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ABSTRACT

This document presents results of a field study of the effect of sheltering of wind sensors by nearby foliage on the validity of wind measurements at the Space Shuttle Landing Facility (SLF). Standard measurements are made at one second intervals from 30-foot (9.1-m) towers located 500 feet (152 m) from the SLF centerline. The centerline winds are not exactly the same as those measured by the towers. A companion study, Merceret (1995), quantifies the differences as a function of statistics of the observed winds and distance between the measurements and points of interest. This work examines the effect of nearby foliage on the accuracy of the measurements made by any one sensor, and the effects of averaging on interpretation of the measurements.

The field program used logarithmically spaced portable wind towers to measure wind speed and direction over a range of conditions as a function of distance from the obstructing foliage. Appropriate statistics were computed. The results suggest that accurate measurements require foliage be cut back to OFCM standards.

Analysis of averaging techniques showed that there is no significant difference between vector and scalar averages. Longer averaging periods reduce measurement error but do not otherwise change the measurement in reasonably steady flow regimes. In rapidly changing conditions, shorter averaging periods may be required to capture trends.

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1. Introduction

This report examines the effect of wind sensor sheltering by nearby foliage on the accuracy of wind measurements at the Space Shuttle Landing Facility (SLF) at the John F. Kennedy Space Center (KSC), Florida. Additionally, it also examines the effects of various averaging methods and periods on the interpretation of the data.

This introduction states the questions to be answered, explains the need to answer them, and describes the conceptual design of the experiment. The following sections describe the instrumentation, the data processing, the specifics of the field experiments, and the results.

English units are used throughout because they are standard for airfield measurements, and all of the runway dimensions, sensor spacings, and data systems are based on English units. Metric units follow in parentheses the first time a measurement appears in a section.

1.1 Statement of the Question

The first question this investigation answers is HOW FAR FROM NEARBY TREES AND SHRUBBERY DOES A WIND SENSOR HAVE TO BE IN ORDER TO MEASURE THE WIND SPEED AND DIRECTION WITHIN SPECIFIED ACCURACY?

The second question which the work answers is WHAT ARE THE EFFECTS OF VARIOUS AVERAGING TECHNIQUES AND PERIODS ON THE ACCURACY OF MEASUREMENT OF WIND SPEED AND DIRECTION?

1.2 Operational Need and Opportunity

1.2.1 SLF Standard Meteorological Wind Tower Geometry

The Shuttle Landing Facility, shown in Figure 1, is a 15,000 foot (4573 m) long concrete runway which is 300 feet (91.5 m) wide. The points of interest for wind measurements are along the runway centerline. Winds are measured from three towers at the standard airport height of 30 feet (9.2 m) by cup anemometers and vanes. To avoid hazards to aircraft operations, the wind towers are located 500 feet (152 m) from the centerline on the east side. One is located near the center of the 15,000 foot length with the other two between six and seven thousand feet (about 2 km) north and south of the center respectively.

Of the three standard SLF wind tower sites, the center site is the best exposed. It meets the Office of the Federal Coordinator for Meteorology (OFCM) standards discussed below. Except for a few trailers 200 feet (60 m) or more away, there is nothing except grass and scrub brush shorter than three feet (1 m) within 1000 feet (300 m) of the sensor.

The exposure of the south site is similar to that of the center site except that trees intrude into the 1000-ft radius to the north and southeast. The closest trees are at least 600 feet (200 m) from the sensor and are no taller than about 20 feet (6 m).

The north site was selected for the field portion of this study because the standard sensor is located within 90 feet (27 m) of a stand of trees ranging from ten to nearly 30 feet (3-10 m) tall. (See Figure 5, page 13). These trees occupy most of the eastern half of the 1000 foot circle centered on the sensor and provide a "reference obstruction" for the array of portable towers. Internal memoranda by Maier (1992) at CSR and Tongue (1993) at JSC/SMG suggested serious sheltering effects on this sensor for certain wind directions.

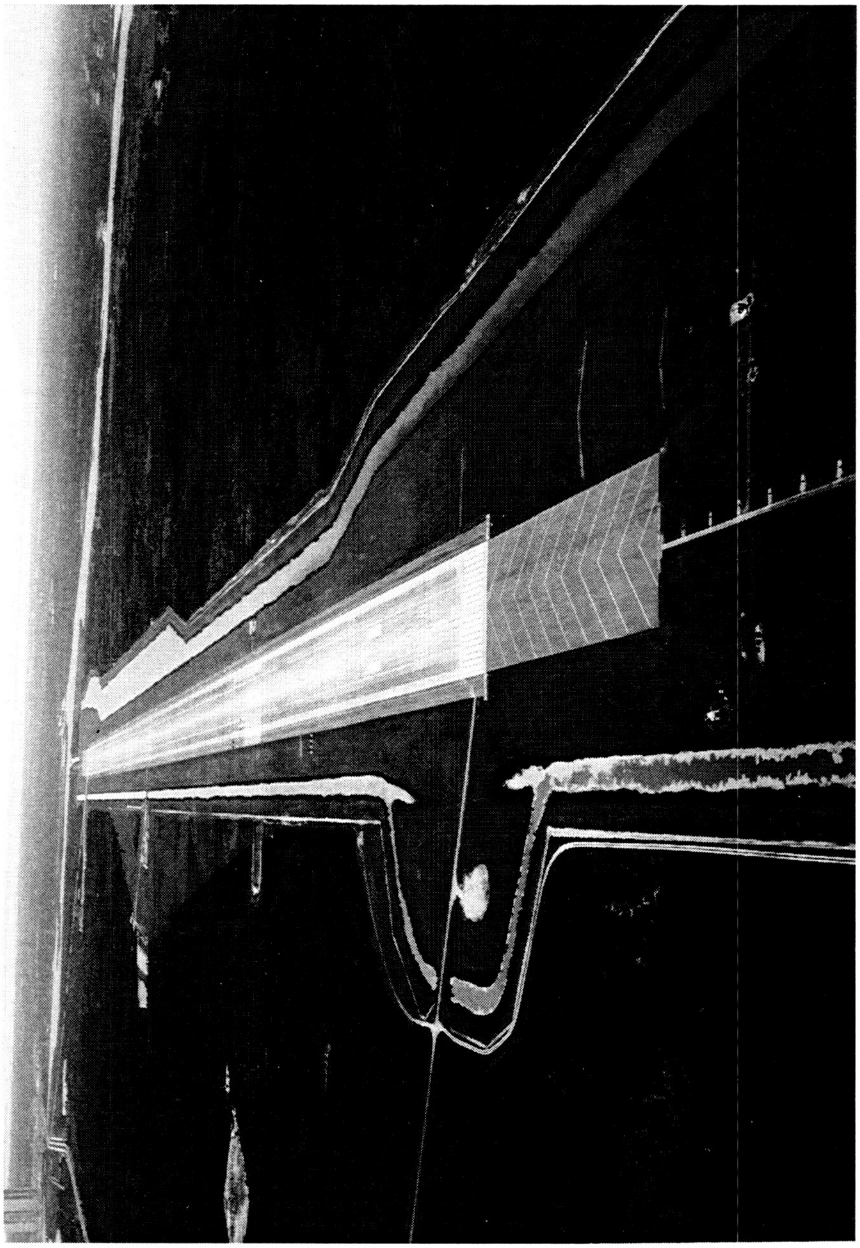

Figure 1. The Shuttle Landing Facility (SLF).

The OFCM has established standards for the siting of wind sensors at airports (Federal Coordinator for Meteorological Services and Supporting Research (1994), section 2.5). These standards provide that a sensor should be:

"(a) ... at least 15 feet (5 meters) above the height of any obstruction (e.g., vegetation ...

(b) ... at least 10 feet (3 meters) higher than the height of any obstruction outside the 500 foot (150 meter) radius, but within a 1000-foot (300-meter) radius of the wind sensor."

An object is considered to be an obstruction if it subtends a lateral angle of ten degrees or more as viewed from the sensor. Since the tangent of ten degrees is 0.176, the rule of thumb is that an object is an obstruction unless it is at least five times further away from the sensor than it is wide.

Since these standards are generally applicable to all airports regulated by the Federal Aviation Administration, they are frequently called the "FAA Standards", but I will refer to them as the OFCM Standards.

1.2.2 Landing and Return to Launch Site (RTLS) Flight Rules

Space Shuttle landing approval will not be given unless certain weather criteria are met. In addition to criteria related to lightning, precipitation, visibility and cloud cover, there are the following constraints on surface winds (NASA Flight Rules (1995):

Surface Wind Turbulence Limits (Knots)
(Extract from Table 2-6-II) (Must not exceed indicated value)

	CROSS PEAK	HEAD PEAK	TAIL AVG	TAIL PEAK	GUST
DAY (all landings)	15	25	10	15	10
NIGHT					
RTLS	15	25	10	15	10
All Other Landings	12	25	10	15	10

As wind speeds approach these constraints, they are closely monitored. Significant systematic differences among observations at the three standard sites casts doubt on the reliability of the measurements. Unreliable data are not acceptable for making the critical go/no-go landing decision. It is essential that any such differences be understood, and that any exposure-induced measurement errors be corrected.

1.2.3 DTO 805 Requirements and Resources

Detailed Test Objective (DTO) 805 is formally titled "Crosswind Landing Performance" (NSTS 16725 Rev R). Its purpose is to demonstrate the capability to perform a manually controlled Shuttle landing in the presence of a crosswind. The required meteorological data are temperature, wind speed and wind direction at the time of landing. The required meteorological conditions are a crosswind component of 10-15 kt (5-8 m s^{-1}) at landing. The long-term goal is to increase landing opportunities by safely relaxing crosswind flight rules.

In order to get the best practical wind data for the DTO, Johnson Space Center provided funding for six portable crank-up wind towers, each instrumented with wind and temperature sensors. These were to be deployed along the Shuttle Landing Facility (SLF) for launches and landings but were made available for redeployment for this study between Shuttle missions.

1.2.4 SLF Wind Data Processing and Dissemination Systems

The SLF wind data are transmitted to the Launch Control Center (LCC) at KSC where they are reformatted for transmission to Cape Canaveral Air Station (CCAS). At both KSC and CCAS, they are averaged and presented to users as graphic and tabular displays.

The data system at the LCC has recently been replaced. The previous system used scalar averaging for the KSC average wind displays. During the changeover, the appropriate averaging methods were discussed extensively. The averaging portion of this study was initiated to answer some of the questions which arose from those discussions. The result was the adoption of vector averaging in the new LCC data system.

At CCAS the data are vector averaged and ingested into the Meteorological Interactive Data Display System (MIDDS) for use by Range Weather Operations (RWO) and Johnson Space Center's Spaceflight Meteorology Group (SMG).

1.3 Conceptual Design of the Investigation

The sheltering field experiment used the portable 30-ft (9.2-m) wind towers in a configuration designed to determine the differences between measurements as a function of the spacing between the sensors and the foliage. These differences were used to develop a reasonable estimate of the actual set-back distance required for accurate measurements under reasonable conditions.

The averaging study combined mathematical analysis with empirical verification using standard wind tower data from STS-52 and STS-53 launches and synthetically generated wind fields. The synthetic wind generation algorithm is described in detail in Appendix 8.3. Vector and scalar averages from the same data were compared to determine whether significant differences existed. Differing averaging periods were examined as well.

2. Instrumentation and Data Processing

2.1 Instrumentation

2.1.1 Anemometers

The wind speed sensor is a Climet three cup anemometer. A light beam is chopped by a rotating slotted disk to generate a pulse train whose frequency is proportional to wind speed. The operating range is 0 to 95.5 kt (49 m s^{-1}) with a starting threshold of 0.5 kt (0.26 m s^{-1}). The rated accuracy is the greater of 1 percent or 0.13 kt (0.07 m s^{-1}). The distance constant is five feet (1.5 m). End to end system accuracy is estimated at less than one knot (0.5 m s^{-1}). These are similar to the anemometers on the standard towers.

2.1.2 Wind Vanes

Wind direction is measured by Climet wind vanes with a speed threshold of 0.65 kt (0.33 m s^{-1}). The vanes are of the dual potentiometer type having a mechanical range of 360 degrees and an electrical range of 540 degrees to avoid the discontinuity at the 0-360 degree transition point. Rated accuracy is two degrees. End to end system accuracy is estimated at about three degrees. The delay distance is less than three feet (1 m). These are also similar to the sensors on the standard towers.

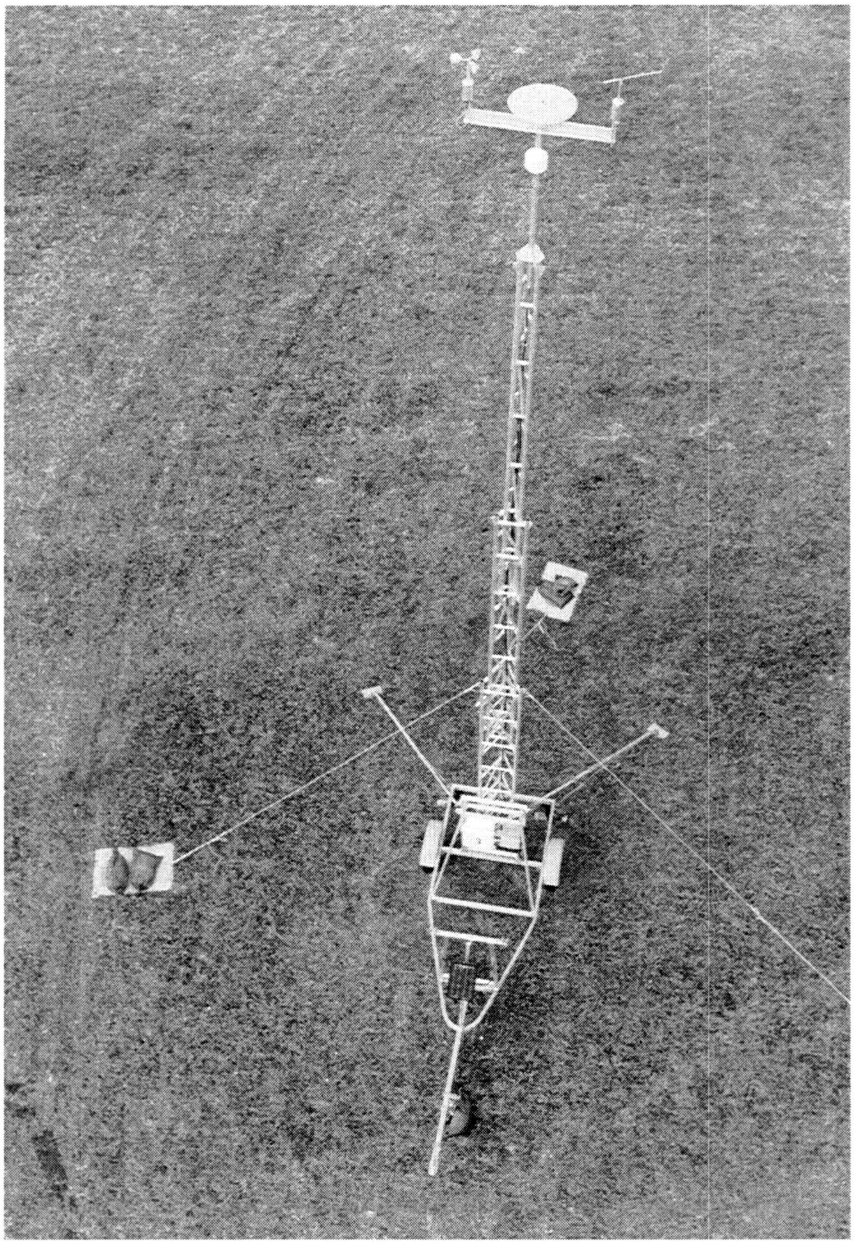

Figure 2. A portable wind tower, extended.

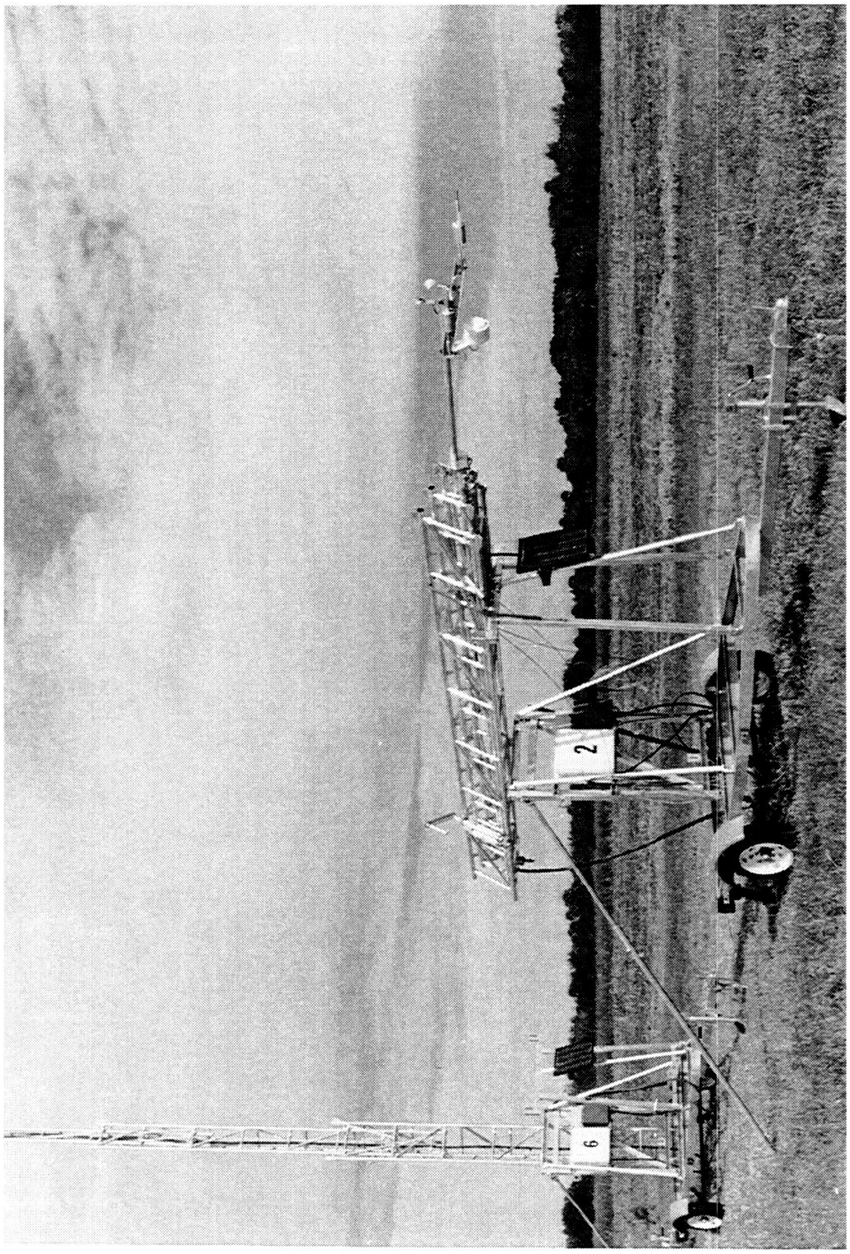

Figure 3. A portable wind tower, retracted.

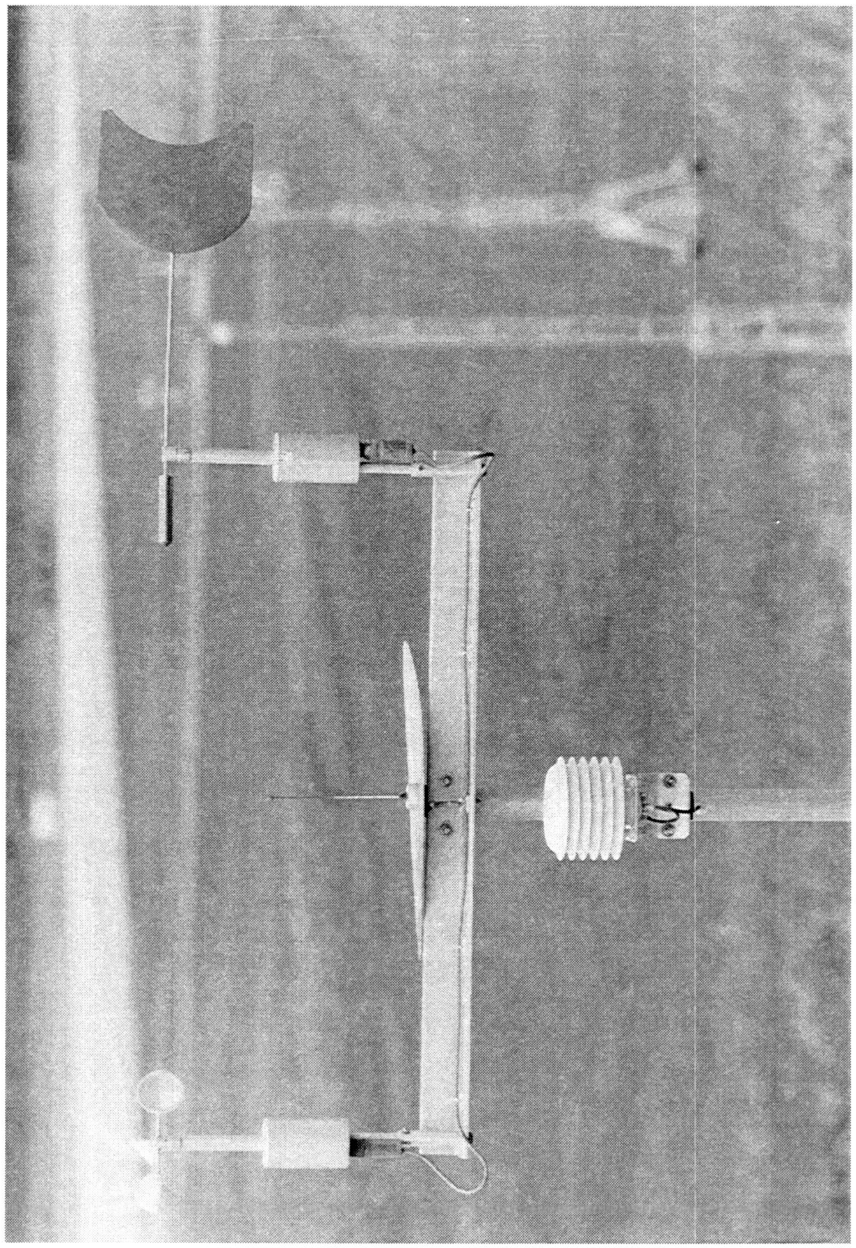

Figure 4. Portable wind tower sensors and antenna.

2.1.3 Trailer and Towers

The instruments are raised to 30 feet (9.2 m) above ground level (AGL) on crank-up aluminum towers which are mounted on trailers for mobility. When lowered, the towers are tilted over on hinges and travel in the horizontal position. When extended, the towers are stabilized by guy wires. Azimuthal alignment is obtained using an optical boresight mounted on each trailer and a visual point of reference. A solar panel, battery, and charger/regulator circuitry are provided to power the instruments and data acquisition systems.

Figure 2 and Figure 3 show a tower in the extended and retracted positions, respectively. A close-up of the mounted instrumentation is shown in Figure 4.

2.1.4 Data Loggers and Control Systems

In addition to the sensors, power, and signal processing electronics, each trailer contains a digital data logger and a UHF radio transceiver for receipt and acknowledgment of commands. The UHF antenna is located at the top of the tower.

The data logger is a Campbell Scientific Model CR10 augmented with an SM716 storage module and an SC532 interface box to permit downloading data to an MS-DOS (R) PC. Software stored in the storage module contains the data acquisition logic and calibration constants for the sensors.

When the system is powered-up, the software is downloaded from the storage module to the data logger. The system then initializes and waits until it receives a "Wake up" command from the UHF receiver. Upon receipt of "Wake up", the command is acknowledged and once-per-second data collection and storage begins and continues until receipt of a "Sleep" command. The data are one-second samples, not averages.

Upon receipt of a "Sleep" command, the system stops sampling or storing data, acknowledges the command, and returns to its " wait for a command" mode.

During data collection, the Master Controller Station may transmit synchronization pulses. When these are received, they are acknowledged and a dedicated data element is set to show receipt of the pulse. This permits synchronization of the six towers to within one second even if their local clocks drift.

The Master Controller Station is an MS-DOS (R) PC used to initiate commands and receive confirmations from the data collection systems. The PC accepts IRIG-B or Global Positioning System (GPS) time signals and logs to a file the exact time each command is sent. This permits synchronization of the tower clocks to a single standard external source for comparison with external data streams if desired.

2.2 Data Processing

Data processing for this experiment was accomplished on IBM compatible MS-DOS (R) personal computers using software written by the author for the Microsoft (R) Professional BASIC Compiler v. 7.0. A wide variety of data files was generated. See Appendix 8.1, SLF Wind Study and DTO 805 KSC Processed File Structure.

2.2.1 Data Preprocessing.

The data are transferred from the data modules on the towers to comma-delimited ACSII files on an MS-DOS (R) PC. The files are larger than necessary because they contain engineering information which is not required for the analysis. They can be of unequal lengths if one or more towers failed to respond to wake-up or sleep commands. Before statistical processing of the data begins, the records must be synchronized, quality controlled, and reformatted.

2.2.1.1 *Synchronization.*

The Control Station sends Wake-up, Synchronization, and Sleep commands to the tower data loggers. A data element in the ASCII records is set to zero unless a command was received during the interval for that record. Upon receipt of a command, that data element is set to 1 for Wake-up, 2 for Synch, or 3 for Sleep.

A program called SLFSYNCH reads the ASCII file and prints each record with a non-zero command element. The record number and entire contents of that record are printed. The SLFSYNCH printouts from each of the six towers are manually compared against each other and against the master controller command record. For each tower, the record number of the starting and ending record is determined. Records at the beginning, end, or both are deleted from the files as necessary so that each file has the same number of records and begins and ends at the same time to the second.

2.2.1.2 *Quality Control*

After the files have been synchronized, a rough quality control check is done by a program called SLFQC. This program reads the synchronized ASCII files and prints the first and last record, the number of records, and any record for which any of the following events occurs:

- Tower ID number changes
- Engineering configuration flag changes
- Wind speed or direction negative
- Wind direction exceeds 540 degrees (electrical)
- Wind speed exceeds 99 kt (51 m s^{-1})
- Wind direction changes by more than 60 degrees
- Wind speed changes by more than five kt (2.6 m s^{-1})

The resulting printout is manually examined. Any flagged record for which an acceptable explanation (such as wind direction scale "wrap-around") is not obvious is examined along with the adjacent records to determine the cause of the flag. Real events such as passage of an aircraft near a sensor are noted to avoid impacting the analysis. Clearly erroneous data, if limited to a single record, are corrected by interpolation from adjacent records from the same sensor.

Fewer than a dozen interpolations were required in the entire experiment, and no aircraft passages contaminated any data.

2.2.1.3 *Formatting*

When the data are synchronized and quality controlled, the engineering data, temperatures, and times are stripped from the files to reduce their size and complexity. Files containing a header with the start and stop times followed by data records are created. The data records contain three elements each: time in serial seconds from the start, wind speed in kt, and wind direction in degrees. This reformatting is done by a program called SLFFMT.

2.2.2 Data Processing.

2.2.2.1 *Basic Statistics*

A program called VECTSTAT computed the mean, standard deviation and variance, skewness, kurtosis, and probability densities and distributions of wind speed and direction.

Tabular listings of all results were printed. Printer graphics plots of the probability densities and distributions were available. The file headers and sample sizes were included with the listings and plots.

The mean (average), μ of a set of data X_i $(i = 1 \ldots N)$ is given by

$$\mu = (1/N)\sum_{i=1}^{N} X_i$$

and represents a typical or effective value for the data. (Snedecor and Cochran, p.26)

The higher moments are defined with reference to departures from the mean. Thus if X_i are the original data, then define the departures from the mean as

$$x_i = X_i - \mu .$$

The variance is the second moment defined by

$$\sigma^2 = (1/N)\sum_{i=1}^{N} x_i^2$$

and represents the amount of scatter in the data about the mean. As computed, this is the sample variance which is smaller than the population variance by a factor of $(N-1)/N$. In this study, N typically was greater than 3000, so the difference is negligible. The square root of the variance is the standard deviation, σ. It measures the scatter in the same units as the mean and the original data. (Snedecor and Cochran p.29)

The normalized third moment is called the Skewness coefficient. It is given by

$$S = (1/N)\sum_{i=1}^{N} x_i^3 / \sigma^3$$

and represents the degree to which the distribution is asymmetrical about the mean. For a Gaussian (normal) distribution, S=0. (Snedecor and Cochran p.78.)

The normalized fourth moment is called the Kurtosis coefficient. It is given by

$$K = (1/N)\sum_{i=1}^{N} x_i^4 / \sigma^4$$

and measures the degree to which the scatter tends to have long "tails". For a Gaussian distribution, K=3. (Snedecor and Cochran p.79)

The probability densities are estimated assigning the data to a finite number of equally sized bins depending on their values and normalizing the bin counts by the total number of samples. The cumulative probability is estimated by summing the probability densities up to the current bin. Thus $p(k)$ = (number of samples in bin k)/(total number of samples) and

$$P(k) = \sum_{i=1}^{k} p(i) \quad \text{(Bendat and Piersol, 1966, p284).}$$

Clearly, $P(M) = 1$ where M is the final bin.

2.2.2.2 *Scalar Wind Averaging*

The simplest method computationally for averaging wind data collected with a cup anemometer and wind vane which produce separate wind speed (WS) and wind direction (WD) outputs is to average WS and WD separately. This treats them as independent scalar quantities. *WS* is averaged without regard to direction, and *WD* is averaged without regard to *WS*.

While this methodology is simple, it also has pitfalls. Wind direction is cyclic. Rotate a 300 degree wind to the right by 45 degrees and you get 345, but rotate it another 45 degrees and you get 30 degrees, not 390. Averages of cyclic data can be perverse. Physically, 359 degree and 001 degree winds are both north winds, but their arithmetic average is 180 degrees, or south! To some extent, this can be mitigated by using sensors with ranges up to 540 degrees, but even these extended range sensors suffer from "wrap-around" error.

2.2.2.3 *Vector Wind Averaging*

To overcome the cyclic variable problem and obtain a physically meaningful average, the wind should be treated as the vector quantity it is. This requires computing the north component (v) and the east component (u) of the wind field separately using

$$v = -WS\cos(WD) \text{ and}$$

$$u = -WS\sin(WD).$$

These components are then arithmetically averaged and the resultant vector averaged wind speed and direction are computed from the component averages using

$$\{WS\} = \sqrt{\left(\langle u\rangle^2 + \langle v\rangle^2\right)} \text{ and}$$

$$\{WD\} = \text{Arctan}\left(\langle u\rangle / \langle v\rangle\right)$$

where $\langle\ \rangle$ denotes a scalar (time) averaged quantity and $\{\ \}$ denotes a vector averaged quantity. Thus the scalar averaged *WS* and *WD* are indicated by $\langle WS\rangle$ and $\langle WD\rangle$. A quadrant adjustment is required in the arctangent function.

Vector averaging always gives the correct "common-sense" answer for the wind direction. It also gives a much better estimate when used to compute aerosol transport or cumulative wind stress effects on structures. If the wind speed is relatively constant but the direction is highly variable, the vector average speed can be considerably lower than the scalar average speed. Typically, this occurs in light and variable wind conditions. It is not usually of concern, although it could be significant for structural stress evaluations under very gusty, high wind conditions such as found in severe thunderstorms. The main disadvantage of the vector average is that it is more complex to compute. With today's available desktop computing power, this disadvantage is usually negligible.

2.2.3 Data Postprocessing.

The volume of information produced by the software described above is difficult to digest and understand. To facilitate comparison of data at differing separations and on different days, selected quantities were manually transcribed onto summary sheets.

For the same reason, selected data were transferred to DeltaGraph (R) spread sheets in order to generate publication quality graphics.

3. The Field Experiments -- Design and Configuration

The towers were deployed in an array especially tailored for this experiment. The position for each tower was surveyed in advance. The towers were towed into position, aligned, guyed and leveled, and cranked up to the operational height. An intercomparison array was used to insure adequate relative sensor calibration.

3.1 The Intercomparison Array

Inter-tower consistency of calibration was essential to interpreting the data for this experiment. Before and after each experimental deployment, the six trailers were brought together for intercomparison. The site was cleared to beyond 500 feet (152 m). The trailers were located within 20 feet (6.1 m) of each other and operated at their standard height for at least four hours under moderate wind conditions.

For each trailer the wind speed and direction statistics were computed from the entire record of one second samples. Sample sizes exceeded 14,000. Agreement of all sensors within rated specifications was a pre-requisite to deployment. On one occasion a bad wind direction sensor was detected and repaired. The entire set was re-compared before deployment.

Post experiment intercomparisons did not detect any departure from rated accuracy. Table 1 shows a typical comparison run. The standard error of measurement was computed by dividing the observed standard deviation by the square root of the sample size. An array was accepted if the largest difference between any two sensors was less than twice the sum of the rated end-to-end error and the standard error of measurement.

Data Taken 03/09/94 at Center Site
14:14:00 to 18:15:16 (14478 records)

Tower #	Mean	Std Dev	Variance	Skewness	Kurtosis
		Wind Speed (kt)			
1	12.09	2.88	8.28	0.32	2.95
2	12.13	2.96	8.76	0.30	3.00
3	12.18	2.89	8.34	0.40	3.07
4	12.25	2.94	8.62	0.36	3.04
5	12.25	3.00	8.99	0.33	3.04
6	12.07	2.85	8.12	0.33	2.96
		Wind Direction (Degrees)			
1	351.26	16.62	276.36	-0.03	2.46
2	348.37	16.74	280.07	-0.08	2.50
3	350.02	16.26	264.32	0.01	2.47
4	352.20	16.27	264.66	-0.01	2.40
5	350.62	16.28	265.15	-0.08	2.49
6	349.43	16.42	269.49	0.02	2.46

Standard Error Measurement:
 Wind Speed: 0.02
 Wind Direction: 0.13
Specified Sensor System End-to-End Accuracy:
 Wind Speed: 1.0
 Wind Direction: 3.0
Conclusions:
 Wind speeds are well within specified accuracy.
 Wind directions are within specified accuracy.

Table 1. A typical sensor intercomparison with annotations as maintained in project records.

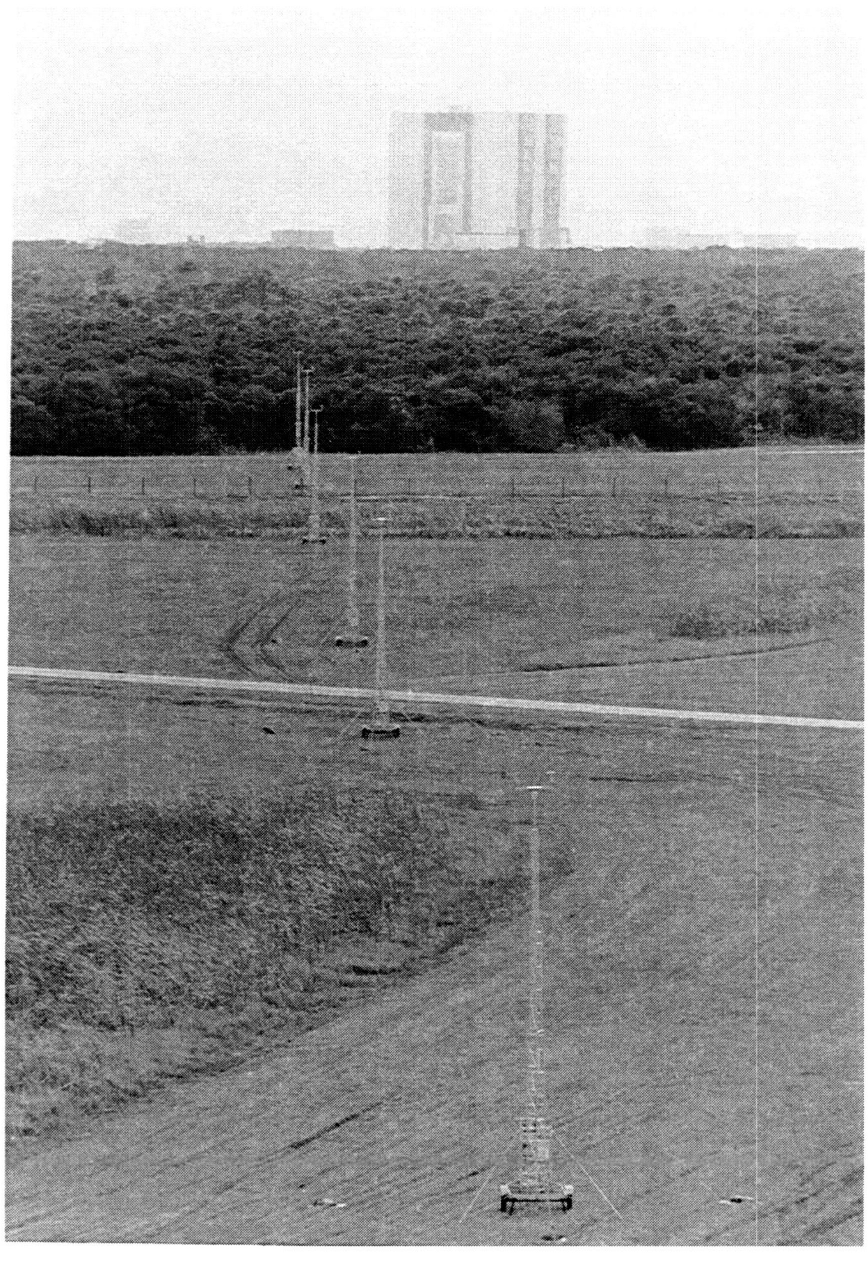

Figure 5. Photograph of the sheltering array.

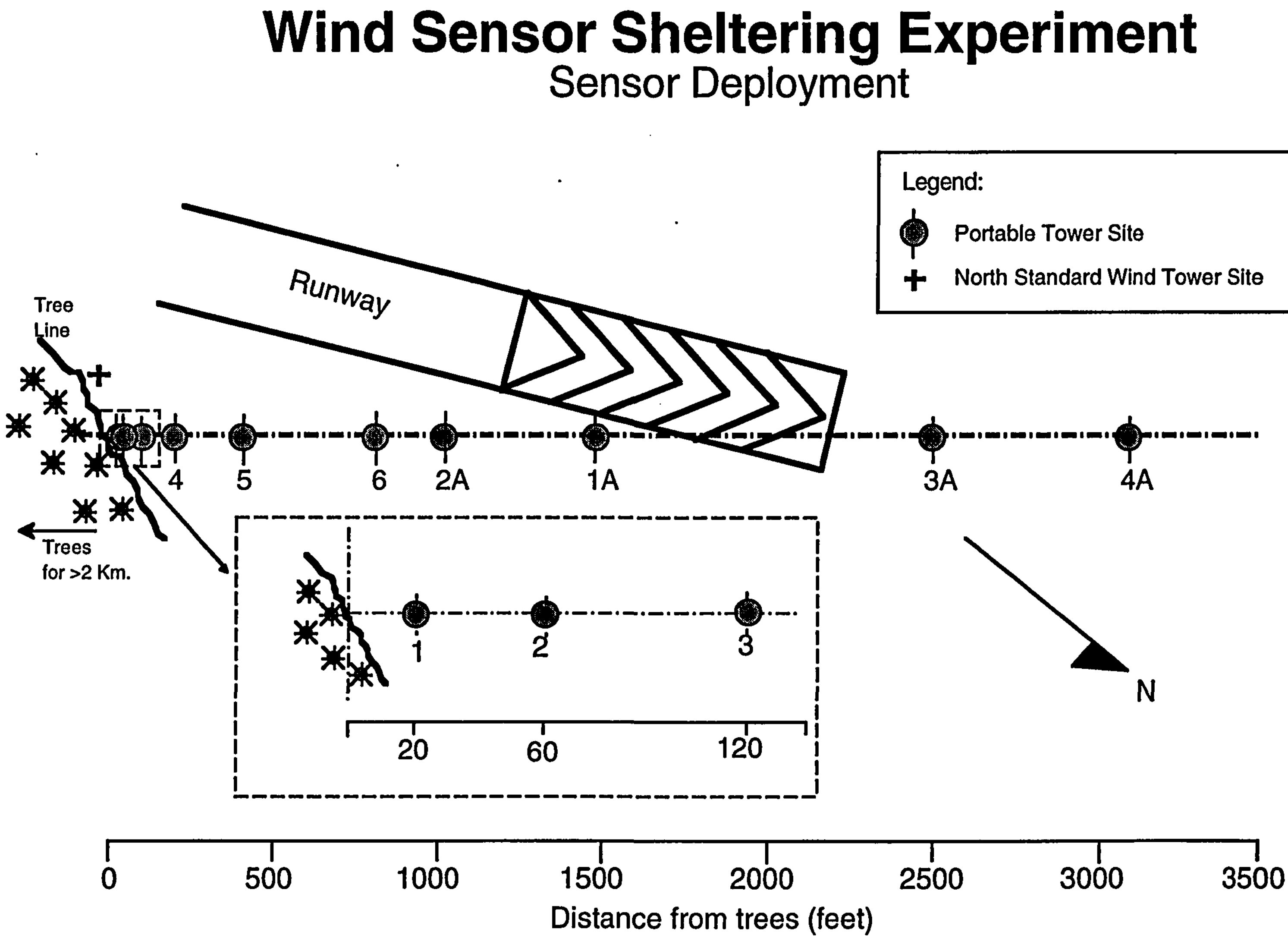

Figure 6. Layout of the Sheltering Array. Note the position of the standard north site with respect to the trees.

3.2 The Sheltering Array

In order to resolve the sheltering issue we used a linear six tower array with logarithmic spacing from 20 feet (6 m) to 3100 feet (945 m) as shown in Figure 5 and Figure 6. It was sited near the north standard sensor and aligned along a bearing of 136 degrees, almost perpendicular to a line of trees which extended back for a distance of more than a mile (2 km). Logarithmic spacing was attractive because it covered a wide range of spacings with a few towers, and provided finer resolution closer to the obstruction. This enabled locating the region of foliage influence with a resolution appropriate to the distance involved.

In order to cover the range of separations needed for this study, ten logarithmically spaced sites were required. For any single experiment, six of the ten sites were selected since we had only six towers available.

4. The Results

4.1 Overview

The results show that improper exposure of the north wind sensor due to foliage within 100 feet (30.5 m) can reduce measured mean wind speeds by as much as 30 percent when the wind blows from the foliage toward the sensor. The wind speed standard deviation increases near the foliage adding uncertainty as well as error to the measurement.

Wind directions are unaffected in the mean, but the measured standard deviation (sigma theta) increases near the trees. This adds uncertainty to the measurement.

The averaging techniques commonly in use by various wind data collection and display systems at KSC and CCAS do not introduce any significant error into the measurements. There is no significant difference between vector and scalar averaging techniques for wind regimes of operational interest to the Shuttle program.

4.2 Wind Speeds

To facilitate intercomparison of the data in different configurations and at different wind speeds, the wind speed data were normalized. Normalization to the free stream was desirable, but normalization to a point common to all of the arrays used was essential. To meet the commonality criterion completely and approximate the free stream one as closely as possible, the common point was taken to be the most distant tower in the shortest array. This point was 820 ft (250 m) from the tree line. Every array used contained a tower at this point. The data presented here are normalized by dividing the actual mean wind speed by the mean wind speed at the 820 foot tower. The variances were similarly normalized.

Figure 7 and Figure 8 show that when the wind blows toward or at right angles to the trees, there is little effect on the wind speed until distances well within 100 feet (30.5 m) are reached. Even then, only a five percent reduction in mean wind speed occurs.

Figure 9 shows logarithmically and linearly that the measured average wind speed is significantly reduced when the wind is blowing from the treeline toward the sensors. The data seem to be well fit $\left(r^2 = 0.932 \text{ for } N = 54\right)$ by a purely empirical hyperbolic tangent relationship

$$WS / WS_{820} = 0.975 + 0.175 \tanh\left(0.9\left(\ln(x) - 6.549481\right)\right)$$

which is plotted along with the data in the figures.

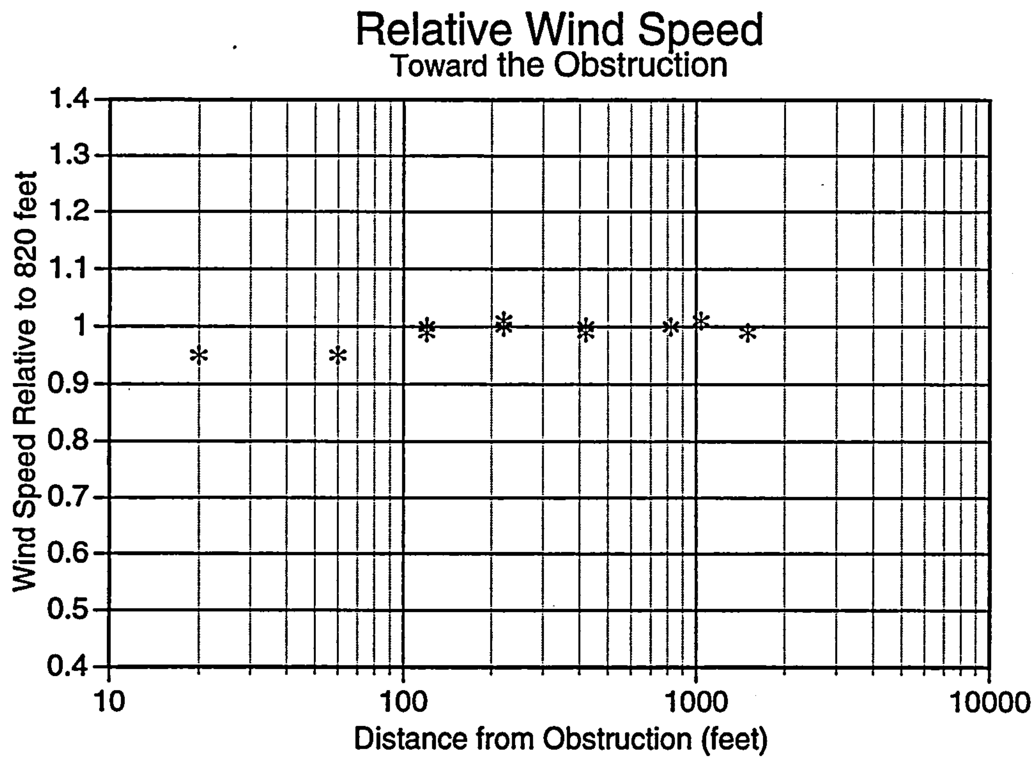

Figure 7. Relative wind speed versus distance, flow toward the obstruction.

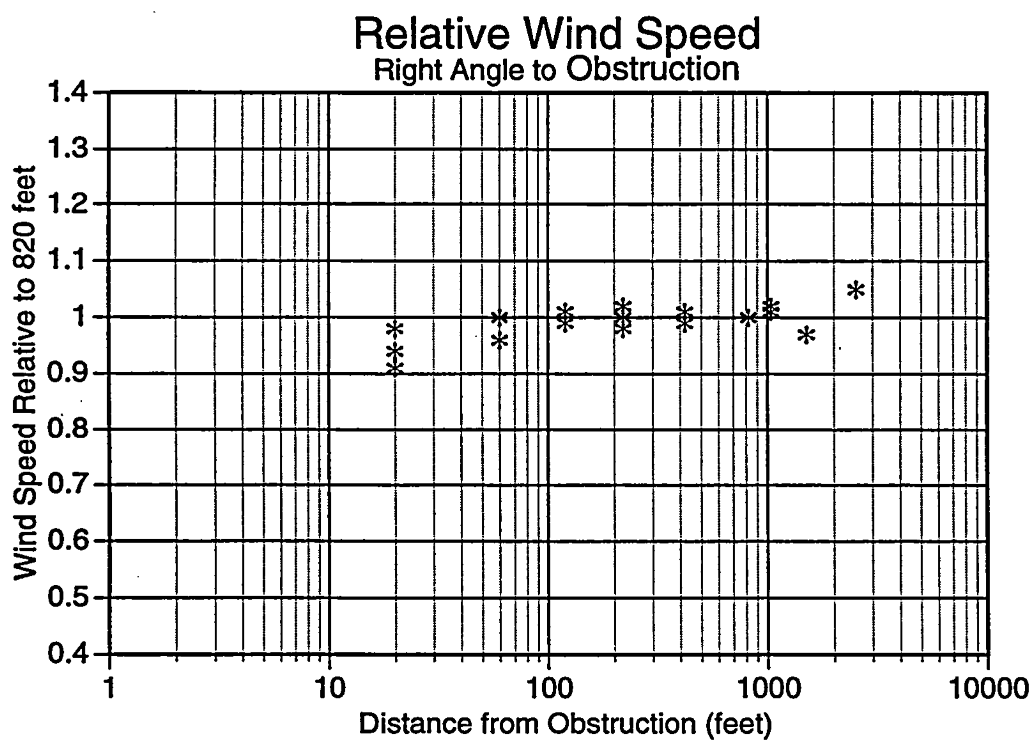

Figure 8. Relative wind speed versus distance, flow at right angle to the obstruction.

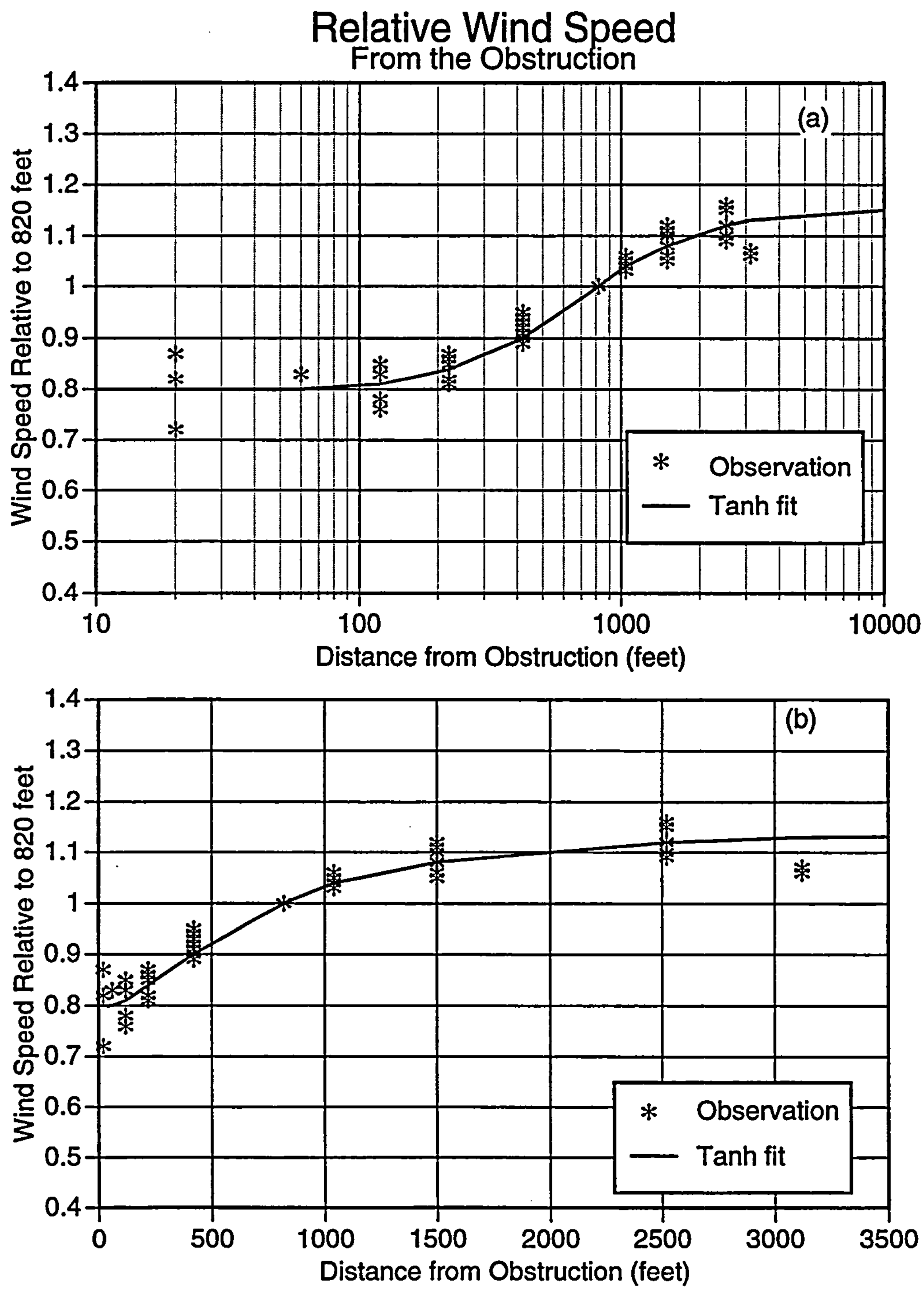

Figure 9. Relative wind speed versus distance, flow from the obstruction. Log and linear scales are shown in (a) and (b), respectively.

This relationship may be used to estimate the wind speed reduction normalized to the free stream asymptote rather than the tower at 820 feet. The results are presented in Figure 10. They appear valid within about ±30 degrees of the bearing directly from the trees. Determining the details of the variation of this empirical model with wind direction would require data beyond the scope and resources of this investigation. Beyond about ±60 degrees, the results approach those presented for the right angle cases.

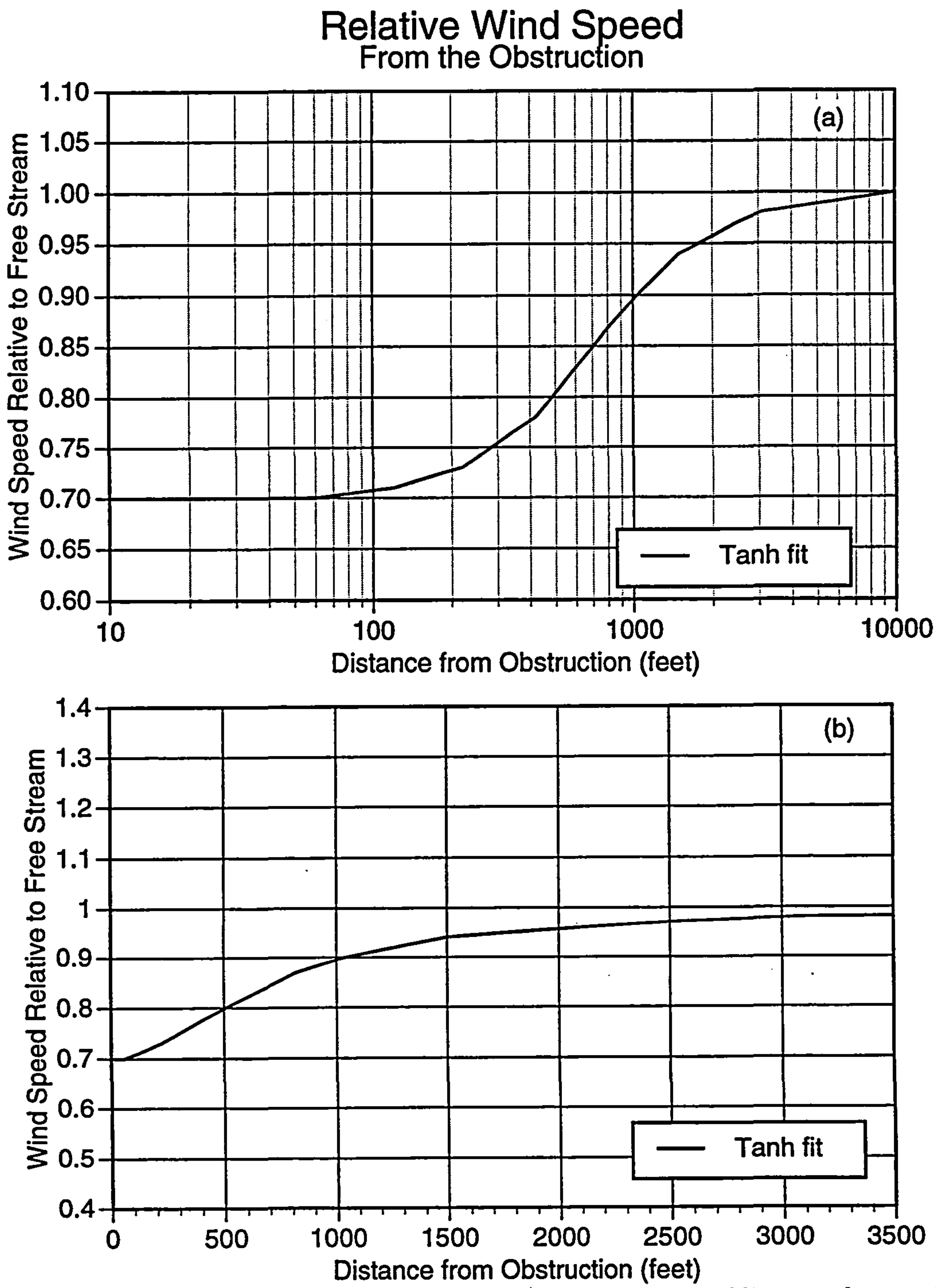

Figure 10. Free stream wind speed reduction based on tanh fit. Log and linear scales are shown in (a) and (b), respectively.

Based on the hyperbolic tangent model, the current placement of the north wind tower approximately 90 feet (27 m) from the tree line results in about a 30% reduction in the measured mean wind when the wind blows from the tree line (southeast winds). To reduce the wind shadowing effect to a 10 percent reduction, the foliage would need to be trimmed (or the sensor moved) to allow for 1000 feet (305 m) of clearance. This distance is the same as that recommended by the Office of the Federal Coordinator for Meteorology (1994).

Figure 11 shows that the normalized wind speed variance, additionally normalized by the wind speed to construct a drag coefficient, rises rapidly approaching the trees. The change takes place in the same region where the wind speed begins to decrease.

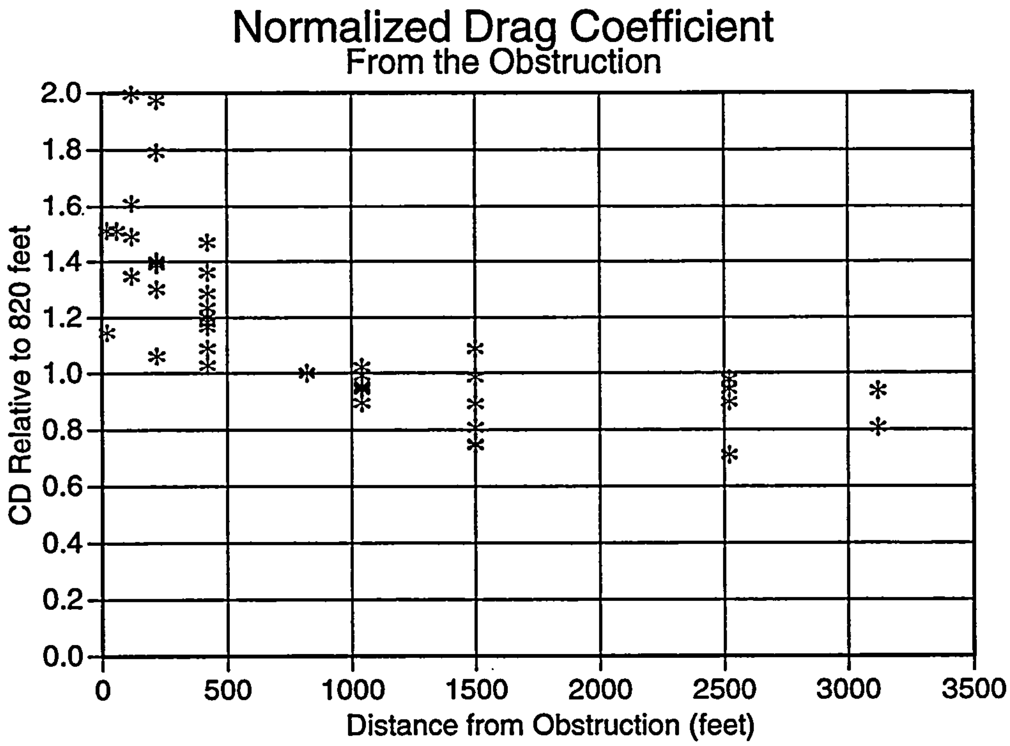

Figure 11. Normalized drag coefficient versus distance from the obstruction.

The data are consistent with the speed reduction and drag coefficient increase being caused by dynamic adjustment of the flow to the change in roughness length rather than to physical "sheltering" or blockage by the trees. This explains why the effects propagate out to such a large distance. Pure blockage effects would not be expected more than a few "tree heights" out beyond the trees, and would be expected to be observed when the flow approaches the trees as well as when it flows from them. On the other hand, roughness adjustments take place mostly downstream from an obstruction, and require adjustment of the entire boundary layer throughout its depth. This adjustment in depth takes much longer to accomplish.

To find theoretical and independent experimental support for the suggested physical mechanism, a brief literature search was performed. Estimates in the published literature sampled varied widely, and theoretical analyses were vague and inconsistent. The sources cited by Wyngaard (1973) indicated a transition length greater than 328 ft (100 m) consistent with our observations although the argument of Stull (1989, Section 14.2) leads to smaller values. In view of this lack of consensus and in the absence of flux measurements or vertical profiles in our data, the physical mechanism presented here must be considered tentative.

4.3 Wind Directions

As shown in Figures 12, 13 and 14, the mean wind direction is not affected by the presence of the trees at any distance regardless of the wind direction of the free flow.

On the other hand, Figure 15 shows that normalized sigma theta increases as one approaches the trees when the mean wind direction is from the tree line. This is also consistent with the hypothesis that the physical explanation for the effect of the foliage on the flow is its effect on the roughness length rather than physical obstruction, with the same caveat concerning lack of flux data and vertical profiles.

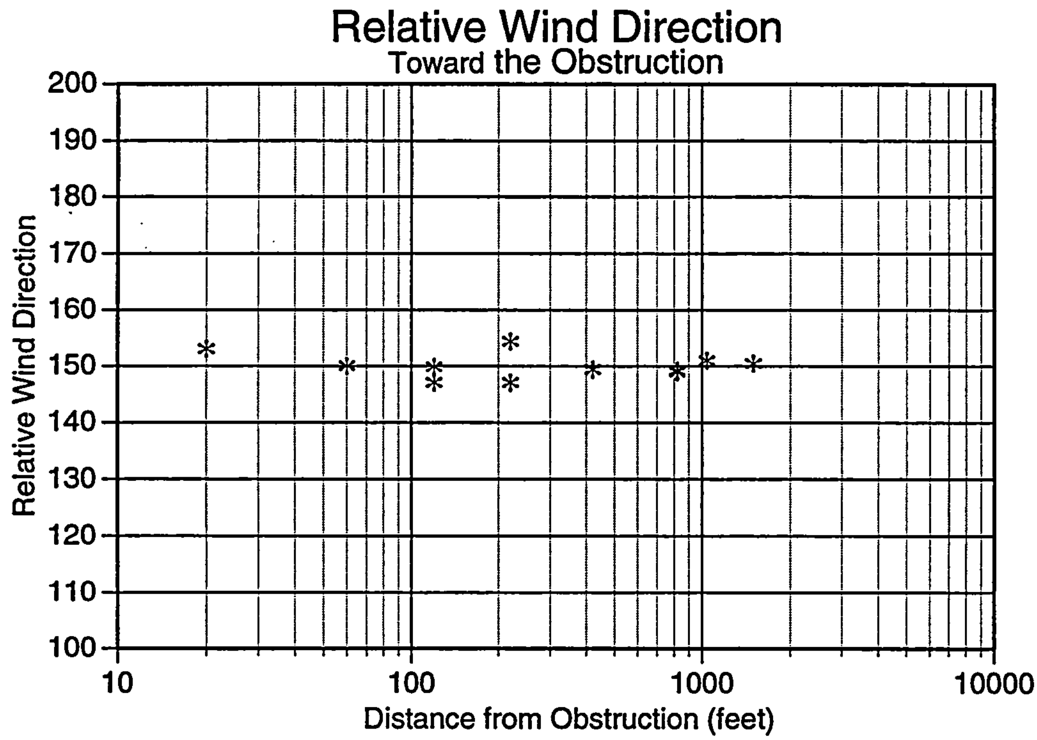

Figure 12. Relative wind direction, flow toward the obstruction.

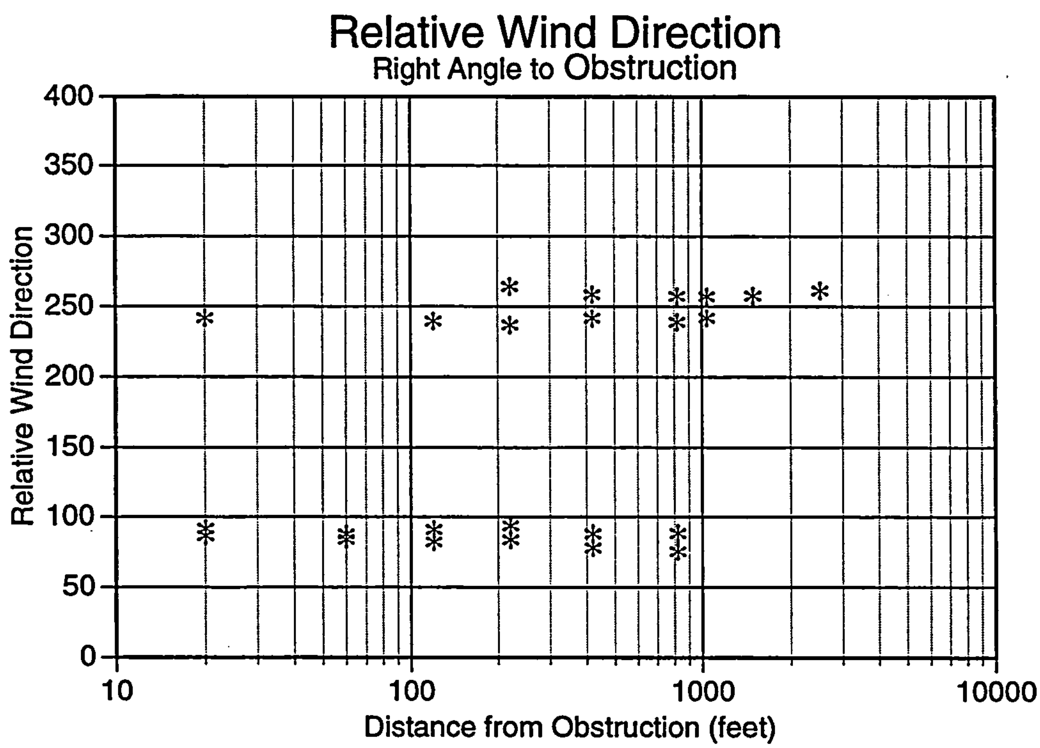

Figure 13. Relative wind direction, flow at right angles to the obstruction.

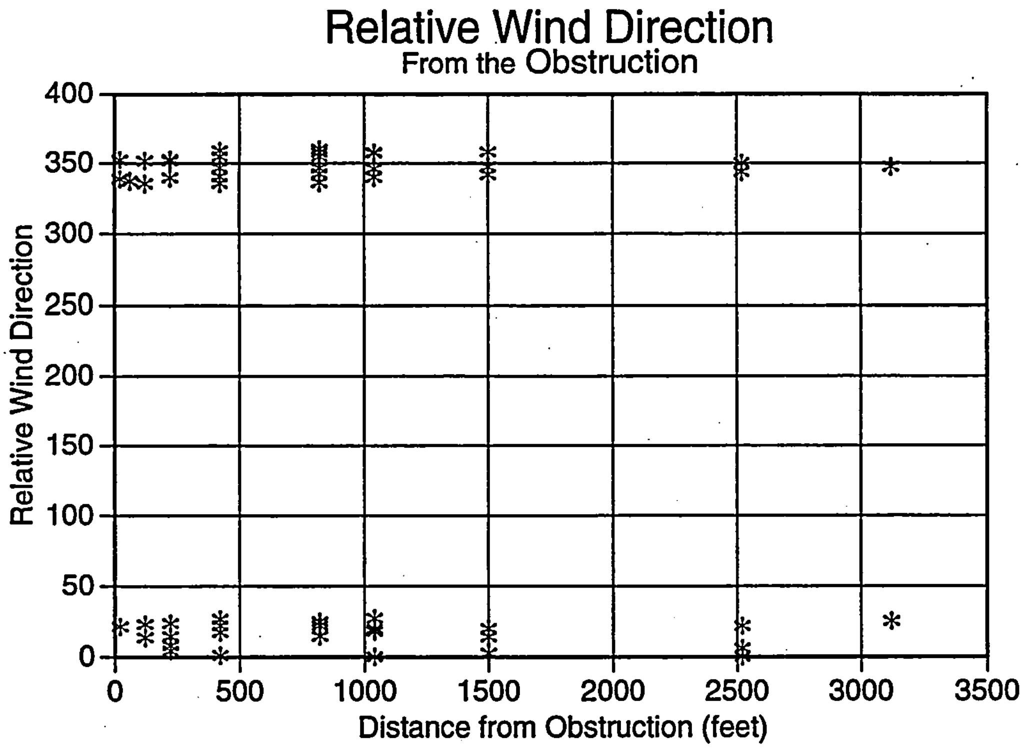

Figure 14. Relative wind direction, flow from the obstruction.

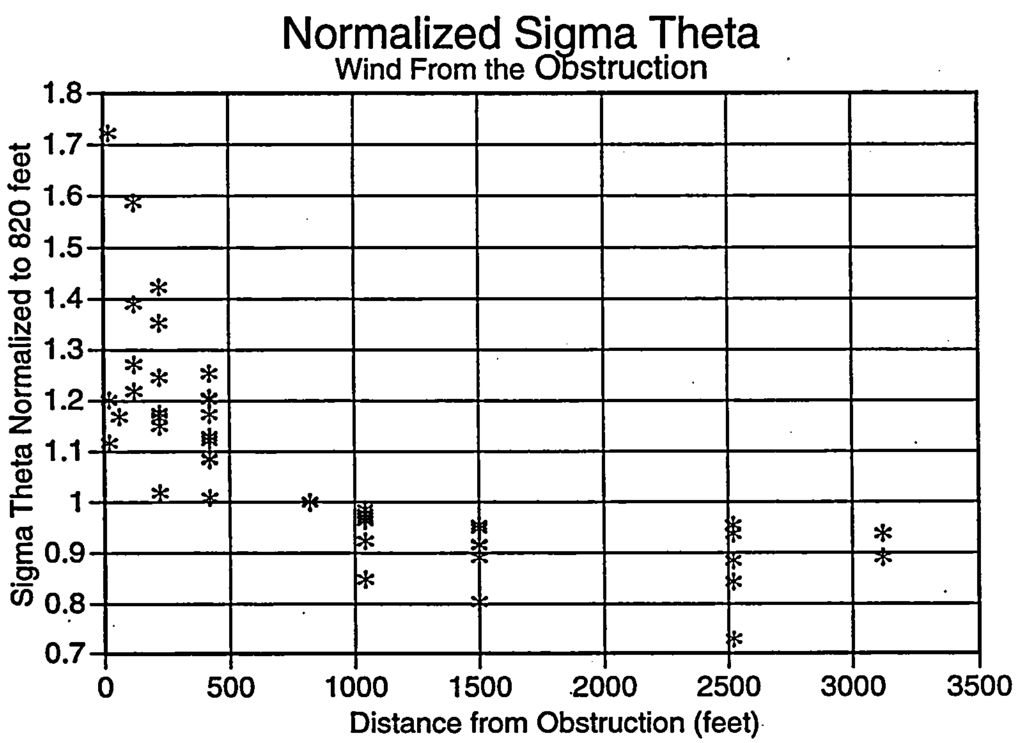

Figure 15. Normalized sigma theta, flow from the obstruction.

4.4 Averaging Techniques

4.4.1 Scalar vs. Vector Averaging

4.4.1.1 Analytical Results

The analytical framework for comparing scalar with vector averaging consisted of evaluating both averages in a geometry designed to simplify the arithmetic. The geometry aligns the mean wind with one coordinate axis, which should result in no loss of generality since the results for any other wind direction can be computed simply by coordinate rotation.

The following notation is adopted:

WS is the instantaneous wind speed measured by the cup anemometer.

WD is the instantaneous wind direction measured by the wind vane. It is the direction FROM which the wind is blowing, referenced to true north.

u is the easterly component of the instantaneous wind vector.

v is the northerly component of the instantaneous wind vector.

$\langle x \rangle$ denotes the time averaged value of x. This is by definition the scalar average of x.

$\{x\}$ denotes the vector average of x, which must be either WS or WD.

x' denotes the instantaneous departure of x from $\langle x \rangle$. Thus by definition $v = \langle v \rangle + v'$ and $u = \langle u \rangle + u'$.

The basic relations from which the results are derived are the following:

Converting wind speed and direction into vector components

$$u = -WS\sin(WD) \qquad v = -WS\cos(WD)$$

Converting components into wind speed and direction

$$WS = \sqrt{u^2 + v^2} \qquad WD = \mathrm{Arctan}(u/v)$$

The scalar averages are $\langle u \rangle$, $\langle v \rangle$, $\langle WS \rangle$ and $\langle WD \rangle$.

The vector averages for WS and WD are defined as follows:

$$\{WS\} = \sqrt{\langle u \rangle^2 + \langle v \rangle^2}$$

$$\{WD\} = \mathrm{Arctan}(\langle u \rangle / \langle v \rangle).$$

In general, the vector and scalar averages of WS and WD will differ. This analysis estimates the magnitude of the difference.

We begin by postulating a steady south wind for which we have

$$\langle v \rangle = V(>0), \quad \langle u \rangle = 0, \quad \{WS\} = \langle WS \rangle = V, \quad \{WD\} = \langle WD \rangle = 180.$$

Upon this we superimpose fluctuations u' and v' having zero mean, and recompute the vector and scalar averages of WS and WD. For analytic convenience, we will restrict these fluctuations to magnitudes smaller than V. This is usually realistic in the atmosphere except in the case of light and variable winds. The resulting instantaneous values to be averaged are thus

$$WS = \sqrt{((V+v')(V+v')+u'^2)} \text{ and}$$

$$WD = \text{Arctan}(u'/(V+v')).$$

With the fluctuations added, we still have $\langle v \rangle = V$ and $\langle u \rangle = 0$, and thus by definition the vector averages are $\{WS\} = V$ and $\{WD\} = 180°$.

The scalar averages for WS and WD are more complicated. To get at them we'll take advantage of the assumption that the fluctuations are smaller in magnitude than V and expand the non-linear functions in power series. For $|x| \le 1$,

$$\text{Arctan}(x) = x - \frac{x^3}{3} + \frac{x^5}{5} \cdots \text{ and}$$

$$\frac{1}{1+x} = 1 - x + x^2 \ldots\ldots \text{ (Souders (1967), p 37).}$$

We can write $u'/(V+v')$ as $(u'/V)/(1+v'/V)$ which becomes $(u'/V)(1-v'/V+\ldots)$. Upon substitution into the expansion for the Arctangent we get

$$\langle WD \rangle = \left\langle \text{Arctan}\left(\frac{u'}{(V+v')}\right)\right\rangle = \frac{\langle u' \rangle}{V} - \frac{\langle u'v' \rangle}{V^2} + \ldots + 180° \text{ (quadrant adjustment to arctangent).}$$

The first term is zero since $\langle u' \rangle = 0$ by definition. The third order and higher terms are negligible compared to the second order term, which thus determines the scalar average. In the surface boundary layer, the second order term is typically of order 0.001 radians or 0.06 degrees because u' and v' are only slightly correlated. Thus the vector and scalar wind direction averages are for practical purposes identical except possibly under light and variable conditions where the fluctuations exceed the mean in magnitude.

Similarly, one may expand

$$\langle WS \rangle = \sqrt{(V+v')^2 + u'^2}$$

After some algebra, the result is

$$\langle WS \rangle = V * \left(1 + \frac{\langle u'^2 \rangle}{2V^2} + \text{4th order and higher.}\right).$$

Thus the scalar average wind speed is always larger than the vector average (which equals V) by the factor $\langle u'^2 \rangle / 2V^2$.

4.4.1.2 Empirical Results

Based on observed characteristics of SLF winds over the range 3.5-15 kt (1.8-7.7 m s^{-1}) and on synthetic wind generator tests, the difference between vector and scalar wind speed averages is of order 0.3 kt (0.2 m s^{-1}). The wind direction difference is within the error of the wind direction sensors and is unmeasurable. These results are generally consistent with those of Thuillier (1995).

4.4.2 Averaging Periods

The effect of varying the averaging period is widely described in the statistical literature such as Bendat and Piersol (1966) or Snedecor and Cochran (1980) and will not be repeated in detail here. In summary, for stationary processes with N samples per average, the computed mean and standard deviation are unbiased estimates regardless of the value of N. The sampling variance is inversely proportional to N.

For non-stationary processes, the sampling variance remains proportional to $1/N$, but is harder to interpret. The mean remains unbiased but is also difficult to interpret. The computed variance increases. For a linear trend, it increases as N^2. This contaminates estimates of the values of sigma theta and wind speed sigma.

For winds acceptable for 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.

4.4.3 Peak Wind Speed and Direction

The wind data system reports a peak wind speed for each five minute interval. For reasons having to do with noise levels in the system, the second highest peak is actually reported. A separate "direction of the peak wind" is not reported by the data system.

A brief empirical study was conducted to determine whether the direction of the peak wind differs significantly from the mean wind direction over the five minute interval. Data from STS-52 and STS-53 were used. Typical observed differences were on the order of ten degrees. The largest observed difference was 22 degrees.

Based on this limited sample, the difference between the mean and peak wind directions appears to be of the order of one sigma theta, and thus is not generally significant since the RMS difference between the sensors and the runway is at least this large (Merceret, 1995).

5. Conclusions

5.1 Summary of Technical Results

The first question we set out to answer was HOW FAR FROM NEARBY TREES AND SHRUBBERY DOES A WIND SENSOR HAVE TO BE IN ORDER TO MEASURE THE WIND SPEED AND DIRECTION WITHIN SPECIFIED ACCURACY?

The answer is provided by Figure 10 which shows that to limit average wind speed measurement reductions to ten percent or less the sensor should be at least 1000 ft (305 m) from the trees in accordance with the OFCM standard.

The second question we set out to answer was WHAT ARE THE EFFECTS OF VARIOUS AVERAGING TECHNIQUES AND PERIODS ON THE ACCURACY OF MEASUREMENT OF WIND SPEED AND DIRECTION?

The answer to this question is that there is no significant difference between vector and scalar averaging techniques except at the lowest wind speeds where the directional deviation becomes large (light and variable winds). Where there is a difference, the "correct" method depends on the use to which the data are to be put. For toxic dispersion purposes, the vector average is always the right choice. For engineering purposes, the vector averaged direction and RMS speed may be more appropriate. For meteorological purposes, the vector averaged direction and scalar averaged speed may be most representative.

Averaging periods may be selected to match the intended usage. Evaluation of Launch Commit Criteria (LCC) and Flight Rules (FR) should be done with the same averaging period used in the climatology from which they were derived (usually five minutes). Engineering applications may require shorter or longer averaging periods. The means are not biased by the averaging period. The standard deviations are reduced with longer averaging periods in steady-state conditions as short- period variance is integrated out by the averaging process.

Peak wind speed and direction are not averages, but single samples and are not affected by the averaging process used.

5.2 Impact on Operational Use of SLF Meteorological Data

For operational use in evaluating LCC and FR, the standard SLF wind sensors must be properly exposed. Foliage or structures must not be allowed to encroach into their near surroundings. Such encroachment alters their readings which are no longer representative of the actual local environment. Proper exposure must be continuously maintained through the necessary landscaping practices.

Selection of vector or scalar wind averaging should have no significant operational impact since they are nearly identical except under light and variable wind conditions which pose no normal operational concern.

Use of the normal range of averaging periods, from one to five minutes, for operational displays poses no operational problem as long as the LCC and FR are evaluated using the averaging period for which they were designed.

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8. APPENDICES

8.1 SLF Wind Study and DTO 805 KSC Processed File Structure – File Naming Conventions

XJJJTTTT.00N where N is the portable tower ID number, JJJ is the Julian day, TTTT is the starting time in HHMM format. X is a prefix with the following values:

F denotes basic data files after reformatting for analysis.

L denotes LCC (60 s) averaged data in F format

M denotes MIDDS (5 min) averaged data in F format.

Q denotes QC'd data in the original format before reformatting for analysis.

T denotes two-minute averaged data in F format.

D files are Difference files in F format with file names of the form DJJJTTTT.N0M where N and M are the tower ID numbers of the files differenced. They were not used in this paper.

S files are SLF standard met tower wind data in F format with file names of the form SJJJTTTT.III where III = N05, C03, or S04 denotes the North site (met tower 5), Center site (tower 3) or South site (tower 4).

File Formats:

F format files have a three line header of form
Filename: HHMMSS to HHMMSS on MM/DD/YY Keywords
(blank line)
N, T WS WD

Exception: The first line of the header in D files contains the names of the files differenced rather than the time/date information.

Following the header are N lines of comma delimited ASCII data containing three fields: time (serial seconds), wind speed (knots), wind direction (degrees).

Q files and raw portable tower data files have no header. Each record occupies one line and contains eight comma delimited ASCII fields: 999,HHMM,SS,WS,WD,TA,S,ID.

The first group is an internal code; the value doesn't matter. The next group is HHMM (hours and minutes GMT). The third group is seconds. The fourth and fifth groups are wind speed (kt) and direction (degrees, 0-540). The sixth group is temperature (°F). The seventh group is the Synch code described below. The last group is the tower ID number. The Synch code is non-zero only when a control signal is transmitted to the unit. If the code is 1, a START command was sent. If the code is 2, a SYNCH reference command was sent. If the code is 3, a SLEEP command was sent.

8.2 Wind Sheltering Data Sets

This table lists the data used for the sheltering analysis presented in this paper. The columns contain the following information:

Fname: File name (See Appendix 8.1). File suffixes of the form 0AN, 0BN etc. are respectively the A, B ... sections of the file with suffix 00N. Segmenting files is sometimes necessary to ensure uniformity of analysis conditions under varying environmental conditions.

N: Number of records in the file

DIST: Distance from the tree line to the tower (feet)

WSBAR: Mean wind speed (kt).

WDBAR: Mean wind direction (deg) relative to the ARRAY. Winds from 000 degrees in this coordinate system are blowing directly from the trees toward the array. Winds of 180 degrees are blowing directly from the array toward the trees. Winds from 090 degrees approach the array from the right if viewed facing the trees from the array. For meteorological wind direction, add 136 degrees to the value shown.

WSDEV: Standard deviation of wind speed (kt).

WDDEV: Wind direction standard deviation (sigma theta) (deg).

Fname	N	Dist	WSBar	WDBar	WSDev	WDDev
F0111351.001	24288	20	6.80	241.86	2.04	18.05
F0111351.002	24288	1040	7.57	241.77	2.03	14.85
F0111351.003	24288	120	7.52	239.61	2.12	15.66
F0111351.004	24288	220	7.50	236.77	2.15	15.84
F0111357.005	24288	420	7.57	241.51	2.09	15.54
F0111351.006	24288	820	7.48	238.82	1.99	14.66
F0951457.001	26067	1500	6.86	257.51	1.71	20.37
F0951457.002	26067	1040	7.24	257.06	1.74	19.41
F0951457.003	26067	2520	7.45	261.33	1.72	18.37
F0951457.004	26067	220	7.21	264.35	1.76	19.23
F0951457.005	26067	420	7.17	258.41	1.76	19.30
F0951457.006	26067	820	7.09	257.17	1.70	19.00
F1731406.0B1	9500	20	5.83	86.75	1.66	23.25
F1731406.0B2	9500	60	5.91	84.26	1.64	21.41
F1731406.0B3	9500	120	6.11	82.37	1.67	20.90
F1731406.0B4	9500	220	6.04	84.01	1.65	20.67
F1731406.0B5	9500	420	6.14	78.03	1.63	22.73
F1731406.0B6	9500	820	6.18	75.67	1.61	24.55
F1741510.001	18845	20	8.46	91.77	2.12	23.45
F1741510.002	18845	60	8.63	87.79	2.13	22.99
F1741510.003	18845	120	8.75	91.12	2.12	23.56
F1741510.004	18845	220	8.66	93.65	2.09	23.16
F1741510.005	18845	420	8.70	88.02	2.16	23.06
F1741510.006	18845	820	8.63	88.62	2.11	21.91
F0061224.0A1	11621	20	6.57	352.37	2.45	16.33
F0061224.0A2	11621	1040	7.90	357.67	2.69	13.12
F0061224.0A3	11621	120	6.43	351.53	2.61	18.91
F0061224.0A4	11621	220	6.54	352.46	2.60	16.94
F0061224.0A5	11621	420	6.87	354.61	2.66	15.95
F0061224.0A6	11621	820	7.57	354.47	2.64	13.60
F0941312.0A1	10730	1500	5.86	2.59	2.07	24.95
F0941312.0A2	10730	1040	5.69	0.16	2.04	26.33
F0941312.0A3	10730	2520	6.10	6.10	2.14	22.60
F0941312.0A4	10730	220	4.79	7.90	1.75	31.61
F0941312.0A5	10730	420	5.13	1.01	1.85	31.29
F0941312.0A6	10730	820	5.52	359.95	1.96	31.03
F0941312.0B1	14840	1500	9.78	357.97	2.24	18.67
F0941312.0B2	14840	1040	9.36	356.81	2.21	19.39
F0941312.0B3	14840	2520	10.22	0.08	2.35	18.79
F0941312.0B4	14840	220	7.76	4.39	2.22	22.62
F0941312.0B5	14840	420	8.16	358.96	2.14	21.37
F0941312.0B6	14840	820	8.89	357.53	2.16	19.68
F1011321.001	20802	1500	16.73	347.37	2.89	10.78
F1011321.002	20802	1040	15.93	345.96	3.01	11.66
F1011321.003	20802	2520	17.51	349.95	2.95	10.21
F1011321.004	20802	220	12.40	351.62	3.48	17.22
F1011321.005	20802	420	13.52	346.58	3.27	15.16
F1011321.006	20802	820	15.10	346.45	3.01	12.10
F0061224.0B1	16750	20	10.65	21.33	2.93	16.67

Fname	N	Dist	WSBar	WDBar	WSDev	WDDev
F0061224.0B2	16750	1040	15.55	27.06	2.85	8.94
F0061224.0B3	16750	120	11.26	22.81	3.00	15.37
F0061224.0B4	16750	220	12.06	23.44	3.04	13.10
F0061224.0B5	16750	420	13.46	26.57	2.96	11.64
F0061224.0B6	16750	820	14.89	24.73	2.80	9.68
F1661705.0B1	21704	20	6.18	338.84	2.07	22.82
F1661705.0B2	21704	60	6.22	337.49	2.09	23.87
F1661705.0B3	21704	120	6.24	335.75	2.08	24.90
F1661705.0B4	21704	220	6.36	339.82	2.06	23.85
F1661705.0B5	21704	420	6.98	335.90	2.07	22.15
F1661705.0B6	21704	820	7.50	336.37	2.05	20.44
F1281420.001	27792	1500	7.81	341.79	2.52	26.38
F1281420.002	27792	1040	7.75	340.00	2.38	28.11
F1281420.003	27792	2520	8.08	343.58	2.43	26.98
F1281420.004	27792	3120	7.89	347.27	2.36	26.99
F1281420.005	27792	420	7.00	340.37	2.26	32.49
F1281420.006	27792	820	7.42	342.54	2.30	28.78
F1291339.001	19063	1500	12.67	19.95	2.13	11.83
F1291339.002	19063	1040	12.25	19.57	2.33	12.64
F1291339.003	19063	2520	13.20	21.72	2.17	11.44
F1291339.004	19063	3120	12.58	25.05	2.20	11.52
F1291339.005	19063	420	11.13	21.94	2.38	15.58
F1291339.006	19063	820	11.75	21.88	2.29	12.93
F0131639.0A1	32000	1500	13.27	14.02	2.77	15.57
F0131639.0A2	32000	1040	12.49	17.84	2.82	15.83
F0131639.0A3	32000	120	9.29	13.42	2.74	20.74
F0131639.0A4	32000	220	9.67	14.56	2.66	19.16
F0131639.0A5	32000	420	10.58	17.09	2.79	18.29
F0131639.0A6	32000	820	11.89	14.52	2.76	16.31
F0161252.001	20186	1500	11.58	150.45	4.03	11.75
F0161252.002	20186	1040	11.72	150.97	3.99	11.65
F0161252.003	20186	120	11.50	147.05	4.07	12.92
F0161252.004	20186	220	11.70	147.05	4.12	12.52
F0161252.005	20186	420	11.69	149.35	4.13	12.72
F0161252.006	20186	820	11.65	148.93	3.91	12.08
F1731406.0A1	9500	20	5.81	153.02	1.74	30.87
F1731406.0A2	9500	60	5.83	150.00	1.75	29.77
F1731406.0A3	9500	120	6.09	149.83	1.83	28.67
F1731406.0A4	9500	220	6.14	154.41	1.83	27.92
F1731406.0A5	9500	420	6.06	149.40	1.79	26.02
F1731406.0A6	9500	820	6.11	149.20	1.84	24.83

8.3 Synthetic Wind Generator Algorithm

The work on averaging techniques was performed more than a year before the portable wind towers were available. One second data from the standard towers were recorded only during Shuttle launches and landings. This limited the available real wind data. In order to get a sufficient amount of data to empirically confirm the analytical results on averaging, I devised an algorithm to generate synthetic winds.

The criteria for the synthetic wind generator were as follows:

- Generate one second wind speed and direction data.
- User selectable mean and standard deviation for both speed and direction.
- All second order properties, including correlations and spectra, realistic.
- Time series appears subjectively "realistic" to experienced observer.
- Logically and computationally simple to implement.

The structure of the synthetic wind generator was determined by trial and error. Based on the probability distributions of the real data from the standard wind towers, a lognormal distribution was selected for wind speed and a Gaussian distribution was selected for wind direction.

A Gaussian random number generator was created using the central limit theorem and the Microsoft Professional BASIC (R) uniform random number generator. Gaussian random numbers having a mean μ and standard deviation σ are generated from uniform random numbers U on the interval 0 to 1 by

$$G(\mu,\sigma)=\left(\sum_{i=1}^{12}U_i-6\right)*\sigma+\mu .$$

Lognormal random numbers were generated by exponentiating Gaussian random numbers with appropriate adjustments to the distribution constants.

To obtain realistic spectra and correlations, the data were smoothed using first order autoregressive (FOAR) filters (Merceret 1983):

$$Y(n)=\alpha Y(n-1)+(1-\alpha)X(n)$$

where $X(n)$ is the nth unfiltered datum and $Y(n)$ is the nth filtered datum. The smoothing constants α for wind direction and wind speed were separately empirically tuned for spectral behavior approximating the inertial subrange. The correct correlation shapes followed from the spectra. The final values were 0.92 for wind speed and 0.79 for wind direction. The filters reduce the variance, so the user selected value was corrected by a factor $\left(1-\alpha^2\right)/(1-\alpha)^2$ before being used by the random number generator.

During the evolution of the program, certain refinements appeared useful and were incorporated. These included protection against wind direction "wrap-around", and default values for the wind direction and speed standard deviations.

Wind direction "wrap-around" occurs when wind directions less than zero or more than 360 degrees are generated. Two protection mechanisms were employed. First, since the real wind data allow for a range of 0 to 540 degrees, that range was also allowed here. Second, a "guard band" of four sigma was placed above zero and below the upper limit (360 or 540). The user is not permitted to select a desired mean within the guard bands.

Based strictly on regression analysis of real winds from the standard SLF towers, formulas for default standard deviations for wind speed and direction were implemented. These are

$$\sigma_s=0.6\langle WS\rangle^{0.6} \text{ for } WS \text{ in kt and}$$

$$\sigma_\theta=44/\sqrt{\langle WS\rangle} \text{ for } WS \text{ in kt and } WD \text{ in degrees.}$$

The resulting values for wind speed sigma are consistent with those reported by Leahy, Hansen and Schroeder (1994), but their values for sigma theta are smaller than those produced by the above formula by about a factor of two. Since their results are for stable conditions and these are for near neutral conditions, and since their topography is much more regular than that near the SLF, the difference for sigma theta may not be significant.

The synthetic wind generator was run with a wide range of values for wind speed and direction, with both default and selected standard deviations. Its performance is summarized as follows:

- It reliably produces one second winds with the desired mean and standard deviations for speed and direction.
- The spectra and correlations approximate those of the inertial subrange as observed for real winds.
- The algorithm was easy to implement and runs quickly.
- Experienced observers looking at the time series judged them realistic except as follows:
    - Occasional "spikes" occurred in the wind speeds
    - The absence of long-term trends, a deliberate design feature, is noticeable and unrealistic but not objectionable.
- Third and fourth moments are usually realistic but are sometimes contaminated by infrequent outliers (the "spikes" observed in the time series).

The results were consistent with the design criteria and the generator was used to provide large quantities of data for comparison of averaging times and procedures. This configuration of the synthetic wind algorithm was not (and should not be) used to generate data for the purpose of examining the properties of peak wind speeds.

The source code in Microsoft Professional BASIC (R) follows:

```
DEFLNG I-N
SUB GetFakeWinds (WindArray(), N, Header$)
REM Generates simulated winds based on user supplied parameters

COLOR 5: CLS 0: NMIN = 2700          'minimum data length
LOCATE 3, 10: PRINT "Simulated wind generator v 1.4  01/93  FJM/KSC"
COLOR 3: LOCATE 5, 1
PRINT "The minimum sample size is "; NMIN; " which is the default."
LOCATE 9, 1

INPUT "How many wind samples do you want for this run?: ", N
IF N < NMIN THEN N = NMIN              'check for minimum length
REDIM WindArray(2, N)                  'allocate enough storage

REM Get the user supplied parameters
CLS
PRINT : PRINT
PRINT "Subroutine GETFAKEWINDS creates simulated winds at one second intervals."
PRINT "You will be asked for the mean and std dev for WS and WD."
PRINT : PRINT : PRINT

AlphaS = .92                          'default value for SLF 30 ft WS
AlphaD = .86 * AlphaS     'compute default WD smoothing from AlphaS and WSBAR

WSbar = 0
DO
   INPUT "Enter the mean(>0) for the windspeed: "; WSbar
LOOP UNTIL WSbar > 0
WSdev = .6 * WSbar ^ .6       'default WS sigma
PRINT : PRINT "The recommended standard deviation for WS is "; WSdev
INPUT "To accept this, press enter; otherwise, enter a positive value: "; Temp
IF Temp > 0 THEN WSdev = Temp
DO
   PRINT
   INPUT "Enter the mean in degrees (0-540) for the wind direction: "; WDbar
LOOP UNTIL (WDbar >= 0) AND (WDbar <= 540)
WDdev = 44 / SQR(WSbar)       'default WD sigma
PRINT : PRINT "The recommended standard deviation for WD is "; WDdev
INPUT "To accept this, press enter; otherwise, enter a value: "; Temp
IF Temp > 0 THEN WDdev = Temp

REM correct Std. Devs for effect of FOAR filters.
WeightD = FOARrespcor(AlphaD): WeightS = FOARrespcor(AlphaS)

REM adjust upper limit and/or WDbar to avoid wrap-around errors
LimWD = 360
IF WDbar > 360 THEN LimWD = 540
IF WDbar > 540 THEN
   PRINT
   PRINT "Mean WD of "; WDbar; " exceeding 540 degrees folded to ";
   WDbar = WDbar MOD 540
   PRINT WDbar
   PRINT
END IF
```

```
WrapBorder = 4 * WDdev
IF WrapBorder > 90 THEN
   WrapBorder = 90
   PRINT
   PRINT "Note: Wrap-around borders exceed 90 degrees - limited to 90."
   PRINT
END IF

REM Protect against zero wrap-around
IF WDbar < WrapBorder THEN
   WDbar = WDbar + 360
   LimWD = 540
   PRINT
   PRINT "WDbar too close to zero. To avoid wrap-around error, scale "
   PRINT "adjusted to 540 and WD adjusted from "; WDbar - 360; " to "; WDbar
   PRINT
END IF

REM Protect against upper limit wrap-around
IF (LimWD - WDbar) < WrapBorder THEN
   PRINT : PRINT "WDbar too close to upper limit to avoid wrap-around error."
   IF LimWD < 540 THEN
      LimWD = 540
      PRINT "Upper limit raised from 360 to 540 degrees."
   END IF

   IF WDbar > 360 THEN
      PRINT "WDbar reduced from "; WDbar; " to ";
      WDbar = WDbar - 360
      PRINT WDbar; " degrees."
   END IF

   PRINT
END IF

PRINT
INPUT "Fake Wind setup complete. Press ENTER to continue.", Flag$
REM initialize the wind generator
RANDOMIZE TIMER
WSold = WSbar                                    'initialize at the means
WDold = WDbar
a = SQR(LOG(1 + (WSdev * WeightS / WSbar) ^ 2))  'compute lognormal parameters
B = LOG(WSbar) - a * a / 2
WindArray(0, 0) = 0                              'initial time
WindArray(1, 0) = WSold                          'initial WS
WindArray(2, 0) = WDold                          'initial WD

PRINT : COLOR 7: PRINT "Generating Synthetic winds."
REM loop to fill the wind arrays
FOR I = 1 TO N
   WindArray(0, I) = I                                  ' Time in array
   WS = EXP(a * Gau(0, 1) + B)                            ' Lognormal variate
   WindArray(1, I) = AlphaS * WSold + (1 - AlphaS) * WS   ' Smoothed WS in array
   WSold = WindArray(1, I)
   WD = Gau(WDbar, WDdev * WeightD)                     ' Gaussian variate
   WindArray(2, I) = AlphaD * WDold + (1 - AlphaD) * WD   ' Smoothed WD in array
   IF WindArray(2, I) > LimWD THEN                      'upper wrap-around
```

```
      WindArray(2, I) = WindArray(2, I) MOD 360
   END IF
   IF WindArray(2, I) < 0 THEN                          'lower wrap-around
      WindArray(2, I) = WindArray(2, I) + 360
   END IF
   WDold = WindArray(2, I)
NEXT I

REM Round the values for display and create the headers
WSbar = CINT(WSbar * 10) / 10         'to tenths of knots
WSdev = CINT(WSdev * 100) / 100       'to hundredths of knots
WDbar = CINT(WDbar)                   'whole degrees
WDdev = CINT(WDdev * 10) / 10         'to tenths of a degree

Header$ = STR$(WSbar) + "," + STR$(WSdev) + "," + STR$(WDbar) + ","
Header$ = Header$ + STR$(WDdev)
REM Header$ = Header$ + "," + STR$(AlphaS) + "," + STR$(AlphaD)
LHead% = LEN(Header$)

BoilerPlate3$ = "Sav,σS,θav,σθ"
BoilerPlate3$ = BoilerPlate3$ + "= "
BoilerPlate2$ = "Syn Winds: " + BoilerPlate3$
BoilerPlate1$ = "Synthetic Winds: WSavg,WSσ,WDavg,WDσ"
BoilerPlate1$ = BoilerPlate1$ + "= "

IF LHead% > 72 THEN
   Header$ = "Header exceeded 72 characters and was omitted."
ELSEIF (LHead% + LEN(BoilerPlate1$)) < 73 THEN
   Header$ = BoilerPlate1$ + Header$
ELSEIF (LHead% + LEN(BoilerPlate2$)) < 73 THEN
   Header$ = BoilerPlate2$ + Header$
ELSEIF (LHead% + LEN(BoilerPlate3$)) < 73 THEN
   Header$ = BoilerPlate3$ + Header$
END IF

END SUB  ' End of GETFAKEWINDS    ***********************************

FUNCTION FOARrespcor (Alpha)
REM corrects for the FOAR response.
REM To account for the reduction of variance by the FOAR filter used to
REM autocorrelate the winds, an adjustment can optionally be made to the
REM standard deviation. The full correction to the standard deviation is
REM SQR((1-Alpha*Alpha)/((1-Alpha)*(1-Alpha))). It gets big at
REM large Alpha. A very close approximation at small Alpha which is
REM smaller at large Alpha is EXP(Alpha).

FOARrespcor = SQR((1 - Alpha * Alpha) / ((1 - Alpha) * (1 - Alpha)))
END FUNCTION
```

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13. ABSTRACT *(Maximum 200 words)*
This document presents results of a field study of the effect of sheltering of wind sensors by nearby foliage on the validity of wind measurements at the Space Shuttle Landing Facility (SLF). Standard measurements are made at one second intervals from 30-foot (9.1m) towers located 500 feet (152m) from the SLF centerline. The centerline winds are not exactly the same as those measured by the towers. A companion study, Merceret (1995), quantifies the differences as a function of statistics of the observed winds and the distance between the measurements and points of interest. This work examines the effect of nearby foliage on the accuracy of the measurements made by any one sensor, and the effects of averaging on interpretation of the measurements.

The field program used logarithmically spaced portable wind towers to measure wind speed and direction over a range of conditions as a function of distance from the obstructing foliage. Appropriate statistics were computed. The results suggest that accurate measurements require foliage be cut back to OFCM standards.

Analysis of averaging techniques showed that there is no significant difference between vector and scalar averages. Longer averaging periods reduce measurement error but do not otherwise change the measurement in reasonably steady flow regimes. In rapidly changing conditions, shorter averaging periods may be required to capture trends.

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