Designation: D 5527 – 00 (Reapproved 2002)$^{\epsilon 1}$

Standard Practices for Measuring Surface Wind and Temperature by Acoustic Means[1]

This standard is issued under the fixed designation D 5527; 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—Made editorial corrections to the table in 3.3 and to Equation 8 in October 2002.

1. Scope

1.1 This practice covers procedures for measuring one-, two-, or three-dimensional vector wind components and sonic temperature by means of commercially available sonic anemometer/thermometers that employ the inverse time measurement technique. This practice applies to the measurement of wind velocity components over horizontal terrain using instruments mounted on stationary towers. This practice also applies to speed of sound measurements that are converted to sonic temperatures but does not apply to the measurement of temperature by the use of ancillary temperature devices.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *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:* [2]

D 1356 Standard Terminology Relating to Sampling and Analysis of Atmospheres

D 3631 Test Methods for Measuring Surface Atmospheric Pressure

D 4230 Test Method of Measuring Humidity with Cooled-Surface Condensation (Dew-Point) Hygrometer

E 337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

E 380 Practice for Use of the International System of Units (SI) (the Modernized Metric System)

3. Terminology

3.1 *Definitions*—Refer to Terminology D 1356 for common terminology.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acceptance angle* ($\pm\alpha$, *deg*)— the angular distance, centered on the array axis of symmetry, over which the following conditions are met: (*a*) wind components are unambiguously defined, and (*b*) flow across the transducers is unobstructed or remains within the angular range for which transducer shadow corrections are defined.

3.2.2 *acoustic pathlength (d, (m))*—the distance between transducer transmitter-receiver pairs.

3.2.3 *sampling period(s)*—the record length or time interval over which data collection occurs.

3.2.4 *sampling rate (Hz)*—the rate at which data collection occurs, usually presented in samples per second or Hertz.

3.2.5 *sonic anemometer/thermometer*—an instrument consisting of a transducer array containing paired sets of acoustic transmitters and receivers, a system clock, and microprocessor circuitry to measure intervals of time between transmission and reception of sound pulses.

3.2.5.1 *Discussion*—The fundamental measurement unit is transit time. With transit time and a known acoustic pathlength, velocity or speed of sound, or both, can be calculated. Instrument output is a series of quasi-instantaneous velocity component readings along each axis or speed of sound, or both. The speed of sound and velocity components may be used to compute sonic temperature (T_s), to describe the mean wind field, or to compute fluxes, variances, and turbulence intensities.

3.2.6 *sonic temperature* (T_s), (K))— an equivalent temperature that accounts for the effects of temperature and moisture on acoustic wavefront propagation through the atmosphere.

3.2.6.1 *Discussion*—Sonic temperature is related to the velocity of sound c, absolute temperature T, vapor pressure of water e, and absolute pressure P by (**1**).[3]

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

Current edition approved Oct. 10, 2002. Published November 2000. Originally published as D 5527 – 94. Last previous edition D 5527 – 94.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

$$c^2 = 403T\ (1 + 0.32e/P) = 403T_s \quad (1)$$

(Guidance concerning measurement of P and e are contained in Test Methods D 3631, D 4230, and E 337.)

3.2.7 *transducer shadow correction*—the ratio of the *true* along-axis velocity, as measured in a wind tunnel or by another accepted method, to the instrument along-axis wind measurement.

3.2.7.1 *Discussion*—This ratio is used to compensate for effects of along-axis flow shadowing by the transducers and their supporting structure.

3.2.8 *transit time (t, (s))*—the time required for an acoustic wavefront to travel from the transducer of origin to the receiving transducer.

3.3 *Symbols:*

B	(dimensionless)	squared sums of sines and cosines of wind direction angle used to calculate wind direction standard deviation
c	(m/s)	speed of sound
d	(m)	acoustic pathlength
e	(Pa)	vapor pressure of water
f	(dimensionless)	compressibility factor
P	(Pa)	ambient pressure
t	(s)	transit time
T	(K)	absolute temperature, K
T_s	(K)	sonic temperature, K
γ	(dimensionless)	specific heat ratio (c_p/c_v)
M	(g/mol)	molar mass of air
n	(dimensionless)	sample size
R^*	(J/mol·K)	the universal gas constant
u	(m/s)	velocity component along the determined mean wind direction
u_s	(m/s)	velocity component along the array u axis
v	(m/s)	velocity component crosswind to the determined mean wind direction
v_s	(m/s)	velocity component along the array v axis
w	(m/s)	vertical velocity
WS	(m/s)	scalar wind speed computed from measured velocity components in the horizontal plane
θ	(deg)	determined mean wind direction with respect to true north
θ_r	(deg)	wind direction measured in degrees clockwise from the sonic anemometer + v_s axis to the along-wind u axis
α	(deg)	acceptance angle
ϕ	(deg)	orientation of the sonic anemometer axis with respect to the true north
σ_θ	(deg)	standard deviation of wind azimuth angle

3.4 *Abbreviations:Units*—Units of measurement used should be in accordance with Practice E 380.[4]

4. Summary of Practice

4.1 A calibrated sonic anemometer/thermometer is installed, leveled, and oriented into the expected wind direction to ensure that the measured along-axis velocity components fall within the instrument's acceptance angle.

4.2 The wind components measured over a user-defined sampling period are averaged and subjected to a software rotation into the mean wind. This rotation maximizes the mean along-axis wind component and reduces the mean cross-component v to zero.

4.3 Mean horizontal wind speed and direction are computed from the rotated wind components.

4.4 For the sonic thermometer, the speed of sound solution is obtained and converted to a sonic temperature.

4.5 Variances, covariances, and turbulence intensities are computed.

5. Significance and Use

5.1 Sonic anemometer/thermometers are used to measure turbulent components of the atmosphere except for confined areas and very close to the ground. This practice applies to the use of these instruments for field measurement of the wind, sonic temperature, and atmospheric turbulence components. The quasi-instantaneous velocity component measurements are averaged over user-selected sampling times to define mean along-axis wind components, mean wind speed and direction, and the variances or covariances, or both, of individual components or component combinations. Covariances are used for eddy correlation studies and for computation of boundary layer heat and momentum fluxes. The sonic anemometer/thermometer provides the data required to characterize the state of the turbulent atmospheric boundary layer.

5.2 The sonic anemometer/thermometer array shall have a sufficiently high structural rigidity and a sufficiently low coefficient of thermal expansion to maintain an internal alignment to within ±0.1°. System electronics must remain stable over its operating temperature range; the time counter oscillator instability must not exceed 0.01 % of frequency. Consult with the manufacturer for an internal alignment verification procedure.

5.3 The calculations and transformations provided in this practice apply to orthogonal arrays. References are also provided for common types of non-orthogonal arrays.

6. Interferences

6.1 Mount the sonic anemometer probe for an acceptance angle into the mean wind. Wind velocity components from angles outside the acceptance angle may be subject to uncompensated flow blockage effects from the transducers and supporting structure, or may not be unambiguously defined. Obtain acceptance angle information from the manufacturer.

6.2 Mount the sonic array at a distance that exceeds the acoustic pathlength by a factor of at least 2π from any reflecting surface.

6.3 To obtain representative samples of the mean wind, the sonic array must be exposed at a representative site. Sonic anemometer/thermometers are typically mounted over level, open terrain at a height of 10 m above the ground. Consider surface roughness and obstacles that might cause flow blockage or biases in the site selection process.

6.4 Carefully measure and verify array tilt angle and alignment. The vertical component of the wind is usually much smaller than the horizontal components. Therefore, the vertical wind component is highly susceptible to cross-component contamination from tilt angles not aligned to the chosen coordinate system. A typical coordinate system may include establishing a level with reference to either the earth or to local terrain slope. Momentum flux computations are particularly susceptible to off-axis contamination (**2**). Calculations and transformations (Section 9) for sonic anemometer data are based on the assumption that the mean vertical velocity ($\overline{w}$) is not significantly different from zero. Arrays mounted above a sloping surface may require tilt angle adjustments. Also, avoid

[4] Excerpts from Practice E 380 are included in Vol 11.03.