Designation: D7145 − 22

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

This standard is issued under the fixed designation D7145; 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 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.

[1] This guide 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 May 2022. Originally approved in 2005. Last previous edition approved in 2015 as D7145 – 05 (2015). DOI: 10.1520/D7145-22.

[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.

4.3 Data acquisition and quality assurance procedures are described.

5. Significance and Use

5.1 Sodars have found wide applications for the remote measurement of wind and turbulence profiles in the atmosphere, particularly in the gap between meteorological towers and the lower range gates of wind profiling radars. The sodar's far field acoustic power is also used for refractive index calculations and to estimate atmospheric stability, heat flux, and mixed layer depth (**1-5**).[3] Sodars are useful for these purposes because of strong interaction between sound waves and the atmosphere's thermal and velocity micro-structure that produce acoustic returns with substantial signal-to-noise ratios (SNR). The returned echoes are Doppler-shifted in frequency. This frequency shift, proportional to the radial velocity of the scattering surface, provides the basis for wind measurement. Advantages offered by sodar wind sounding technology include reasonably low procurement, operating, and maintenance costs, no emissions of eye-damaging light beams or electromagnetic radiation requiring frequency clearances, and adjustable frequencies and pulse lengths that can be used to optimize data quality at desired ranges and range resolutions. When properly sited and used with adequate sampling methods, sodars can provide continuous wind and turbulence profile information at height ranges from a few tens of meters to over a kilometer for typical averaging periods of 1 to 60 minutes.

6. Monostatic Sound Direction and Ranging

6.1 *Sodar Design Types.* Most commercially available sodars operate using a monostatic phased array antenna design composed of a planar array of acoustic transmitters that form the emitted beam and steer it towards the desired direction. Other designs, including those based on non-phased antennas for each beam and those based on bi-static configurations, are also available. An advantage offered by bi-static sodars is that they use signals scattered from small scale velocity fluctuations that are not available in monostatic configurations. Except for beam forming, steering, and the simplified monostatic sodar equation, the information provided below is generally applicable to those designs as well.

6.2 *Description of Operation.* A phased array monostatic sodar emits acoustic pulses (adiabatic compression waves) at a transmit frequency or frequencies. Pulses from each antenna are formed into a conical beam or wavefront with its vertex at the antenna. Individual transducer pulse timing or phase shifting methods, indicated by Φ in Fig. 1, are used to shape the beam and steer it in the desired direction. As it travels along a radial direction through the atmosphere at speed of sound (c), this acoustic wave experiences attenuation by spreading, absorption, and scattering as described below. Temperature inhomogeneities and sharp gradients encountered by the propagating beam deform and scatter the beam. Wind velocity components along the axis of propagation also Doppler- shift the acoustic frequency of backscattered signals. A schematic drawing of acoustic wavefront generation and backscatter from a reflecting surface is presented in Fig. 1. After its transmission of an acoustic pulse train, the sodar switches to listening mode for backscattered acoustic signals. Returning signals are characterized by their intensity (amplitude), spectral width, Doppler-shifted frequency, and elapsed time (t) from initial pulse transmission. Returns from lower heights are received sooner than returns from greater heights. The relationship between elapsed time (t), speed of sound (c), and radial range (r) to the scattering surface is given by:

$$r = ct/2 \tag{1}$$

where the factor of 2 accounts for travel along outward propagating and return paths. Wind profiling sodars that transmit a minimum of three radial beams resolve horizontal and vertical wind components. Assuming homogeneity in the wind field above the sodar, trigonometry is used to resolve distance along each radial, which is then converted to height above the sodar antenna. The user is then presented with a vertical profile of wind, turbulence, and signal strength information. Height ranging, range resolution, and signal quality are functions of sodar performance and its operating environment, as described below.

6.3 *The Sodar Equation.* The power received (P_r) by a sodar's acoustic antenna is a product of sodar performance and atmospheric attenuation factors. Sodar performance factors include effective transmitted power (P_t) at its transmitted frequency(ies), effective antenna aperture (A_e), transmitter and receiver efficiency factors (ε_T and ε_R), and pulse length (τ). Atmospheric scattering factors include the acoustic scattering crossection (σ) and attenuation factors φ_m and φ_x. Attenuation factor φ_m represents "classical" viscous losses plus the combination of molecular rotational and vibrational absorption. The second factor (φ_x) represents excess attenuation due to complex interactions of the acoustic beam with larger scale atmospheric features. The sodar performance and atmospheric factors are combined in a simplified monostatic sodar equation for received power:

$$P_r = \{sodar\ performance\}\{atmospheric\ factors\}$$
$$= \{(P_t A_e)(\varepsilon_T \varepsilon_R)(c\tau/2)\}\{\sigma\varphi_m\varphi_x\} \tag{2}$$

6.4 *Sodar Performance.* Sodar performance characteristics include the sodar transmitted acoustic power, and the efficiency with which power is transmitted and received. P_t A_e is the power-aperture product. $A_e = AG/r^2$ is the solid angle subtended by an antenna of aperture (A, m^2) multiplied by the effective aperture factor (G, the antenna's gain), as viewed at range (r) from the scattering volume. Range resolution ($\Delta r = c\tau/2$) is the length (m), along the radial axis of signal propagation, of the instantaneous scattering volume and defines the volume from which a backscattered signal is resolved. Note that range resolution determines range gate thickness. Scattering surfaces that produce useful acoustic returns often occupy only a fraction of the scattering volume in the real atmosphere (see Fig. 1 and 6.6). The magnitude of the returned signals is directly proportional to the percentage of the scattering volume occupied by scattering surfaces and the intensity of the turbulence (C_T^2) producing the return.

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

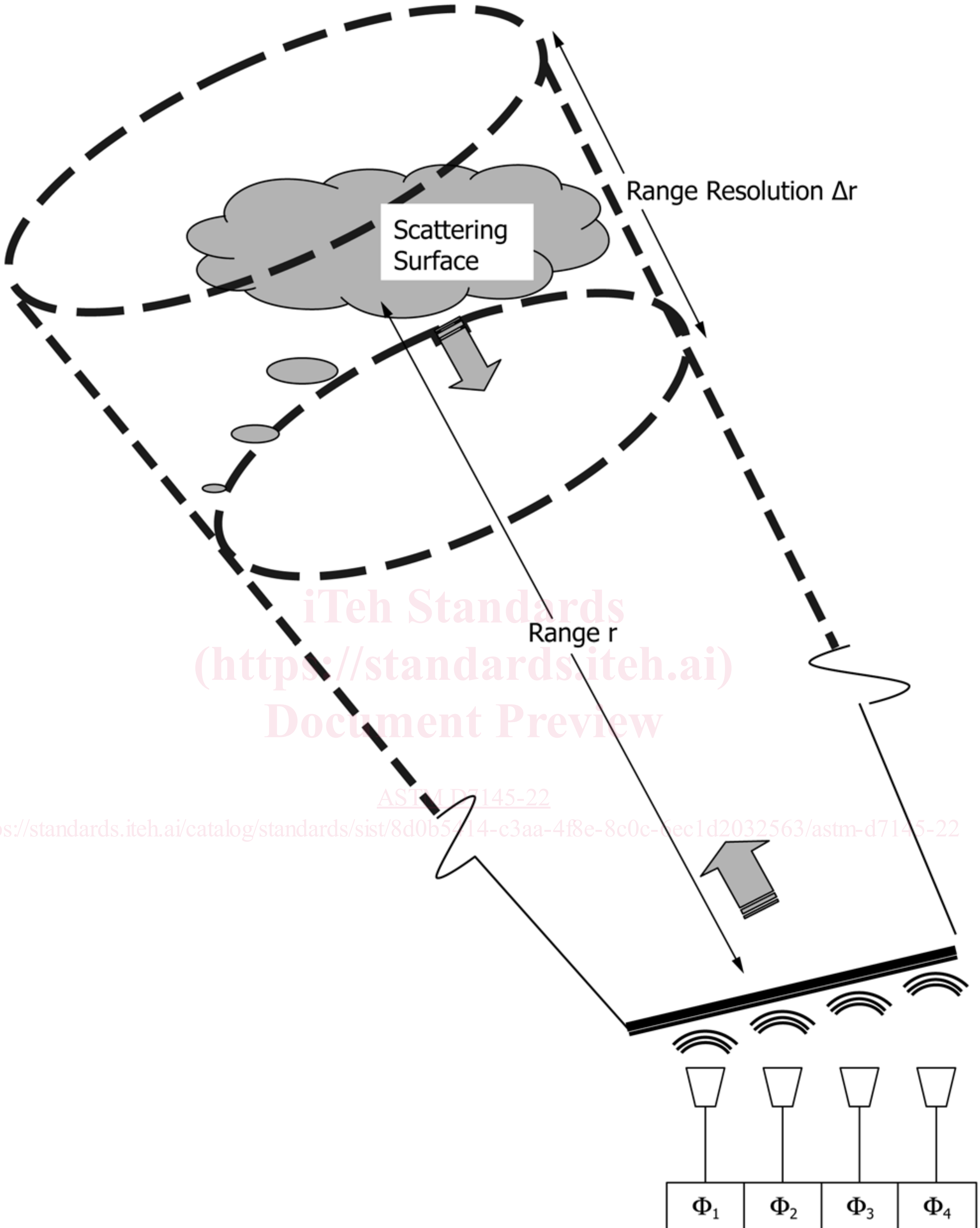

FIG. 1 Acoustic Wavefront Generation and Backscatter

6.5 *Pulse Length and Inter Pulse Period (IPP).* Pulse length and IPP (t_{max}) define height and velocity limits for valid sodar signals. Pulse length and system settling time (time of recovery from the state of excitation during pulse transmission) determine the minimum height (first range gate) from which backscattered signals can be received. IPP determines the maximum range from which unambiguous backscattered returns are received. If all measurable returns are not received prior to the initiation of the next pulse, it is possible that returns from the earlier pulse will be received in the same time period as returns from the new pulse. This causes an ambiguous signal known as range aliasing. Because t_{max} represents the maximum time between pulses, the maximum unambiguous range is defined by:

$$r_{max} = ct_{max}/2 \tag{3}$$

Any returns from targets beyond r_{max} will appear as spurious signals in a range gate intended for returns from the subsequent pulse. Like r_{max}, Doppler shifted velocity measurements can be unambiguously determined only within certain limits. The frequency limits over which the Doppler shift can be unambiguously determined depends on t_{max}, which should be as high as needed to unambiguously sample the maximum anticipated velocity. Thus, a sodar's maximum and minimum range, range resolution, and maximum velocity range are defined by τ and t_{max} settings and the transmitted central frequency. Some sodars are designed to operate using pulse coding with multiple central frequencies. This feature helps distinguish backscattered signal from clutter and enhances the probability of useful returns.

6.6 *Attenuation by Absorption.* Absorption reduces the radiated power of a propagating acoustic wave through viscous losses, and by the excitation of rotational and vibrational modes in atmospheric gases (**6**). The excitation of atmospheric gases is strongly dampened by the presence of atmospheric water vapor. Thus, sodar performance is enhanced in moist rather than dry environments. Combined absorption effects are represented by the viscous and molecular attenuation factor $\varphi_m = e^{-2\hat{a}r}$. This factor contains the product of $\hat{a}$, the molecular and viscous absorption coefficient, with range. Note that distances from the transmitter to the range gate and from the range gate to the receiver are assumed to be the same. This is true for a monostatic sodar, but range distances can vary for bistatic configurations.

6.7 *Excess Attenuation.* An additional factor known as excess attenuation φ_x, usually manifested as excessive beam spreading and loss of returned acoustic power, is also present in the atmosphere. Excess attenuation is highly variable in magnitude and duration due to the complex interactions between transient shear and turbulence effects with a propagating acoustic wavefront and its path geometry (**7,8**). Excess attenuation increases with the wind speed, turbulence level, and acoustic frequency, but decreases with increasing beamwidth.

6.8 *Scatter.* Scatter disperses propagating acoustic signal power, but also produces the sodar's returned (backscattered) signal. Scattering happens as acoustic wavefronts propagating through the atmosphere encounter perturbations in the acoustic refractive index caused by turbulent patches of air containing temperature gradients. The magnitude of this turbulence is represented by the temperature structure parameter C_T^2. Refractive index inhomogeneities most effectively scatter acoustic energy of twice their wavelength. Energy propagating along one direction is scattered over many directions when it encounters a scattering surface, but the magnitude of the off-axis power loss during a scattering event is usually much smaller than the incident power. Therefore, most of the acoustic power continues to propagate along its original path. This Born "single scatter" approximation (**6**) also applies to backscattered signals. Most back-scattered signals are expected to reach the receiver without being completely dispersed by multiple scattering. Acoustic scattering cross-section per unit volume (σ) defines the fraction of incident power at frequency (f) backscattered per unit distance. For a monostatic sodar, σ is represented by (**9**):

$$\sigma = 0.0039(2\pi f/c)^{0.333} C_T^2 / T_K^2 \tag{4}$$

where T_K is the absolute temperature in Kelvins. Monostatic sodars rely on returns from the atmosphere's thermal gradients, while returns to bistatic sodars are enhanced by additional scatter from velocity fluctuations. Thermal gradients and turbulence is often weak during the transition periods through sunrise and sunset, which degrades the performance of monostatic sodars during these times.

6.9 *Acoustic Wavelength and Frequency.* Acoustic beams of wavelength λ and frequency (f) propagating through the atmosphere can be characterized in terms of amplitude and phase. Amplitude is in proportion to the energy content or strength (intensity) of an acoustic pulse, and phase refers to the position of a point along the wave relative to a chosen reference. Phase is expressed in circular units, with a complete wave corresponding to 360° or 2π radians. Wavelength is the distance between two consecutive points of the same phase along the wave. Frequency is the number of wavelengths that pass a measurement point per unit time, which is usually measured in cycles per second or Hertz (Hz). The relationship between frequency, wavelength, and speed of sound (c, nominally 340 ms^{-1}) is:

$$f\lambda = c \tag{5}$$

6.10 *The Doppler Effect.* The Doppler effect is created by the action of reflecting surface (target) motion on a propagating acoustic beam. Target velocity (V_t) is considered positive if it is moving away from the acoustic source and negative if moving towards the acoustic source. Velocity of the target along the direction of acoustic propagation either lowers (target moving away from the source of the acoustic beam) or raises (target moving towards the source of acoustic beam) the frequency of the backscattered wavefront in direct proportion to target velocity, as given by:

$$f_D = -2\, V_t/\lambda \tag{6}$$

The factor 2 in Eq 6 indicates a double Doppler shift: one shift occurs as the acoustic beam impinges on the target or scattering surface; another occurs as the backscattered wavefront departs the scattering surface. Thus, a 4000 Hz acoustic beam impinging on a receding target moving along the radial at a speed of +2 ms^{-1} would be Doppler shifted –47 Hz, returning a backscattered wavefront of 3953 Hz.

6.11 *Turbulence Effects.* Because the sodar uses atmospheric reflections from pulse-volume conical sections (range gates), turbulent motions of scales larger than the scattering volume within a range gate produce the desired Doppler effect, while turbulent motions smaller than the scattering volume give rise to a pulse volume filtering effect that causes signal spectral broadening (**10**). Spectral broadening of the scattered signal is also related to the antenna beam width and is enhanced by wind shear present within the range gate. Refer to 7.3 and Fig. 2 below for a description of spectra and signal processing. Being a highly variable and transitory phenomenon, changes in turbulence intensity account for much of the variability in sodar performance.

6.12 *Wind Speed Effects.* High and low wind speeds can have adverse effects on sodar performance. Deleterious effects of high winds include: (*1*) increasing the background noise level; (*2*) deflecting the acoustic beam; (*3*) increasing turbulent mixing, thereby diminishing thermal inhomogeneities that backscatter acoustic energy. Winds blowing across the ground, through telephone wires, and so forth contribute to clutter that

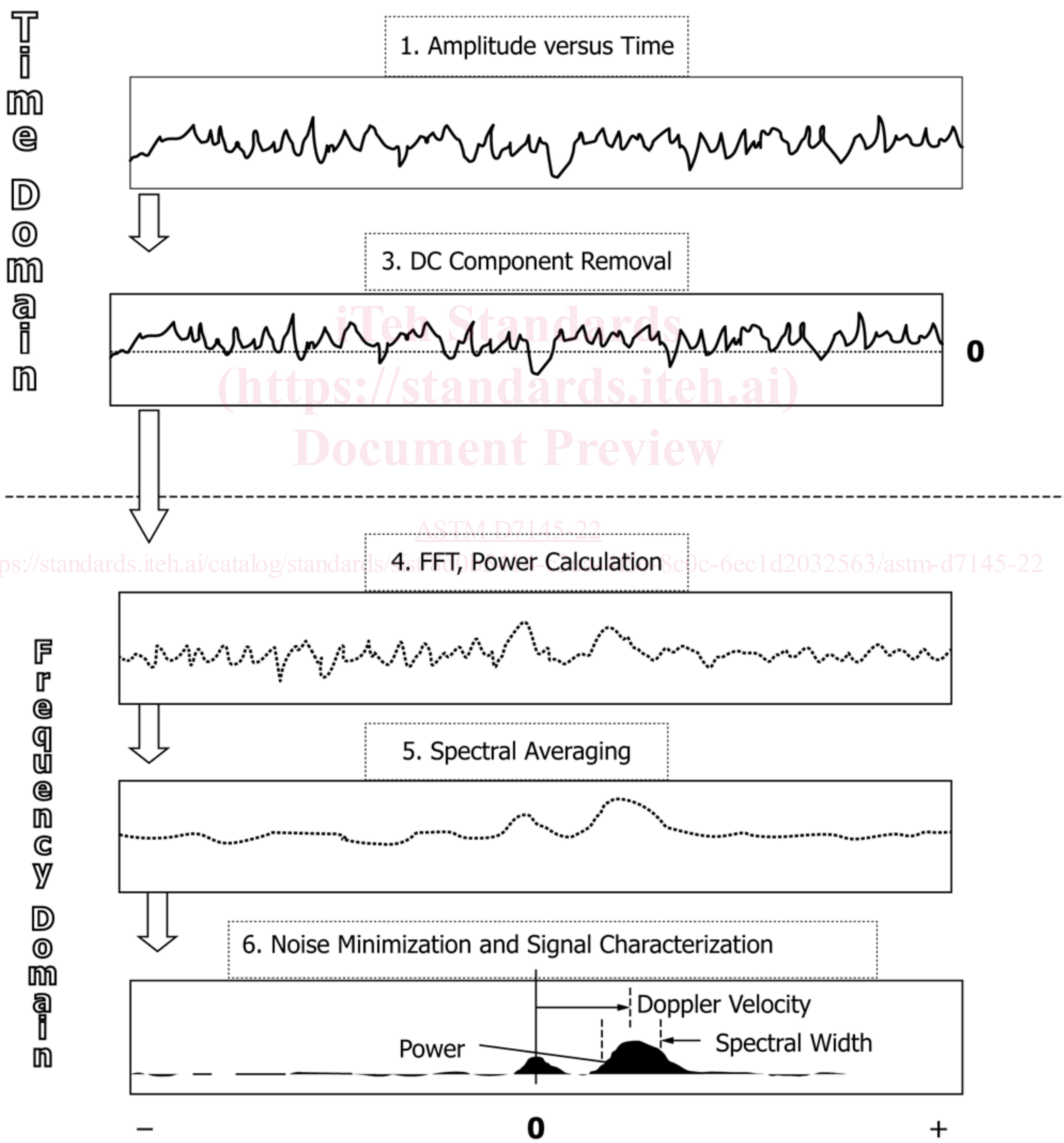

FIG. 2 Sodar Signal Processing Steps

mask the returned acoustic signal. This, combined with lower backscattered signal strength due to weaker thermal inhomogeneities, lowers the SNR. Although a sodar's acoustic beam is usually quite broad, strong winds can sometimes deflect it far enough that backscattered echoes miss the receiver. These adverse effects increase with wind speed, particularly when the winds are gusty. The backscattered signal will be weaker (in terms of SNR) and less likely to impinge upon the receiver in stronger than in lighter crossbeam winds. The net effect is that, in strong gusty winds, a tendency exists for the sodar to under-sample the stronger winds. Conversely, very low wind speeds produce near zero Doppler shifts. Fixed echo returns from stationary objects also produce a zero Doppler shift that is difficult to distinguish from light wind returns.

6.13 *Noise Effects.* The SNR is a major limiting factor in sodar performance. This degradation is due to broadband or narrow-band noise from active or passive sources (**11**). The principal effect of active broadband noise from sources such as industrial operations and road or aircraft traffic is to raise the noise level, thereby decreasing the SNR. Active narrow-band noise from sirens, beepers, rotating fans, birds, and insects that are in the sodar's frequency range can also be misinterpreted by the sodar as valid returns. Passive noise sources are objects such as buildings, trees, towers, or transmission lines that act as acoustic reflectors. Unless identified and eliminated, stationary passive sources produce returns at zero velocity, thereby biasing the sodar's returned signal spectrum towards zero.

6.14 *Precipitation Effects.* Precipitation presents extra scattering surfaces traveling at velocities that differ from free air motions. The scattered signal from falling precipitation, which increases with precipitation rate, usually greatly exceeds the returns from the free air. Therefore, precipitation is particularly problematic for vertical velocity measurements. Precipitation striking solid surfaces also increases background noise, and snow is a good sound absorber. Depending on their design and discrimination algorithm efficiency, sodars are subject to varying degrees of bias and data loss during precipitation and will likely not produce usable wind profile data above the first few range gates during heavy precipitation. Peters et al. (1998) discuss sodar performance during precipitation and illustrate the effects of precipitation rate on data validity (**12**).

6.15 *Compensating Sodar Software.* Commercially available sodars typically include algorithms used to distinguish valid returned signal from noise, and may include compensation for other deleterious atmospheric effects. Sodar software can be adjusted to optimize operation in various acoustic environments. Careful site selection and noise analysis are needed to optimize sodar performance and assure data quality.

6.16 *Sodar Data.* The types of data typically provided by a sodar include vertical profiles of the strength of returns from the atmosphere, the vertical and horizontal winds, and perhaps standard deviations of these wind measurements. Profiles of returned signal strength provide useful information about atmospheric features such as the depth of turbulent mixing (mixing depth) during the day, and the heights of wind shear or turbulent layers aloft that occur at night. Profiles of wind speed and direction, and their standard deviations are also provided so long as there is sufficient returned power and data quality algorithms are satisfied. Sodar measurement capabilities were extensively studied over a period ranging from the mid-1970s to the mid-1990s. Results from these studies are most usefully presented in terms of bias and comparability. Bias is the mean difference between measurements provided by the sodar and a reference instrument. Comparability is the square root of the squared difference, which includes the effects of both bias and random errors. Crescenti (1997) presents a summary of sodar studies indicating that a properly sited sodar operating under favorable conditions can produce data with negligible bias, wind speed measurements with an average comparability of $1.11 \pm 0.1\ ms^{-1}$, and wind direction comparability of 22 ± 2.1 degrees (**13**). Sodar measurements of turbulence, presented as the standard deviations of wind directions, can be problematic due to beam divergence, pulse volume averaging, and a slow pulse repetition rate. However, usable vertical velocity standard deviation measurements have been reported during convection [see (**13**) and references cited therein].

7. Equipment Description

7.1 A sodar consists of an antenna array with a transmitter/receiver unit, an acoustic signal processor, and a control and data acquisition system. Signal and power cables connect the transmitter/receiver unit to the data processor and acquisition system.

7.2 The antenna unit consists of compression drivers or piezo-electric transducers, typically in an array that lies within an acoustic enclosure. The drivers or transducers create an acoustic pulse (typically in the 1000 to 6000 Hz range), forms the transmitted acoustic beam, and then switches to a listening mode to intercept scattered acoustic returns, converting those returns into signal voltages. The acoustic enclosure minimizes side lobe emissions and reflected noise. The enclosure may also be lined with acoustic foam to minimize unwanted reflections and ambient noise intrusion.

7.3 The acoustic signal processor generates a signal that drives the transmitter/receiver to generate the transmitted beam, listens for, and then processes the retuned signal. The returned signal (or an average of several signals), which consists of a complex waveform sampled over a unit of time limited by the IPP, is converted into a frequency spectrum typically using a fast Fourier transform algorithm. The central frequency of this spectrum is the transmitted frequency (zero Doppler shift), with positive and negative departures from zero presented to the left and right of the central frequency. The spectrum consists of four measurable quantities: (*1*) the background signal (noise) power; (*2*) back-scattered signal power; (*3*) the Doppler shift of the signal peak; (*4*) the width of the returned signal. The background signal strength is a measure of the average noise level in the atmosphere plus any system-generated noise. Returned signal power indicates the strength of returns from scattering surfaces encountered by the acoustic beam, while the Doppler shift defines the movement of these scattering surfaces along the radial. Signal strength and signal spectral width also indicate the degree of turbulence (or presence of hydrometeors, insects, side lobe returns, other