Standard Practice for Characterizing Surface Wind Using a Wind Vane and Rotating Anemometer[1]

This standard is issued under the fixed designation D 5741; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Editorially added a new Reference item in October 2002.

1. Scope

1.1 This practice covers a method for characterizing surface wind speed, wind direction, peak one-minute speeds, peak three-second and peak one-minute speeds, and standard deviations of fluctuation about the means of speed and direction.

1.2 This practice may be used with other kinds of sensors if the response characteristics of the sensors, including their signal conditioners, are equivalent or faster and the measurement uncertainty of the system is equivalent or better than those specified below.

1.3 The characterization prescribed in this practice will provide information on wind acceptable for a wide variety of applications.

NOTE 1—This practice builds on a consensus reached by the attendees at a workshop sponsored by the Office of the Federal Coordinator for Meteorological Services and Supporting Research in Rockville, MD on Oct. 29–30, 1992.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

D 5096 Test Method for Determining the Performance of a Cup Anemometer or Propeller Anemometer[2]

D 5366 Test Method for Determining the Dynamic Performance of a Wind Vane[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *aerodynamic roughness length* (z_0, m)—a characteristic length representing the height above the surface where extrapolation of wind speed measurements, below the limit of profile validity, would predict the wind speed would become zero **(1)**.[3] It can be estimated for direction sectors from a landscape description.

3.1.2 *damped natural wavelength* (λ_d, m)—a characteristic of a wind vane empirically related to the delay distance and the damping ratio. See Test Method D 5366 for test methods to determine the delay distance and equations to estimate the damped natural wavelength.

3.1.3 *damping ratio* (η, dimensionless)—the ratio of the actual damping, related to the inertial-driven overshoot of wind vanes to direction changes, to the critical damping, the fastest response where no overshoot occurs. See Test Method D 5366 for test methods and equations to determine the damping ratio of a wind vane.

3.1.4 *distance constant* (L, m)—the distance the air flows past a rotating anemometer during the time it takes the cup wheel or propeller to reach (1 − 1/e) or 63 % of the equilibrium speed after a step change in wind speed. See Test Method D 5096.

3.1.5 *maximum operating speed* (u_m, m/s)—*as related to anemometer*, the highest speed as which the sensor will survive the force of the wind and perform within the accuracy specification.

3.1.6 *maximum operating speed* (u_m, m/s)—*as related to wind vane*, the highest speed at which the sensor will survive the force of the wind and perform within the accuracy specification.

3.1.7 *standard deviation of wind direction* (σ_θ, degrees)—the unbiased estimate of the standard deviation of wind direction samples about the mean horizontal wind direction. The circular scale of wind direction with a discontinuity at north may bias the calculation when the direction oscillates about north. Estimates of the standard deviation such as suggested by **(2, 3)** are acceptable.

[1] This practice is under the jurisdiction of ASTM Committee D22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.11 on Meteorology.

Current edition approved May 10, 1996. Published July 1996.

[2] *Annual Book of ASTM Standards*, Vol 11.03.

[3] The boldface numbers in parentheses refers to the list of references at the end of this standard.

3.1.8 *standard deviation of wind speed* (σ_u, m/s)—the estimate of the standard deviation of wind speed samples about the mean wind speed.

3.1.9 *starting threshold* (u_0, m/s)—*as related to anemometer*, the lowest speed at which the sensor begins to turn and continues to turn and produces a measurable signal when mounted in its normal position (see Test Method D 5096).

3.1.10 *starting threshold* (u_0, m/s)—*as related to system*, the indicated wind speed when the anemometer is at rest.

3.1.11 *starting threshold* (u_0, m/s)—*as related to wind vane*, the lowest speed at which the vane can be observed or measured moving from a 10° offset position in a wind tunnel (see Test Method D 5366).

3.1.12 *wind direction* (θ, degrees)—the direction, referenced to true north, from which air flows past the sensor location if the sensor or other obstructions were absent. The wind direction distribution is characterized over each 10-min period with a scalar (non-speed weighted) mean, standard deviation, and the direction of the peak 1-min average speed. The circular direction range, with its discontinuity at north, requires special attention in the averaging process. A unit vector method is an acceptable solution to this problem.

3.1.12.1 *Discussion*—Wind vane direction systems provide outputs when the wind speed is below the starting threshold for the vane. For this practice, report the calculated values (see 4.3 or 4.4) when more than 25 % of the possible samples are above the wind vane threshold and the standard deviation of the acceptable samples, σ_θ, is 30° or less, otherwise report light and variable code, 000.

3.1.13 *wind speed* (u, m/s)—the speed with which air flows past the sensor location if the sensor or other obstructions were absent. The wind speed distribution is characterized over each 10-min period with a scalar mean, standard deviation, peak 3-s average, and peak 1-min average.

3.2 For definitions of additional terms used in this practice, refer to Terminology D 1356.

4. Summary of Practice

4.1 *Siting of the Wind Sensors*:

4.1.1 The wind sensor location will be identified by an unambiguous label which will include either the longitude and latitude with a resolution of 1 s of arc (about 30 m or less) or a station number which will lead to that information in the station description file. When redundant sensors or microscale network stations (for example, airport runway sensors) are available, they will have individual labels which unambiguously identify the data they produce.

4.1.2 The anemometer and wind vane shall be located at a 10-m height above level or gently sloping terrain with an open fetch of at least 150 m in all directions, with the largest fetch possible in the prevailing wind direction. Compromise is frequently recognized and acceptable for some sites. Obstacles in the vicinity should be at least ten times their own height distant from the wind sensors.

4.1.3 The wind sensors shall preferably be located on top of a solitary mast. If side mounting is necessary, the boom length should be at least three times the mast width. In the undesirable case that locally no open terrain is available and the measurement is to be made above some building, then the wind sensor height above the roof top should be at least 1.5 times the lesser of the maximum building height and the maximum horizontal dimension of the major roof surface. In this case, the station description file shall indicate the height above ground level (AGL) of the highest part of the building, the height of the wind sensors above ground, AGL, and the height of the wind sensors above roof level. Site characteristics shall be documented in sectors no greater than 45 nor smaller than 30 in width around the wind sensors. The near terrain may be characterized with photographs, taken at wind sensor height if possible, aimed radially outward at labeled central angles, with respect to true north. Average roughness of the nearest 3 km of each sector shall be characterized according to the roughness class as tabulated above **(4)**. The z_0 numbers in Table 1 are typical and not precise statements.

4.1.4 Important terrain features at distances larger than 3 km (hills, cities, lakes, and so forth, within 20 km) shall be identified by sector and distance. Additional information, such as aerial photographs, maps, and so forth, pertinent to the site, is recommended to be added to the basic site documentation.

NOTE 2—Cameras using 35-mm film in the landscape orientation will have the following theoretical focal length to field angle relationships:

50 mm yields 40°
40 mm yields 48°
28 mm yields 66°

Prints or transparencies may not utilize the total theoretical width of the image. It is desirable to label known angles in the photograph. For

TABLE 1 Characterizations Extracted from Wieringa, J. (4)

No.	z_0, m	Landscape Description
1:	0.0002 Sea	Open sea or lake (irrespective of the wave size), tidal flat, snow-covered flat plain, featureless desert, tarmac and concrete, with a free fetch of several kilometres.
2:	0.005 Smooth	Featureless land surface without any noticeable obstacles and with negligible vegetation; for example, beaches, pack ice without large ridges, morass, and snow-covered or fallow open country.
3:	0.03 Open	Level country with low vegetation (for example, grass) and isolated obstacles with separations of at least 50 obstacle heights; for example, grazing land without windbreaks, heather, moor and tundra, runway area of airports.
4:	0.10 Roughly open	Cultivated area with regular cover of low crops, or moderately open country with occasional obstacles (for example, low hedges, single rows of trees, isolated farms) at relative horizontal distances of at least 20 obstacle heights.
5:	0.25 Rough	Recently developed young landscape with high crops or crops of varying heights, and scattered obstacles (for example, dense shelter-belts, vineyards) at relative distances of about 15 obstacle heights.
6:	0.5 Very rough	Old cultivated landscape with many rather large obstacle groups (large farms, clumps of forest) separated by open spaces of about 10 obstacle heights. Also low-large vegetation with small interspaces, such as bushland, orchards, young densely planted forest.
7:	1.0 Closed	Landscape totally and quite regularly covered with similar-size large obstacles, with open spaces comparable to the obstacle heights; for example, mature regular forests, homogeneous cities, or villages.
8:	>2 Chaotic	Centers of large towns with mixture of low-rise and high-rise buildings. Also irregular large forests with many clearings.

example, a 45° sector photograph could have a central label of 360 with marker flags located at 337.5° and 022.5° true.

4.2 *Characteristics of the Wind Systems*—There are two categories of sensor design within this practice. *Sensitive* describes sensors commonly applied for all but extreme wind conditions. *Ruggedized* describes sensors intended to function during extreme wind conditions. The application of this practice requires the starting threshold (u_0) of both the wind vane and the anemometer to meet the same operating range category.

4.2.1 *Operating Range*:

Category	Starting Threshold, u_0	Maximum Speed, u_m
Sensitive	0.5 m/s	50 m/s
Ruggedized	1.0 m/s	90 m/s

4.2.2 *Dynamic Response Characteristics*—Dynamic response characteristics of the measurement system may include both the sensor response and a measurement circuit contribution. The specified values are for the entire measurement system, including sensors and signal conditioners **(5)**. It is expected that the characteristics of the sensors, which can be independently determined by the referenced Test Methods D 5096 and D 5366, will not be measurably altered by the circuitry.

Anemometer	Distance constant, L	<5 m
Wind vane	Damping ratio, η	>0.3
Wind vane	Damped natural wavelength, λ_d	<10 m

4.2.3 *Measurement Uncertainty*:

Wind speed	Between 0.5 (or 1) and 10 m/s	±0.5 m/s
Wind speed	>10 m/s	5 % of reading
Wind direction	Degrees of arc to true north	±5° (see Note 5)

NOTE 3—The relative accuracy of the position of the vane with respect to the sensor base should be less than ±3° for averaged samples. The bias of the sensor base alignment to true north should be less than ±2°.

4.2.4 *Measurement Resolution*:

	Average	Standard Deviation
Wind speed	0.1 m/s	0.1 m/s
Wind direction	1°	0.1°

4.2.5 *Sampling*—Periods of time, specified as the averaging intervals, are fixed clock periods and not running or overlapping intervals, except for the three-second gust. Outputs must be continuously and uniformly sampled during the reporting period. Incomplete data must be identified.

Wind speed	1 to 3 s (see Note 4)
Wind direction	1 to 3 s (see Note 5)

NOTE 4—A true 3-s average wind speed results from counting the output pulses of the anemometer transducer for 3 s. If a pulse-generating transducer is not used, a suitable sampling rate and averaging method is required to produce a true 3-s average.

NOTE 5—A sample of the wind direction may be used ONLY when the sample of wind speed is at or above the wind direction starting threshold.

4.3 *Standard Data Output for Archives*—Time labels should use the ending time of the interval. If a different labeling method is consistently used, it must be defined. The data outputs are listed as follows:

4.3.1 Ten-minute scalar averaged wind speed.

4.3.2 Ten-minute unit vector or scalar averaged wind direction.

4.3.3 Fastest 3-s gust during the 10-min period.

4.3.4 Time of the fastest 3-s gust during the 10-min period.

4.3.5 Fastest 1-min scalar averaged wind speed during the 10-min period (fastest minute).

4.3.6 Average wind direction for the fastest 1-min wind speed.

4.3.7 Standard deviation of the wind speed samples (1 to 3 s) about the 10-min mean speed (σ_u).

4.3.8 Standard deviation of the wind direction samples (1 to 3 s) about the 10-min mean direction (σ_θ).

4.4 *Optional Condensed Data Output for Archives*—Some networks will not be able to save eight 10-min data sets (48 values plus time and identification) each hour. For those cases, an abbreviated or condensed alternative is provided. When the condensed output is employed the following outputs are required.

4.4.1 Sixty-minute scalar averaged wind speed.

4.4.2 Sixty-minute unit vector or scalar averaged wind direction.

4.4.3 Fastest 3-s gust during the 60-min period.

4.4.4 Wind direction for the fastest 3-s gust.

4.4.5 Fastest 1-min scalar averaged wind speed during the 60-min period.

4.4.6 Average wind direction for the fastest 1-min wind speed.

4.4.7 Ending time of the fastest 1-min wind speed.

4.4.8 Root-mean-square of six 10-min standard deviations of the wind speed samples about their 10-min mean speeds.

4.4.9 Root-mean-square of six 10-min standard deviations of the wind direction samples about their 10-min mean directions.

4.5 *Nonstandard Data Outputs for Archives*—When some, but not all, of the required outputs are reported from a station which meets all of the measurement and sensor performance specifications, they may be reported as conforming to the standard with missing data. Stations which report all the standard outputs but do not meet the measurement specifications may not claim to meet this practice.

5. Significance and Use

5.1 This practice will characterize the distribution of wind with a maximum of utility and a minimum of archive space. Applications of wind data to the fields of air quality, wind engineering, wind energy, agriculture, oceanography, forecasting, aviation, climatology, severe storms, turbulence and diffusion, military, and electrical utilities are satisfied with this practice. When this practice is employed, archive data will be of value to any of these fields of application. The consensus reached for this practice includes representatives of instrument manufacturers which provides a practical acceptance of these theoretical principles used to characterize the wind.

6. Sampling Techniques

6.1 The longest sampling interval used in this practice is 3 s. It is possible to satisfy the requirement for a 3-s average wind speed and a 3-s sample wind direction by using a strategy which takes data into the system processor each 3 s. This generates 200 values for calculating the standard deviations for each 10-min period, when all samples are above the starting threshold speed. A better characterization of the peak 3-s speed comes from faster sampling. A 1-s sampling period is preferred, when possible, to find the peak 3-s speed from a running average rather than the clock-dependent average necessary with 3-s sampling. The 1-s sampling generates 600 values for calculating the standard deviations for each 10-min period.

7. System Operational Considerations and Requirements

7.1 The mounting design and protective measures taken should protect the measurement system from hostile environments such as high winds, icing, lightning, salt, or dust particles. The following considerations will optimize the value of these data taken during destructive storms.

7.2 *Survivability*—The support hardware must be designed to survive the maximum speed range of the sensors. To ensure this performance, the support structure with all instruments installed should withstand the forces of wind speeds 25 % higher than the measurement maximum. For maximum data recovery, the power system must have backup resources to record all wind data when primary power sources fail.

7.3 *Special Data Recovery*—Provisions can be made to save all the highest time resolution data during periods of destructive storms. This special recording should begin when either the 1-min average speed exceeds 20 m/s or when the 3-s average speed exceeds 25 m/s. The special recording should end 1 h after the last trigger event is observed. This process should be automatic and the data survival should be independent of commercial power.

8. Data Quality

8.1 *Quality Assurance*:

8.1.1 All calibrations or audits should use standard methods, such as those found in ASTM standards or described in **(6)**. All calibrations should be documented in site logs and should specify the calibration authority, such as NIST, to which calibration instruments can be traced or referenced, when necessary. Of special importance is the starting threshold for both wind speed and wind direction sensors which will predictably degrade with bearing wear and contamination.

8.1.2 Calibrations and audits verify performance at one point in time. The data should also be routinely inspected to validate the performance of the measurement system between calibrations or audits. At a minimum, range tests and rate-of-change tests should be automatically performed on machine-processible data. Discrepancies found, flagged, and responded to with corrective action should be documented and noted in the site log.

8.2 *Data Availability*:

8.2.1 Data quality is judged by the ability to learn all the necessary details about where and how the data were collected. A station file must be maintained and made available to data users. The operators of the measurement systems are responsible for gathering the necessary information, maintaining a station log on site, and transmitting the information in a standard format to a data archive such as National Climatic Data Center (NCDC). Then, the data user may acquire copies of the data and the support documentation from the same source.

8.2.2 The support documentation must include the following:

8.2.2.1 Station name and identification number,

8.2.2.2 Station location in longitude and latitude or equivalent,

8.2.2.3 Sensor type (sensitive or ruggedized),

8.2.2.4 Date of first continuous operation,

8.2.2.5 Siting information including,

(*1*) Sensor heights, AGL,

(*2*) Building top height, AGL, if appropriate,

(*3*) Surface roughness analysis by sector with analysis date,

(*4*) Site photographs with date (five-year repeat cycle),

(*5*) Tower size and distance of sensors from centerline, if appropriate, and

(*6*) Size and bearing of nearby obstructions to flow.

8.2.2.6 Measurement system description, including model and serial numbers,

8.2.2.7 Date and results of calibrations and audits,

8.2.2.8 Date and description of repairs and upgrades,

8.2.2.9 Data flowchart with sample rates and averaging methods,

8.2.2.10 Statement of exceptions to standard requirements, if any, and

8.2.2.11 Software documentation of all generated statistics.

9. Keywords

9.1 anemometer; fastest minute; peak gust; Sigma Theta; Sigma U; wind direction; wind speed; wind vane

REFERENCES

(**1**) Wieringa, J., "Representative Roughness Parameters for Homogeneous Terrain," *Boundary-Layer Meteorology*, Vol 63, 1993, pp. 323–363.

(**2**) Yamartino, R. J., "A Comparison of Several′ Single-Pass' Estimates of the Standard Deviation of Wind Direction," *Journal of Climate Applied Meteorology*, Vol 23, 1984, pp. 1362–1366.

(**3**) Mori, Y., "Evaluation of Several 'Single-Pass' Estimators of the Mean and the Standard Deviation of Wind Direction," *Journal of Climate Applied Meteorology*, Vol. 25, 1986, pp. 1387–1397.

(**4**) Wieringa, J., "Updating the Davenport Roughness Classification," *Journal of Wind Engineering Industrial Aerodynamics*, Vol 41, 1992, pp. 357–368.

(**5**) Snow, J. T., Lund, D. E., Conner, M. D., Harley, S. B., and Pedigo, C. B.," The Dynamic Response of a Wind Measuring System," *Journal of Atmospheric and Oceanic Technology*, Vol 6, 1989, pp. 140–146.

(**6**) "Quality Assurance Handbook for Air Pollution Measurement Systems," *Meteorological Measurements*, Vol IV, EPA/600/4-90/003, U.S. Environmental Protection Agency, Office of Research and Development, AREAL, Research Triangle Park, NC 27711, 1989, p. 207.