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Standard Guide for Measurement of Atmospheric Wind and Turbulence Profiles by Acoustic Means[1]

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1. Scope

1.1 This guide describes the application of acoustic remote sensing for measuring atmospheric wind and turbulence profiles. It includes a summary of the fundamentals of atmospheric sound detection and ranging (sodar), a description of the methodology and equipment used for sodar applications, factors to consider during site selection and equipment installation, and recommended procedures for acquiring valid and relevant data.

1.2 This guide applies principally to pulsed monostatic sodar techniques as applied to wind and turbulence measurement in the open atmosphere, although many of the definitions and principles are also applicable to bistatic configurations. This guide is not directly applicable to radio-acoustic sounding systems (RASS), or tomographic methods.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this guide.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *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]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

3. Terminology

3.1 *Definitions*—Refer to Terminology D1356 for general terms and their definitions.

3.2 *Definitions of Terms Specific to This Standard:*

Note: The definitions below are presented in simplified, common, qualitative terms. Refer to noted references for more detailed information.

3.2.1 *acoustic beam, n*—focused or directed acoustic pulse (compression wave) propagating in a radial direction from its point of origin.

3.2.2 *acoustic power, n*—relative amplitude or intensity (dB) of an atmospheric compression wave.

3.2.3 *acoustic refractive index, n*—ratio of reference (at a standard temperature of 293.15 K and 1013.25 hPa pressure) speed of sound value to its actual value.

3.2.4 *acoustic scatter, n*—the dispersal by reflection, refraction, or diffraction of acoustic energy in the atmosphere.

3.2.5 *acoustic scattering Cross-section Per Unit Volume (σ, m^{-1}), n*—fraction of incident power at the transmit frequency that is backscattered per unit distance into a unit solid angle.

3.2.6 *acoustic attenuation (φ, dB/100m), n*—loss of acoustic power (acoustic wave amplitude) by beam spreading, scattering, and absorption as the transmitted wavefront propagates through the atmosphere.

3.2.7 *backscatter, n*—power returned towards a receiving antenna.

3.2.8 *beamwidth (degrees), n*—one way angular width (half angle at –3dB) of an acoustic beam from its centerline maximum to the point at the beam periphery where the power level is half (3 decibels below) centerline beam power.

3.2.9 *bistatic, adj*—sodar configuration that uses spatially separated antennas for signal transmission and reception.

3.2.10 *clutter, n*—undesirable returns, particularly from sidelobes, that increase background noise and obscure desired signals.

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[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.

3.2.11 *decibel (dB), n*—logarithmic (base 10) ratio of power to a reference power, usually one-tenth bell; for power P1 and reference power P2, the ratio is given by $10\log_{10}$ (P1/P2).

3.2.12 *directivity, n*—concentration of transmitted power (dB) within a narrow beam by an antenna, measured as a ratio of power in the main beam to power radiated in all directions.

3.2.13 *Doppler frequency (f_D, Hz), n*—shifted frequency measured at the receiver from the scattered acoustic signal.

3.2.14 *effective antenna aperture (A_e, m^2), n*—product of antenna area with antenna efficiency.

3.2.15 *gain (G), n*—increase in power (dB) per unit area arising from the product of antenna directivity with efficiency.

n—non-dimensional effective aperture amplification factor arising from an antenna's directivity.

3.2.16 *inter pulse period (t_{max}, s), n*—time between the start of successive transmitted pulses or pulse sequences.

3.2.16.1 *Discussion*—The inter pulse period (IPP) is the inverse of the pulse repetition frequency (PRF) in Hertz (Hz).

3.2.17 *monostatic, adj*—sodar configuration that uses the same antenna for transmission and reception.

3.2.18 *Neper, n*—natural logarithm of the ratio of reflected to incident sound energy flux density at a given range.

3.2.19 *pulse, n*—finite burst of transmitted energy.

3.2.20 *pulse length (τ, s), n*—duration of a single pulse.

3.2.21 *pulse sequence, n*—train of pulses, often at different frequencies.

3.2.22 *range (r, m), n*—distance from the antenna surface to the scattering surface.

3.2.23 *range aliasing, n*—sampling ambiguity that arises when returns are received from a transmission that was made prior to the latest transmitted pulse sequence, usually from a scattering surface located beyond the maximum unambiguous range.

3.2.24 *range gate, n*—conical section of the atmosphere containing the scattering volume from which acoustic returns can be resolved.

3.2.25 *range resolution (D_r, m), n*—length of a segment of the scattering volume along the axis of beam propagation.

3.2.25.1 *Discussion*—Range resolution equals half the product of speed of sound and pulse length ($\Delta r = c\tau/2$).

3.2.26 *received power (P_r, W), n*—electrical power received at an antenna during listening mode; the product of received acoustic power with receiver conversion efficiency from acoustic to electrical power.

3.2.27 *scattering volume (m^3), n*—volume of a conical section in the atmosphere centered on the radial along which the acoustic beam propagates.

3.2.27.1 *Discussion*—This is commonly calculated from the 3 dB beamwidth.

3.2.28 *sidelobes, n*—acoustic energy transmitted in a direction other than the main beam (or lobe).

3.2.28.1 *Discussion*—Sidelobes vary inversely with antenna size and transmitted frequency.

3.2.29 *signal-to-noise-ratio, n*—ratio of the calculated received signal power to the calculated noise power, frequently abbreviated as SNR.

3.2.30 *sound detection and ranging (sodar), adj*—remote sensing technique that generates acoustic pulses that propagate through the atmosphere, and subsequently samples the scattered atmospheric returns.

n—instrument that performs these functions.

3.2.31 *temperature structure parameter (C_T^2, K), n*—structure constant for measurement of fast-response temperature differences over small spatial separations that accounts for the effects of molecular diffusion and turbulent energy dissipation into heat.

3.2.32 *transmit frequency (f, Hz), n*—selected frequency or frequencies at which an acoustic transmitter's output is achieved.

3.2.33 *transmitted power (P_t, W), n*—electrical power in watts measured at the antenna input; acoustic power radiated by an antenna is the product of transmitted electrical power with the conversion efficiency from electrical to acoustic power.

3.3 *Symbols:*

$\hat{a}$ = viscous and molecular sound absorption coefficient, Nepers per wavelength, m^{-1},
A_e = effective antenna aperture, m^2,
c = speed of sound, ms^{-1},
C_T^2 = temperature structure parameter, K $m^{-2/3}$,
ε_R = receiver electromechanical efficiency,
ε_T = transmitter electromechanical efficiency,
f = central acoustic frequency transmitted by the sodar, Hz,
f_D = Doppler frequency, Hz,
G = antenna gain,
P_r = received electrical power, W,
P_t = transmitted electrical power, W,
r = range from transmitter to a range gate, m,
r_{max} = maximum unambiguous range, m,
t = time between transmission of an acoustic pulse and reception of returning echoes, s,
T_K = temperature in Kelvins, K,
t_{max} = IPP, the maximum listening time between transmitted pulses or pulse sequences, s,
V_t = target velocity, ms^{-1},
Δr = range resolution, m,
φ_m = combined viscous and molecular attenuation factor,
φ_x = excess attenuation factor,
λ = acoustic wavelength, m,
σ = acoustic scattering crossection per unit volume, m^{-1}, and
τ = pulse length, s.

4. Summary of Guide

4.1 The principles of atmospheric wind and turbulence profiling using the sound direction and ranging technique are described.

4.2 Considerations for sodar equipment, site selection, and equipment installation procedures are presented.