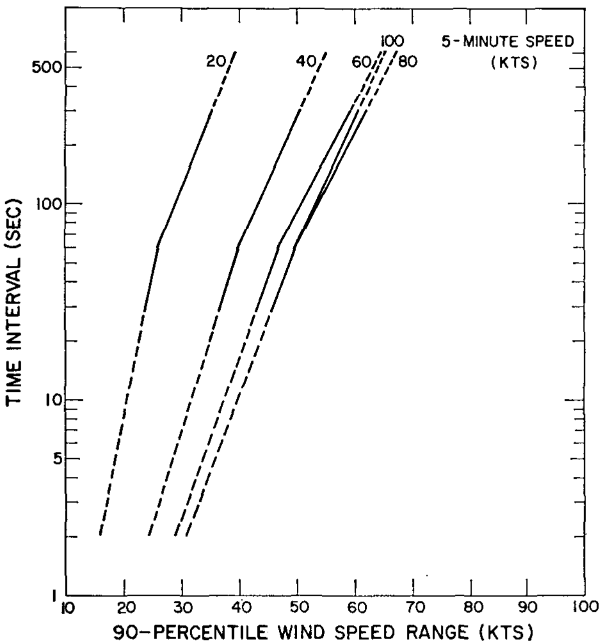

FIG. 10. Ninety percentile wind speed range versus time interval and 5 min speed.

The wind speed range increases with increasing mean speed and increasing time interval. The rate of increase, however, becomes smaller with increasing 5 min speed. There is even a slight decrease in range from 80 to 100 kt at the longer time intervals, as can be seen in Figs. 8–11.

Since rms differences for the Mt. Washington wind speed range data increase at the higher percentiles (Table 1), it is logical to assume that there is an associated decrease in accuracy at the higher percentile nomograms.

The results are considered applicable to most airport locations at the average height of the data used, 15 m (50 ft).

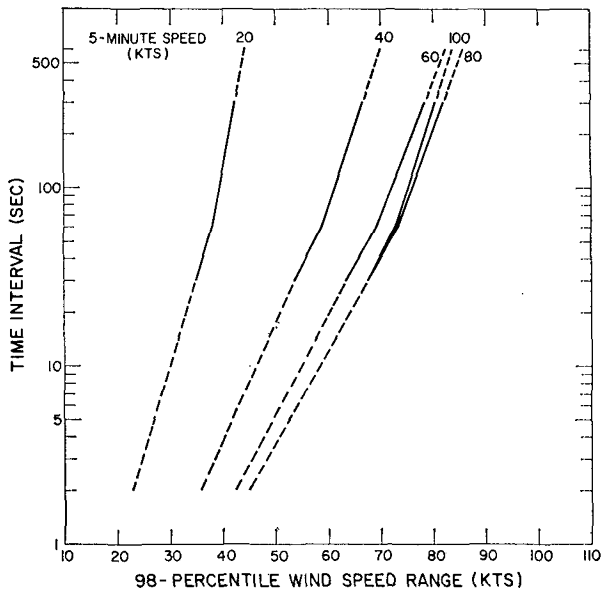

FIG. 11. Ninety-eight percentile wind speed range versus time interval and 5 min speed.

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