This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: D6011 – 96 (Reapproved 2022)

Standard Test Method for Determining the Performance of a Sonic Anemometer/Thermometer[1]

This standard is issued under the fixed designation D6011; 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.

1. Scope

1.1 This test method covers the determination of the dynamic performance of a sonic anemometer/thermometer which employs the inverse time measurement technique for velocity or speed of sound, or both. Performance criteria include: (*a*) acceptance angle, (*b*) acoustic pathlength, (*c*) system delay, (*d*) system delay mismatch, (*e*) thermal stability range, (*f*) shadow correction, (*g*) velocity calibration range, and (*h*) velocity resolution.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C384 Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D5527 Practices for Measuring Surface Wind and Temperature by Acoustic Means

IEEE/ASTM SI 10 American National Standard for Metric Practice

3. Terminology

3.1 *Definitions*—For definitions of terms related to this test method, refer to Terminology D1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *axial attenuation coefficient*—a ratio of the free stream wind velocity (as defined in a wind tunnel) to velocity along an acoustic propagation path (v_t / v_d) (**1**).[3]

3.2.2 *critical Reynolds number (R_c)*—the Reynolds number at which an abrupt decrease in an object's drag coefficient occurs (**2**).

3.2.2.1 *Discussion*—The transducer shadow corrections are no longer valid above the critical Reynolds number due to a discontinuity in the axial attenuation coefficient.

3.2.3 *Reynolds number (R_e)*—the ratio of inertial to viscous forces on an object immersed in a flowing fluid based on the object's characteristic dimension, the fluid velocity, and viscosity.

3.2.4 *shadow correction (v_{dm}/v_d)*—the ratio of the true along-axis velocity v_{dm}, as measured in a wind tunnel or by another accepted method, to the instrument along-axis wind measurement v_d.

3.2.4.1 *Discussion*—This correction compensates for flow shadowing effects of transducers and their supporting structures. The correction can take the form of an equation (**3**) or a lookup table (**4**).

3.2.5 *speed of sound (c,* (m/s)*)*—the propagation rate of an adiabatic compression wave:

$$c = \left(\gamma \partial P / \partial \rho\right)_s^{0.5} \quad (1)$$

where:

P = pressure
ρ = density,
γ = specific heat ratio, and
s = isentropic (adiabatic) process (**5**).

3.2.5.1 *Discussion*—The velocity of the compression wave

[1] This test method 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 March 1, 2022. Published April 2022. Originally approved in 1996. Last previous edition approved in 2015 as D6011 – 96 (2015). DOI: 10.1520/D6011-96R22.

[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 standard.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

defined along each axis of a Cartesian coordinate system is the sum of propagation speed c plus the motion of the gas along that axis. In a perfect gas (6):

$$c = (\gamma R^* T/M)^{0.5} \tag{2}$$

The approximation for propagation in air is:

$$c_{air} = [403\, T\,(1 + 0.32\, e/P)]^{0.5} = (403\, T_s)^{0.5} \tag{3}$$

3.2.6 *system clock*—the clock used for timing acoustic wavefront travel between a transducer pair.

3.2.7 *system delay (δt,* μs*)*—the time delay through the transducer and electronic circuitry (7).

3.2.7.1 *Discussion*—Each path through every sonic array axis can have unique delay characteristics. Delay (on the order of 10 to 20 μs) can vary as a function of temperature and direction of signal travel through the transducers and electronic circuitry. The average system delay for each axis in an acoustic array is the average of the delays measured in each direction along the axis:

$$\delta t = (\delta t_1 + \delta t_2)/2 \tag{4}$$

3.2.8 *system delay mismatch (δt_t,* μs *)*—the absolute difference in microseconds between total transit times t_t in each direction (t_{t1}, t_{t2}) through the system electronics and transducers.

3.2.8.1 *Discussion*—Due principally to slight differences in transducer performance, the total transit time obtained with the signal originating at one transducer can differ from the total transit time obtained with the signal originating at its paired transducer. The manufacturer should specify the system delay mismatch tolerance.

$$\delta t_t = |\, t_{t1} - t_{t2}\,| \tag{5}$$

3.2.9 *thermal stability range* (°C)—a range of temperatures over which the corrected velocity output in a zero wind chamber remains at or below instrument resolution.

3.2.9.1 *Discussion*—Thermal stability range defines a range of temperatures over which there is no step change in system delay.

3.2.10 *time resolution (Δt,* μs*)*—resolution of the internal clock used to measure time.

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

3.2.11.1 *Discussion*—Transit time (also known as time of flight) is determined by acoustic pathlength d, the speed of sound c, the velocity component along the acoustic propagation path v_d, and cross-path velocity components) v_n (8):

$$t = d[(c^2 - v_n^2)^{0.5} \pm V_d]/[c^2 - (v_d^2 + v_n^2)] \tag{6}$$

The transit time difference between acoustic wavefront propagation in one direction (t_1, computed for $+ v_d$) and the other (t_2, computed for $- v_d$) for each transducer pair determines the magnitude of a velocity component. The inverse transit time solution for the along-axis velocity is (9):

$$v_d = \frac{d}{2}\left[\frac{1}{t_1} - \frac{1}{t_2}\right] \tag{7}$$

The total transit times t_{t1} and t_{t2}, include the sum of actual transit times plus system delay through the electronics and transducers in each direction along an acoustic path, δ_{t1} and δ_{t2}. System delay must be removed to calculate v_d, that is:

$$t_1 = t_{t1} - \delta_{t1} \tag{8}$$

$$t_2 = t_{t2} - \delta_{t2} \tag{9}$$

3.2.11.2 *Discussion*—Procedures in this test method include a test to determine whether separate determinations of $\delta\, t_1$ and δt_2 are needed, or whether an average δt can be used. The relationship of transit time to speed of sound is:

$$c^2 = \left[\frac{d}{2}\left(\frac{1}{t_1} + \frac{1}{t_2}\right)\right]^2 + v_n^2 \tag{10}$$

and the inverse transit time solution for sonic temperature in air is as follows (5):

$$T_s = \left(\frac{d^2}{1612}\right)\left[\frac{1}{t_1} + \frac{1}{t_2}\right]^2 + \frac{v_n^2}{403} \tag{11}$$

3.2.12 *velocity calibration range (U_c* to *U_s,* (m/s))—the range of velocity between creeping flow and the flow at which a critical Reynolds number is reached.

3.2.12.1 *Discussion*—The shadow correction is valid over a range of velocities where no discontinuities are observed in the axial attenuation coefficient.

3.2.13 *velocity resolution (δv,* (m/s)*)*—the largest change in an along-axis wind component that would cause no change in the pulse arrival time count.

3.2.13.1 *Discussion*—Velocity resolution defines the smallest resolvable wind velocity increment as determined from system clock rate. For some systems, δv defined as the standard deviation of system dither can also be reported.

3.3 *Symbols:*

c	=	speed of sound, m/s,
C_p	=	specific heat at constant pressure, J/(kg·K),
C_v	=	specific heat at constant volume, J/(kg·K),
e	=	vapor pressure, Pa,
d	=	acoustic pathlength, m,
f	=	compressibility factor, dimensionless,
M	=	molecular weight of a gas, g/mol,
P	=	pressure, Pa,
R^*	=	universal gas constant, 8.31436 J/(mol·K),
RH	=	relative humidity, %,
t	=	transit time, μs,
t_t	=	total transit time, μs,
T	=	absolute temperature, K,
T_s	=	sonic absolute temperature, K,
U_c	=	upper limit for creeping flow, m/s,
U_s	=	critical Reynolds number velocity, m/s,
v_d	=	velocity component along acoustic propagation path, m/s,
v_{dm}	=	tunnel velocity component parallel to the array axis (v_t, cos θ), m/s,
v_n	=	velocity component normal to an acoustic propagation path, m/s,
v_t	=	free stream wind velocity component (unaffected by the presence of an obstacle such as the acoustic array), m/s,
δt	=	system delay, μs,