NASA TM - 1999 - 208544

Estimating the Effect of Sensor Spacing on Peak Wind Measurements at Launch Complex 39

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March 1999

National Aeronautics and
Space Administration

John F. Kennedy Space Center

KSC FORM 16-12 (REV. 6/95) PREVIOUS EDITIONS MAY BE USED

ABSTRACT

This paper presents results of an empirical study to estimate the measurement error in the peak wind speed at Shuttle Launch Complex 39 (LC-39) which results from the measurement being made by sensors 1300 feet away.

Quality controlled data taken at a height of 30 feet from an array of sensors at the Shuttle Landing Facility (SLF) were used to model differences of peak winds as a function of separation distance and time interval. The SLF data covered wind speeds from less than ten to more than 25 knots. Winds measured at the standard LC-39 site at the normal height of 60 feet were used to verify the applicability of the model to the LC-39 situation.

The error in the peak wind speed resulting from separation of the sensor from the target site obeys a power law as a function of separation distance and varies linearly with mean wind speed. At large separation distances, the error becomes a constant fraction of the mean wind speed as the separation function reaches an asymptotic value. The asymptotic average of the mean of the absolute difference in the peak wind speed between the two locations is about twelve percent of the mean wind speed. The distribution of the normalized absolute differences is half-Gaussian.

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Table of Contents

List of Figures

List of Tables

1. Introduction and Statement of the Problem

In the autumn of 1998, the Space Shuttle program conducted a review of its ground winds Launch Commit Criterion (LCC). This LCC prohibits launch if the peak wind measured at the 60 foot level of the LC-39 wind towers at camera sites 3 and 6 of the active pad (LC-39 A or LC-39B) exceed a specified threshold. The threshold is mission specific and depends on the wind direction, but is typically between 20 and 35 knots (10 and 18 m/s). The review included a thorough analysis of several sources of uncertainty or error in the measurement of the peak wind.

This paper presents results from an examination of one source of error in measuring the peak wind: spatial separation. The peak wind is desired for evaluating the LCC at the vehicle on the pad. The measuring sites are 1300 feet (400 m) away to avoid interference from the pad structures and destruction of the sensors during launch. The author was asked to develop a quantitative estimate of the distribution of peak wind speed differences as a function of site separation distance and mean wind speed assuming no other sources of error.

2. Summary of Related Previous Work

In order to complete the investigation before the launch of STS- 88, the primary analysis was restricted to quality controlled data which were immediately available. These data were collected in 1993 and 1994 for two previous studies. Both studies used arrays of portable wind towers deployed at the Shuttle Landing Facility. Winds were measured using cup anemometers and wind vanes at a height of 30 feet (9 m). Details of the instrumentation and experiments are presented in Merceret 1995a, 1995b.

The first study (Merceret, 1995a) examined the effect of sensor spacing on measurement of the *mean* wind speed and wind direction as a function of the separation distance and averaging time. Distances from 32 to 3200 feet (10 to 975 m) were used, and both crosswind and along-wind separations were employed. The results were presented as normalized structure functions which appeared to behave according to the inertial subrange 2/3 power law for separations less than about 400 feet (122 m). At separations larger than 400 feet, the structure functions appeared to reach an asymptotic value. No significant difference between along wind and crosswind separations was noticed. There was substantial scatter in the results. Some of the scatter may be due to environmental differences since the data were not stratified for stability because temperature profiles were not measured.

The second study (Merceret 1995b) examined the effects of averaging techniques on measured winds. It also examined the effect of nearby foliage on the measurements. Since the sensors at LC-39 and all sensors used in the current work were free and clear from foliage effects, no discussion of that portion of the previous study will be presented here.

Weather LCC are evaluated by the 45th Weather Squadron using five minute mean and peak winds from the Meteorological Interactive Data Display System (MIDDS). MIDDS performs a vector average on wind direction and wind speed reported every second. Three hundred one second values are averaged to get the five minute mean. In addition, the highest one second wind speed within the five minute period is stored as the peak wind. Merceret (1995b) presented the effects of vector versus scalar averaging along with the effects of varying the averaging period. The difference between the direction of the peak wind and the average wind direction was briefly discussed. The following extracts summarize the results for averaging effects on wind speed and direction:

> . . . over the range 3.5 - 15 Kt . . . the difference between the vector and scalar wind speed averages is of order 0.3 Kt. . . . The wind direction difference is within the error of the wind direction sensors and is unmeasurable. (Merceret, 1995b, Section 4.4.1.2)
>
> For winds acceptable to operations at the SLF, the effects of varying the averaging period from one to fifteen minutes are small. Except in the case of the passage of sea-breeze boundaries or fronts, even the effects of non-stationarity may be neglected for averaging periods in this range. (*Id.*, section 4.4.2)
>
> . . . the difference between the mean and peak wind directions appears to be of order one sigma theta, and thus is not generally significant since the RMS difference between the sensors and the runway is at least this large . . . (*Id.*, Section 4.4.3)

3. Data Sets Used for the Current Work

The data from the field programs discussed in Section 2 above had been archived on CD-ROM in 1995 because of their high quality and potential future utility. The availability of this quality controlled one-second data from logarithmically spaced arrays of wind towers made the current work possible. Quality control on the original data had included internal consistency checks, limit checks and manual examination any suspect data. Details are given in Merceret (1995a).

There were two logarithmic arrays used to collect the data used here. The first (December 1993) used a cross aligned with one arm parallel to the SLF and one arm perpendicular to it. It is shown in Figure 1. Five runs totaling more than 24 hours of one-second data were obtained from this configuration. The second (March 1994) was a linear array shown in Figure 2. Three runs totaling about 16 hours were obtained from this array. Detailed descriptions of each file are provided in Appendix A.

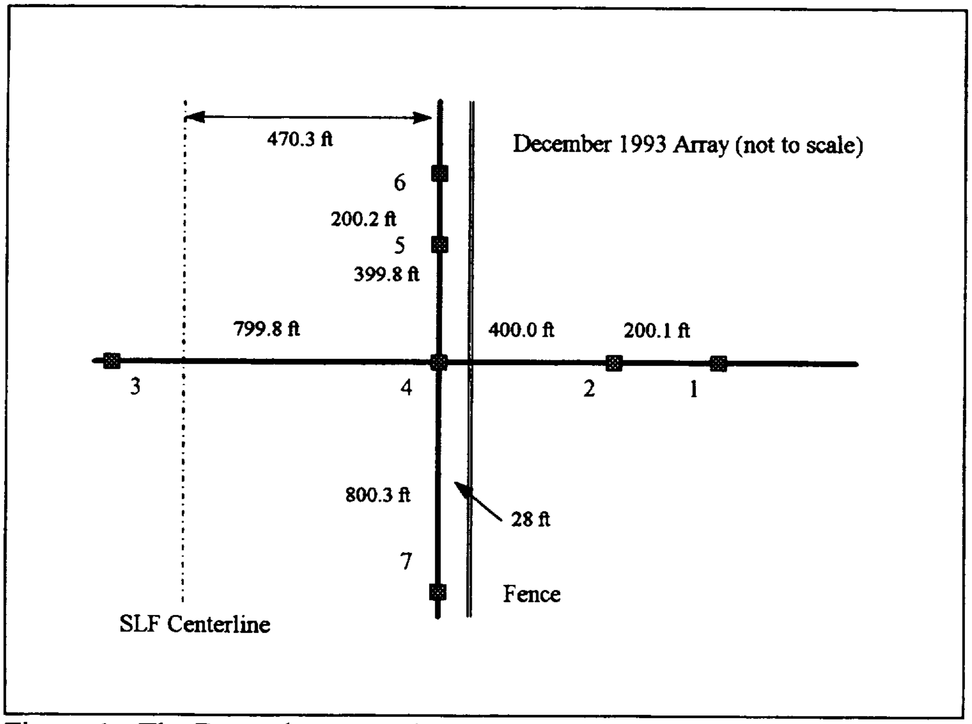

Figure 1. The December 1993 Array.

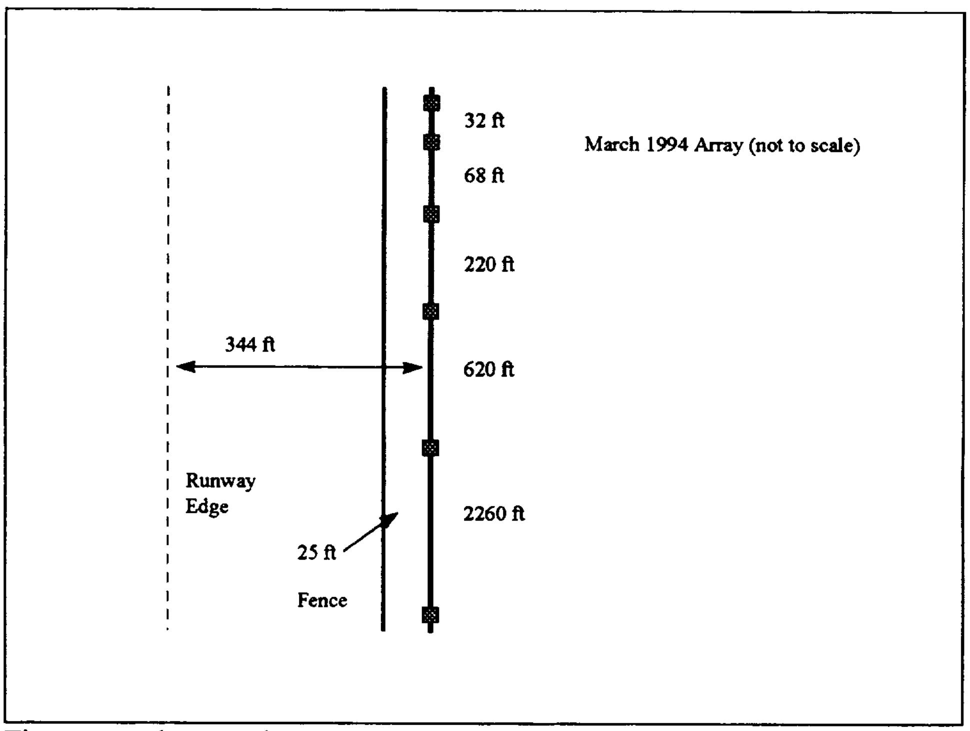

Figure 2. The March 1994 Array.

Cross wind, along wind, and skew separations were in these data sets, but based on the results described above, they were not separately analyzed. The separation distances involved are orders of magnitude larger than the correlation lengths of the fine structure responsible for the production of individual peaks. Due to turbulent momentum transport and vortex stretching the peaks should not persist long enough to survive advection between sites for along wind separations, and the distinction between streamwise and crosswind separations is lost.

Temperature profiles were not measured, so neither the previous studies nor the current one stratify the data by stability. The presence of precipitation was also not measured. In general, data were taken on days where steady, light to moderate winds were forecast. Qualitatively, these environments were non-precipitating with near-neutral stability.

There was concern about whether an analysis of data taken at the SLF at 30 feet would be applicable to LC-39 data taken at 60 feet. There was additional concern that the SLF data were all taken at mean wind speeds below 15 Kt (8 m/s), whereas the ground wind LCC (peak) thresholds are nearly twice as large. To assuage these concerns, two additional data sets were obtained and quality controlled.

Nine hours of LC-39 sixty-foot wind data from STS-52 sampled at 60/second were obtained and reprocessed to one sample per second by averaging to mimic the response of the anemometers and data systems currently used (which are the same as used for the SLF data). There were data from all four camera sites (Pad A site 3 is denoted by A3. Similarly for A6, B3 and B6. See figure 3.) in this set. The four towers fell along a single straight line aligned about 65 degrees to the mean wind direction for the period. Spacings between various combinations of these four towers ranged from 2600 to 11400 feet (790 to 3480 m). Five minute mean wind speeds ranged from about ten knots to about 20 knots (5 to 10 m/s) with an overall mean just less than 15 knots.

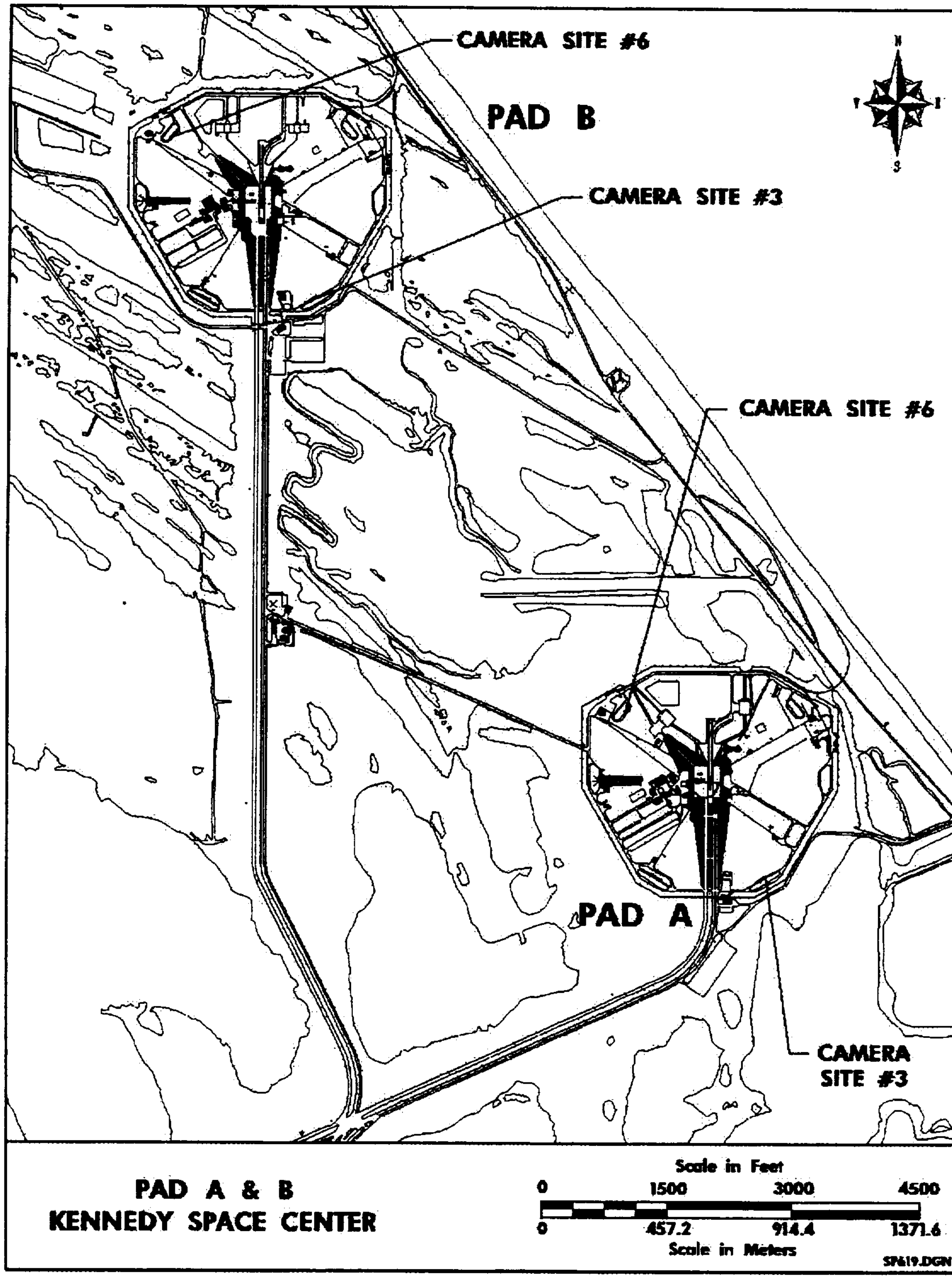

Figure 3. The LC-39 camera sites at which the wind sensors are located.

On 5 November 1998, Hurricane Mitch passed through the Florida Keys and brought some moderate winds to Kennedy Space Center. The portable wind towers used for the SLF experiment had been deployed for an experiment (DTO-805, landing cross winds) during the launch of STS-95 and were in place along the SLF awaiting the STS-95 landing. Arrangements were made to collect data as Mitch passed in order to examine a higher wind speed case. Six hours of one second data with five-minute means ranging from less than 10 to more than 25 Kt was collected. These data were quality controlled by the same process used for the previous studies. Unfortunately, this rigorous QC removed several towers from consideration and only two of the six towers covering one useful spacing, 2500 feet (760 m), remained available. The mean wind direction was within 20 degrees of the direction of the spacing between the towers.

4. Methodology

For each data set, five-minute variables were generated for each wind tower. These variables included the mean and standard deviation of the wind speed, the mean and standard deviation of the wind direction, and the peak wind speed. Scalar averages were used to simplify writing and testing the software. The use of scalar rather than vector averages should not significantly affect the utility of the results (see section 2 above).

Statistics were generated on the five-minute variables. These statistics included the mean, standard deviation, minimum and maximum for windspeed, wind direction and the peak wind at each tower. In addition, the same statistics were computed for the absolute value of the differences in the peak winds between each pair of towers. Again, scalar averages were used. The probability distribution for the peak wind for each tower was generated.

Because of the wide range of mean wind speeds in the data set, and the relatively small sample size, the peak wind differences were normalized by the mean wind speeds. This permitted the data from the various wind speeds to be aggregated into a single data set of larger size. The normalized peak wind differences from the SFL experiment were plotted as a function of tower spacing and least squares fits to that function were generated.

A tentative model for estimating normalized peak wind differences as a function of separation distance was prepared and used to "predict" the results from a similar analysis of the Mitch and STS-52 data. These data were then processed and compared with the model's prediction.

Several quick experiments were conducted in which low-pass filters were applied to the data before generating the five-minute data, but these experiments did not produce any significant difference in the outcome. Most of the work with filtering was based on a 23 second autoregressive moving average (ARMA) filter. This filter is of the form

$$Y(k) = \alpha\, Y(k-1) + (1-\alpha)\, X(k)$$

where Y(k) is the kth filtered datum and X(k) is the kth unfiltered datum. This acts as a low-pass filter with an e-folding time of N points where

$N = -1/\ln(\alpha)$.

The half-power spectral response cutoff $f_{1/2}$ is given by

$$f_{1/2} = 1/2\pi \cos^{-1} \{2 - (1+\alpha^2)/2\alpha\}.$$

More details on this filter may be found in Merceret (1983) which was based on information from Bendat and Piersol (1971) and Jenkins and Watts (1969). For this analysis $\alpha = 0.9565$, $N = 22.5$ and $f_{1/2} = 0.007$ Hz corresponding to a period of 141 s.

The other filter tested was a 23 second uniformly weighted moving average ("boxcar") with $f_{1/2} = 0.0193$ Hz corresponding to a period of 52 s.

5. Results

5.1 Probability Distribution of the Peak Wind

The peak wind speeds could be fit to a Gaussian distribution with an r^2 value exceeding 0.9 and often 0.99. An example is shown in Figure 4 for which the sample size, N, was 48. (In this and subsequent figures, the Z-score is used. Z is defined as the number of standard deviations from the mean for the variable of interest.) There were exceptions; an example is presented in Figure 5 (N=47). Smoothing the one second data with a 23 second autoregressive moving average (ARMA) filter did not change the shape of the distribution (see Figure 6, N=48), but it reduced both the mean and the standard deviation to 83 percent of the unfiltered value. The standard deviations of the peak wind speeds were not correlated with their means.

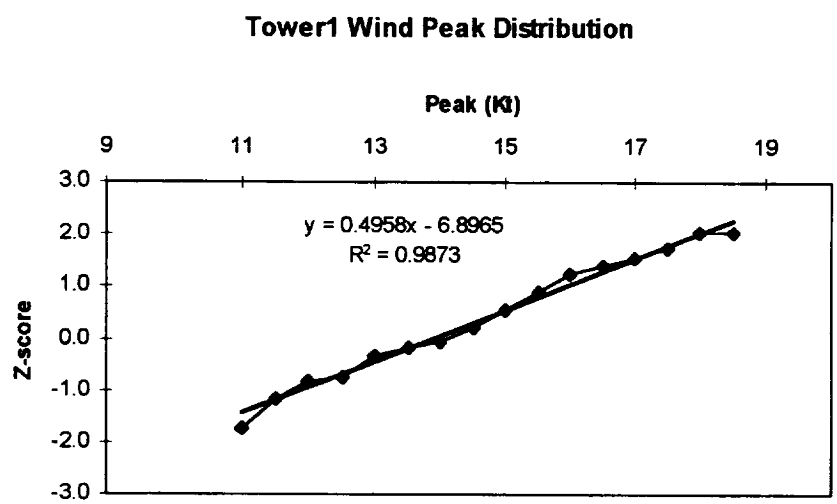

Figure 4. An example of a nearly Gaussian distribution of peak wind speed.

Tower7 Wind Peak Distribution

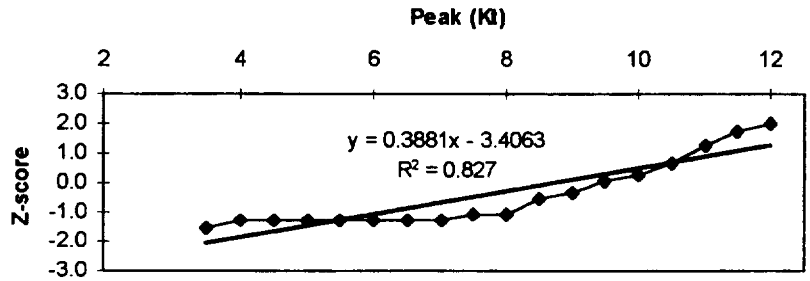

Figure 5. An example of a non-Gaussian peak wind speed distribution

Tower1 Wind Peak Distribution

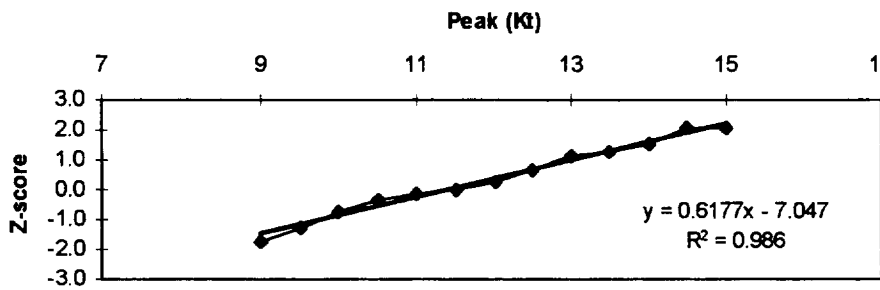

Figure 6. Results of applying a 23 second ARMA filter to the data for Figure 4.

As expected, the peak values at different locations are correlated, but not perfectly. Towers separated by between 900 and 1000 feet (275 - 300 m) showed r^2 values near one-half for the unfiltered data. An example is given in Figure 7 (N=48) for which $r^2 = 0.51$ at a separation of 940 feet (287m). The ARMA23 filtered data for the same case had $r^2 = 0.61$.

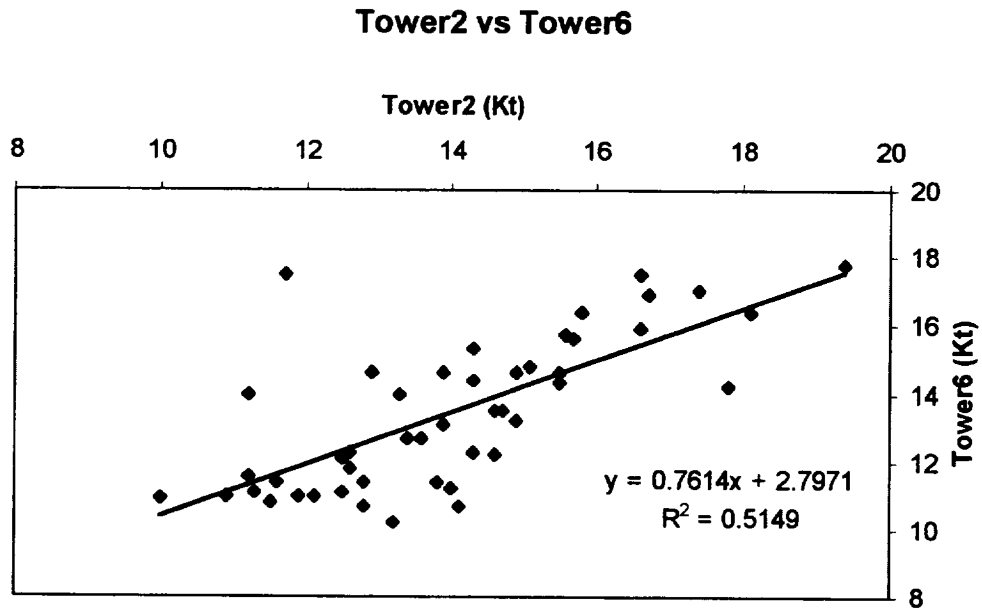

Figure 7. Correlation between towers separated by 940 feet (287 m) for unfiltered data.

5.2 Normalized Absolute Peak Wind Differences vs Spacing

The means of the speed-normalized absolute values of the wind differences for the original SLF data are presented as a function of separation distance in Figure 8 (N=134) along with a least-squares regression line to a power-law. The scatter is large and is reflected in the low value of r^2 which accounts for less than half of the variance. If the region of analysis is restricted to separations less than 400 feet, the results are slightly better as shown in Figure 9 (N=134). A power law was selected for two reasons: first, atmospheric structure functions (see Appendix C) obey a power law in the boundary layer (Stull, 1988; Merceret, 1995a) and this analysis seemed analogous to a structure function analysis; second, other functional forms including polynomial and logarithmic were tried and did not work as well.

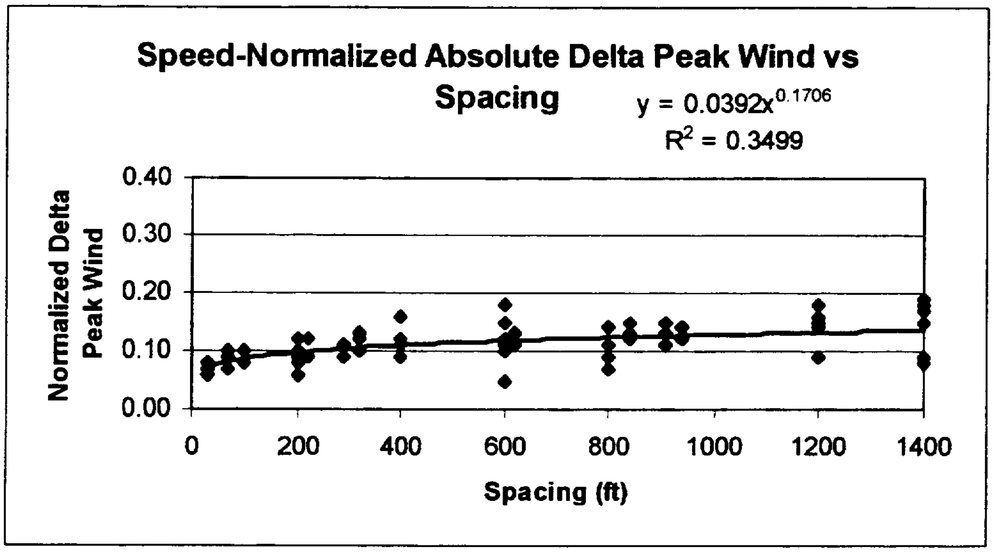

Figure 8. Speed-normalized absolute values of the wind differences as a function of separation distance

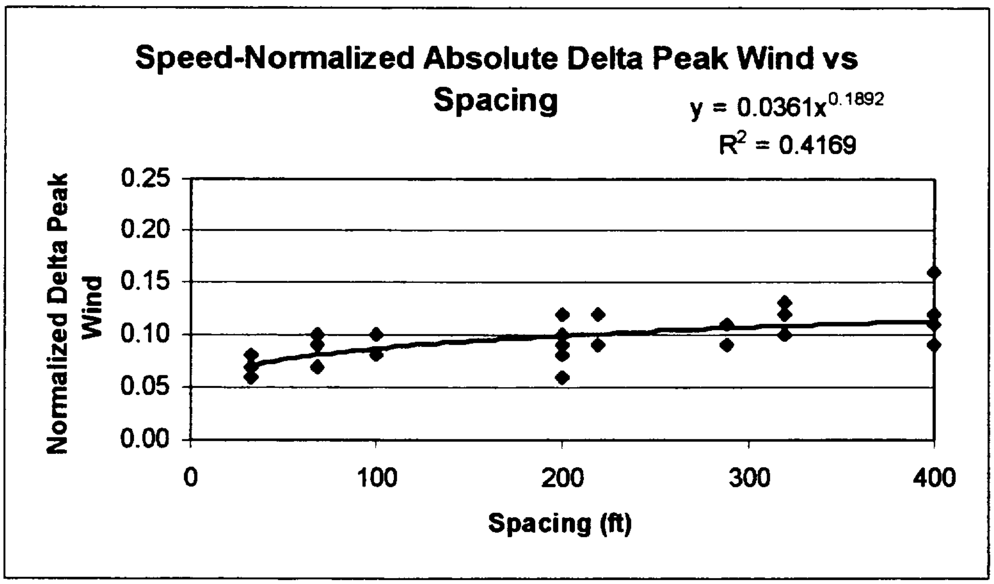

Figure 9. Speed-normalized absolute values of the wind differences as a function of separation distance over a restricted range

Because of the large scatter in the data, an examination of the probability distribution was undertaken. The standard deviations of the normalized absolute differences were compared with their means and a strong linear relationship was found. Figure 10 (N=156) shows the results for the unfiltered data. Figure 11 (N=156) shows the results for the filtered data. In both cases the small offset and near unity slope suggested the possibility that the absolute values of the differences might be exponentially distributed since a defining characteristic of that one-parameter distribution is that the standard deviation and the mean are equal (Hahn and Shapiro, 1967).

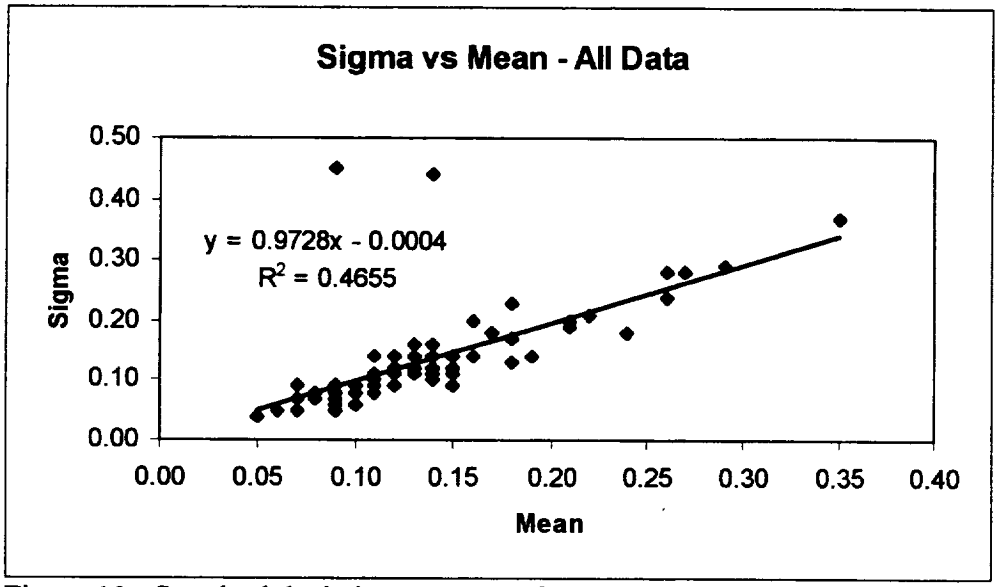

Figure 10. Standard deviation vs mean of raw normalized peak wind differences. The two outliers both involve tower 5 in file 3560000. Without them the regression is 1.0254x - 0.0158 with $r^2 = 0.8752$.

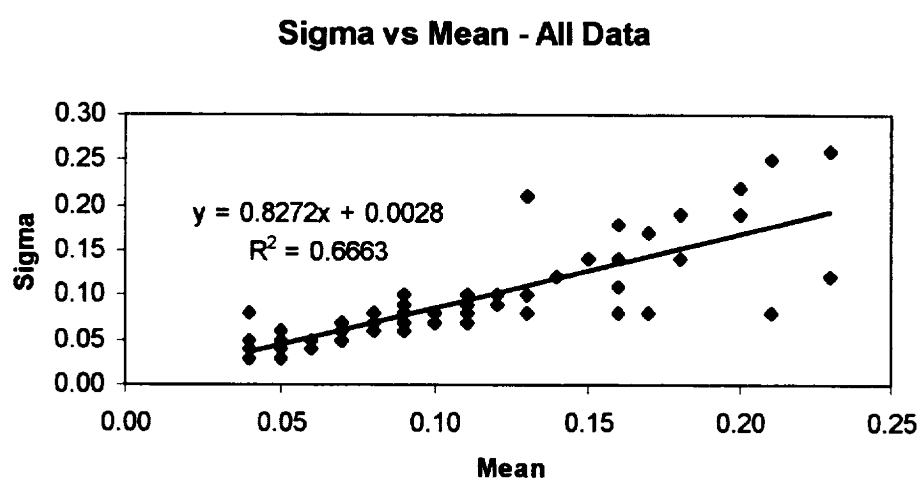

Figure 11. Standard deviation vs mean of ARMA filtered normalized peak wind differences

Figure 12 (N=18) shows the application of the exponential distribution to one set of data. Figure 13 shows the fit of the same set to a Gaussian model. Both fits account for more than 90% of the variance although the exponential fit is clearly superior in this case. Since the exponential and Gaussian distributions (with $\sigma = \mu$) do not differ by more than 30 percent over most of the positive domain (see Appendix B), they are not easy to distinguish in small samples over limited intervals.

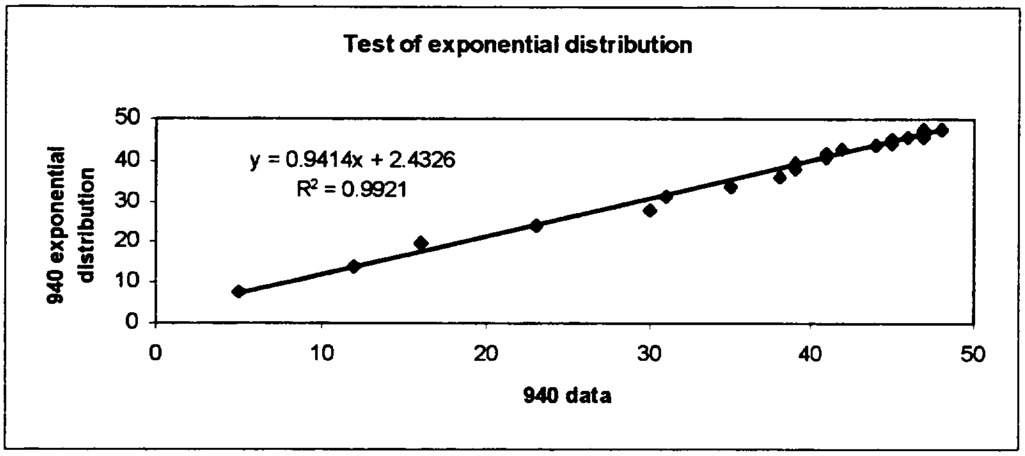

Figure 12. Exponential Distribution Model for normalized absolute peak wind differences

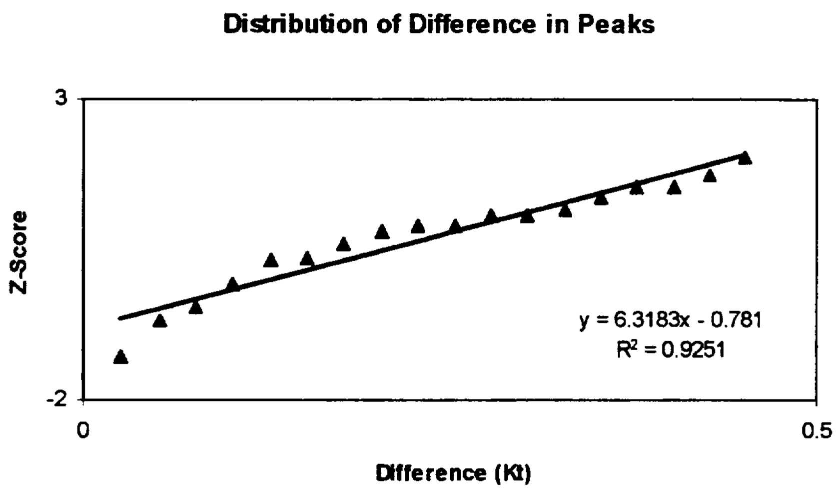

Figure 13. Gaussian Distribution Model for normalized absolute peak wind differences

If the differences in peak values are normally distributed about a zero mean, then their absolute values will be governed by the "half-Gaussian" distribution (Hahn and Shapiro, 1967). This distribution will also fit to a Gaussian if only positive values of the independent variable are considered. Since there is reason to believe the peak differences are normally distributed (see sections 5.1 above and 5.3 below), the half-Gaussian is a more logical candidate for the distribution of their absolute values than the exponential.

If the mean is not zero, absolute values of a Gaussian distribution will have a "folded normal distribution" (Leone *et al.*, 1961) which is considerable more complex than the half-Gaussian. The mean values of the peak wind differences in this study were usually small, although not always. Considering the small sample sizes and large variances, the extra complexity of using the folded normal distribution was not warranted.

Additional information on the distributions may be obtained by examining the second, third and fourth moments of the data. Table 1 shows the moments of Gaussian, exponential and half-Gaussian distributions as a function of their defining parameters. The exponential and half-Gaussian are single parameter distributions whereas the Gaussian is a two-parameter distribution.

Distribution and parameters	Mean	Standard deviation	Skewness	Kurtosis	Ratio of std. dev. to the mean
Gaussian μ,σ	μ	σ	0	3	(arbitrary)
Half-Gaussian σ	0.798σ	0.602σ	0.995	3.869	0.754
Exponential λ	$1/\lambda$	$1/\lambda$	2.0	9.0	1.0

Table 1. Moment properties of several distributions (Hahn and Shapiro, 1967)

Table 2 shows the empirical results from both the unfiltered and the ARMA23 filtered normalized absolute differences. Several extreme values for skewness (exceeding 10) and kurtosis (exceeding 70) appeared in very light winds due to the normalization procedure. Since the higher moments are quite sensitive to rare "outlier" events such as a case where the normalizing mean wind speed is close to zero, the skewness and kurtosis data in this table were restricted to runs having a mean wind speed of 10 Kt or more.

Data set	Mean skewness	Mean kurtosis	Slope of least squares fit of std. dev. vs mean
Unfiltered	1.32	5.06	0.97
ARMA23	1.27	5.48	0.83

Table 2. Moment properties of the data sets.

Comparison of Table 1 with Table 2 shows that the moments of the data behave in a manner intermediate between an exponential distribution and a half-Gaussian (HG) one. The standard deviation ratio for the unfiltered data looks purely exponential but the ratio for the filtered data is closer to the HG. The third and fourth moments are closer to the HG in both cases. Examination of the Mitch and STS-52 data (see section 5.3 below) suggested that those data fit the HG model substantially better than the exponential one.

Based on this analysis, the scatter in the data is a natural result of the process of taking the absolute value of the differences of Gaussian variables resulting in a half-Gaussian distribution. The power law fit described at the beginning of this section can be used to estimate the mean value of the normalized absolute difference as a function of separation distance and the HG distribution can be used to estimate the error to be expected in applying the model.

Table 3 presents the model based on the data from the SLF arrays.

Quantity	ARMA23 Filtered Data	Unfiltered Data
Scaling coefficient a	0.017	0.035
Exponent b	0.277	0.200
Spacing x (ft)	y (see caption)	y (see caption)
1	0.02	0.04
2	0.02	0.04
5	0.03	0.05
10	0.03	0.06
20	0.04	0.06
32	0.04	0.07
68	0.05	0.08
100	0.06	0.09
200	0.07	0.10
400	0.09	0.12
600	0.10	0.13
800	0.11	0.13
1200	0.12	0.14
1300	0.12	0.15
1400	0.13	0.15
2500	0.15	0.17

Table 3. The power law model $y = ax^b$ where y is the ratio of the mean of the absolute values of the peak wind differences to the mean wind speed as a function of the separation distance, x (ft).

In reality, we would expect the ratio to become asymptotic to some value as the spacing becomes sufficiently large that all scales contributing significantly to the creation of the peak values become uncorrelated. This distance may depend on specific environmental conditions. Structure functions become asymptotic in this manner (Merceret, 1995a). Based on the data and also on the gradients in the values in Table 3, the 1300 foot spacing between the weather sensors and the pads at Launch Complex 39 is in the asymptotic region with less than 20 percent variation in the ratio from half that spacing to twice that spacing. A value of 0.12 for the filtered data is appropriate.

5.3 Comparison with Mitch and STS-52

By the time that the data from Hurricane Mitch and STS-52 had become available, much of the analysis reported above had been completed. Those results suggested that the distribution of the normalized peak differences as well as that of their absolute values should be examined. This was done for both data sets. The distribution of the normalized peak differences for both data sets fit the Gaussian model extremely well as shown in Table 4 for the ARMA23 data. Due to time limitations, unfiltered data was not processed for Mitch. The r^2 values for the unfiltered STS-52 data are almost identical to the filtered values.

Tower Pair	1 - 2	A3 - A6	B3 - B6	A3 - B3	A3 - B6	A6 - B3	A6 - B6
Spacing (ft)	2500	2600	2600	8800	11400	6200	8800
r^2	0.97	0.98	1.00	1.00	1.00	0.98	0.99

Table 4. Goodness of fit to the Gaussian distribution for Mitch (towers 1 and 2) and STS-52 (towers A3, A6, B3 and B6) normalized peak wind differences when absolute value is not taken.

For the Mitch data at the only available spacing (2500 ft, 760m), the ratio of the mean of the normalized absolute peak differences to the mean wind speed was 0.12, in excellent agreement with the model and the asymptotic assumption presented above. Moreover, the ratio of the standard deviation of these normalized absolute peak differences to their mean was 0.75, in essentially exact agreement with the half-Gaussian distribution. This implies that the model built at the lower wind speeds remains valid at least up to the speeds encountered in Mitch and verifies the model on an independent data set.

All of the results reported to this point are based on measurements taken at the SLF at a height of 30 ft. The STS-52 data test these results against measurements taken at LC-39 at 60 ft. The ARMA filtered results are displayed in Table 5.

Tower Pair	A3 - A6	B3 - B6	A3 - B3	A3 - B6	A6 - B3	A6 - B6	Overall Average
Mean	0.10	0.13	0.16	0.10	0.13	0.10	0.12
Std. Dev.	0.06	0.09	0.09	0.07	0.09	0.07	0.08
Ratio	0.62	0.66	0.52	0.71	0.68	0.71	0.65

Table 5. Means and standard deviations of the normalized absolute peak wind differences for STS-52. The ratio of the standard deviation to the mean is also included.

Once again, the results are consistent with the model and the asymptotic assumption. For these data, the ratio of the standard deviation to the mean falls somewhat below that of the HG distribution and thus very far below that of the exponential distribution. The unfiltered results are similar to the filtered ones except that the overall average mean value is 0.13 rather than 0.12.

6. Summary and Conclusions

An analysis of the peak values over five minute intervals of the differences of one-second wind speeds measured at separated sites has been conducted. The analysis was based on quality controlled data taken at 30 ft height at the Shuttle Landing Facility under a limited range of wind speeds. The differences were normalized by the mean wind speeds for each interval to allow intercomparison and generalization from measurements made over a range of wind conditions. Probability distributions of the raw and absolute values of these normalized differences were generated. The differences are Gaussian and their absolute values are half-Gaussian. The mean values of the normalized differences were fit to a power law as a function of the separation distance. This was done for both unfiltered and low-pass filtered (ARMA23) data.

A model was developed for estimating the peak wind differences as a function of separation using the power law fit and an assumption that the mean of the normalized peak differences reaches an asymptote at distances larger than about 1000 ft. This model was tested against 30 foot SLF data obtained during Hurricane Mitch and 60 foot LC-39 data obtained during the launch countdown for STS-52.

The Mitch data and the STS-52 data were consistent with both the assumptions and the predictions of the model. For the 1300 foot separation between the camera sites and the pad at LC-39, the mean difference in the peak wind measured at the camera site and the peak at the pad in a five minute interval is about 12 percent of the mean wind speed measured at the camera site for ARMA23 filtered data. For the unfiltered data the value is slightly higher.

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8. Acknowledgments

The author appreciates reviews of this paper and suggestions for its improvement by Mr. William Roeder of the 45th Weather Squadron, USAF, Cape Canaveral Air Station and Dr. Stanley Adelfang of Computer Sciences Corporation at Marshall Space Flight Center.

9. Appendices

Appendix A. Description of Files from SLF Logarithmically Spaced Arrays

File Names	Date	Array Type	# Records	# 5 minute sections	Good Towers ID#	Mean Wind (Kt)
F0731552	94/03/13	Linear	14436	48	1-6	10
F0751604	94/03/15	Linear	14408	48	1-6	10
F0841222	94/03/24	Linear	29230	97	1-6	7
F3511457	93/12/17	Cross	14488	48	1-4,7	10
F3541402	93/12/20	Cross	14369	47	1,2,4-7	5
F3551756	93/12/21	Cross	21789	72	1-7	12
F3560000	93/12/22	Cross	22672	75	1-7	4
F3561555	93/12/22	Cross	14391	47	1-7	4

Spacing	Day 073	075	084	351	354	355	356
32 ft	5 - 6	5 - 6	5 - 6				
68	4 - 5	4 - 5	4 - 5				
100	4 - 6	4 - 6	4 - 6				
200				1 - 2	1 - 2, 5 - 6	1 - 2, 5 - 6	1 - 2, 5 - 6
220	3 - 4	3 - 4	3 - 4				
288	3 - 5	3 - 5	3 - 5				
320	3 - 6	3 - 6	3 - 6				
400				2 - 4	2 - 4	2 - 4	2 - 4
600				1 - 4	1 - 4, 6 - 4	1 - 4, 6 - 4	1 - 4, 6 - 4
620	2 - 3	2 - 3	2 - 3				
800				4 - 3, 4 - 7	4 - 7	4 - 3, 4 - 7	4 - 3, 4 - 7
840	2 - 4	2 - 4	2 - 4				
908	2 - 5	2 - 5	2 - 5				
940	2 - 6	2 - 6	2 - 6				
1200				2 - 3	5 - 7	2 - 3, 5 - 7	2 - 3, 5 - 7
1400				1 - 3	6 - 7	1 - 3, 6 - 7	1 - 3, 6 - 7
2260	1 - 2	1 - 2	1 - 2				
2880	1 - 3	1 - 3	1 - 3				
3100	1 - 4	1 - 4	1 - 4				
3168	1 - 5	1 - 5	1 - 5				
3200	1 - 6	1 - 6	1 - 6				
Mean Wind	10	10	7	10	5	12	4
# 5 min sets	48	48	97	48	47	72	75,47

The file name format is FDDDHHMM where DDD is the Julian day and HHMM is hours and minutes (UTC) of the starting time for the data in the file.

Appendix B. Gaussian and Exponential Distributions Compared

x	Exponential	Gaussian	E/G Ratio
0.1	0.095	0.184	0.517
0.15	0.139	0.198	0.705
0.2	0.181	0.212	0.856
0.25	0.221	0.227	0.976
0.3	0.259	0.242	1.071
0.4	0.330	0.274	1.202
0.5	0.393	0.309	1.275
0.6	0.451	0.345	1.309
0.7	0.503	0.382	1.318
0.8	0.551	0.421	1.309
0.9	0.593	0.460	1.290
1	0.632	0.500	1.264
1.2	0.699	0.579	1.206
1.5	0.777	0.691	1.124
2	0.865	0.841	1.028
3	0.950	0.977	0.972
5	0.993	1.000	0.993
10 or more	1.000	1.000	1.000

This table presents the exponential and Gaussian cumulative probability distributions as functions of the normalized variate x where the parameters of both distributions have been selected to yield a mean and standard deviation of 1.0. The ratio of the distributions is also presented.