Designation: D 5389 – 93 (Reapproved 1997)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Open-Channel Flow Measurement by Acoustic Velocity Meter Systems[1]

This standard is issued under the fixed designation D 5389; 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 measurement of flow rate of water in open channels, streams, and closed conduits with a free water surface.

1.2 The test method covers the use of acoustic transmissions to measure the average water velocity along a line between one or more opposing sets of transducers—by the time difference or frequency difference techniques.

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

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.* Specific precautionary statements are given in Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Terminology Relating to Water[2]

D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D-19 on Water[2]

D 3858 Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method[2]

2.2 *ISO Standard:*

ISO 6416 Liquid Flow Measurements in Open Channels—Measurement of Discharge by the Ultrasonic (Acoustic) Method[3]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acoustic path*—the straight line between the centers of two acoustic transducers.

3.2.2 *acoustic path length*—the face-to-face distance between transducers on an acoustic path.

3.2.3 *acoustic transducer*—a device that is used to generate acoustic signals when driven by an electric voltage, and conversely, a device that is used to generate an electric voltage when excited by an acoustic signal.

3.2.4 *acoustic travel time*—the time required for an acoustic signal to propagate along an acoustic path, either upstream or downstream.

3.2.5 *discharge*—the rate of flow expressed in units of volume of water per unit of time. The discharge includes any sediment or other materials that may be dissolved or mixed with it.

3.2.6 *line velocity*—the downstream component of water velocity averaged over an acoustic path.

3.2.7 *measurement plane*—the plane formed by two or more parallel acoustic paths of different elevations.

3.2.8 *path velocity*—the water velocity averaged over the acoustic path.

3.2.9 *stage*—the height of a water surface above an established (or arbitrary) datum plane; also gage height.

3.2.10 *velocity sampling*—means of obtaining line velocities in a measurement plane that are suitable for determining flow rate by a velocity-area integration.

4. Summary of Test Method

4.1 Acoustic velocity meter (AVM) systems, also known as ultrasonic velocity meter (UVM) systems, operate on the principle that the point-to-point upstream traveltime of an acoustic pulse is longer than the downstream traveltime and that this difference in travel time can be accurately measured by electronic devices.

4.2 Most commercial AVM systems that measure streamflow use the time-of-travel method to determine velocity along an acoustic path set diagonal to the flow. This test method[4] describes the general formula for determining line velocity defined as (Fig. 1 and Fig. 2):

[1] This test method is under the jurisdiction of ASTM Committee D-19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

Current edition approved April 15, 1993. Published June 1993.

[2] Annual Book of ASTM Standards, Vol 11.01.

[3] Available from the American National Standards Institute, 11 W. 42nd Street, 13th Floor, New York, NY 10036.

[4] Laenen, A., and Smith, W., "Acoustic Systems for the Measurement of Streamflow," *U.S. Geological Survey Water Supply Paper 2213*, 1983.

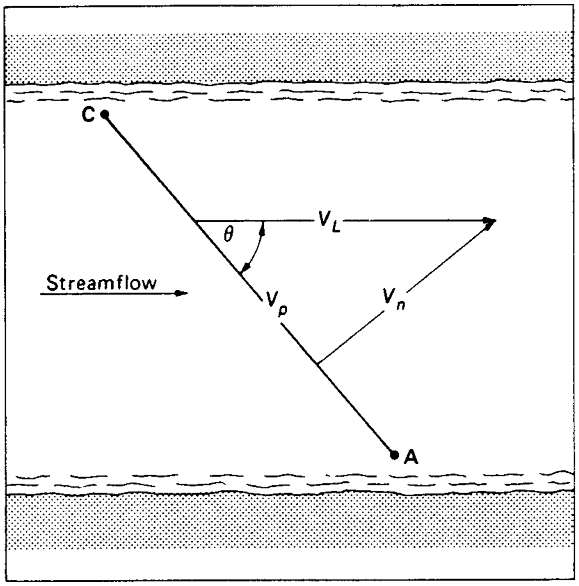


FIG. 1 Velocity Component Used in Developing Travel-Time Equations

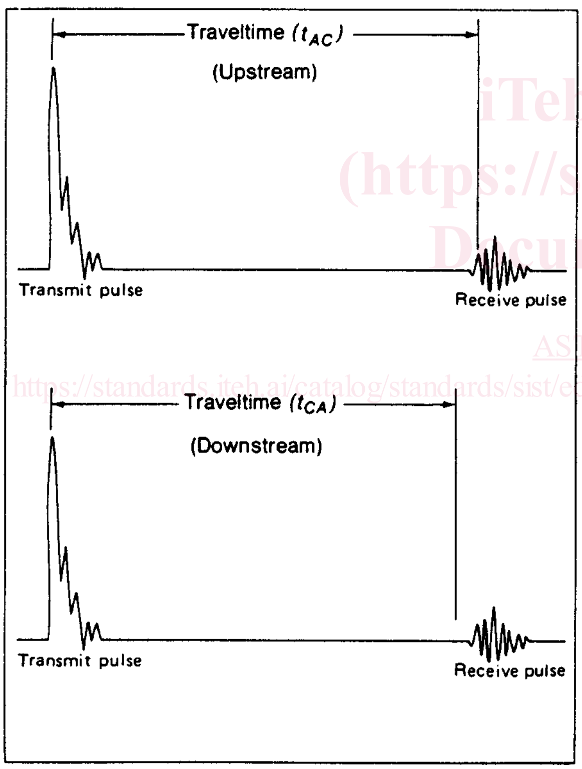


FIG. 2 Voltage Representation of Transmit and Receive Pulses at Upstream and Downstream Transducers

$$V_L = \frac{B}{2\cos\theta}\left[\frac{1}{{}^{t}CA} - \frac{1}{{}^{t}AC}\right] \quad (1)$$

where:

V_L = line velocity, or the average water velocity at the depth of the acoustic path,
θ = angle of departure between streamflow and the acoustic path,
${}^{t}AC$ = traveltime from A to C (upstream),
${}^{t}CA$ = traveltime from *C* to *A* (downstream), and
B = length of the acoustic path from *A* to *C*.

4.3 The discharge measurement or volume flow rate determination made with an AVM relies on a calibrated or theoretical relation between the line velocity as measured by the AVM and mean velocity in the flow segment being measured. Taking more line velocity measurements across the channel at different elevations in the acoustic plane and performing a numerical integration or weighted summation of the measured velocities and areas of flow can be used to better define the volume flow rate. The spacing between acoustic paths, the spacing between the top path and the liquid surface, and the spacing between the lowest path and the bottom are determined on the basis of stream cross-section geometry or estimates of the vertical-velocity distribution and by the required measurement accuracy. In addition to several line velocity measurements, it is necessary to provide water level (stage) and cross-sectional area information for calculation of the volume flow rate (see Fig. 3).

5. Significance and Use

5.1 This test method is used where high accuracy of velocity or continuous discharge measurement over a long period of time is required and other test methods of measurement are not feasible due to low velocities in the channel, variable stage-discharge relations, complex stage-discharge relations, or the

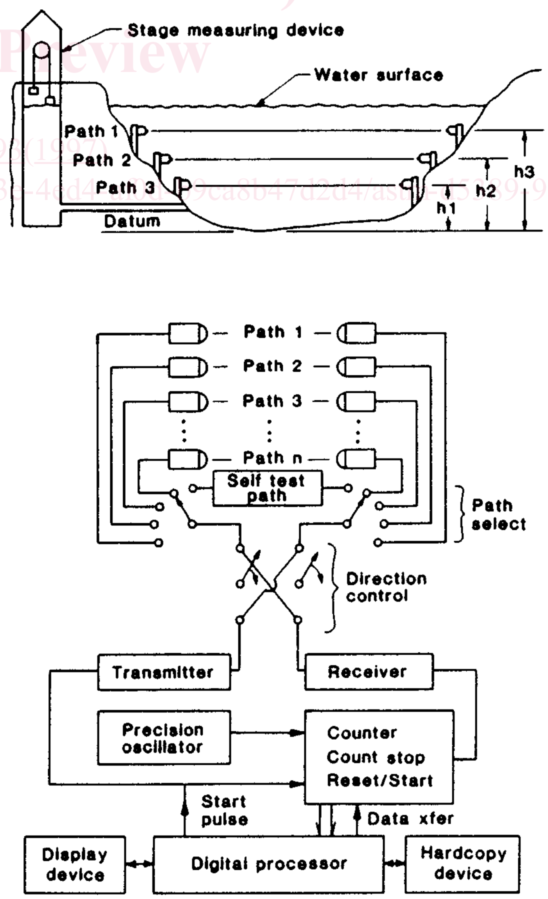


FIG. 3 Example of Acoustic Velocity/Flow Measuring System

presence of marine traffic. It has the additional advantages of requiring no moving parts, introducing no head loss, and providing virtually instantaneous readings (1 to 100 readings per second).

5.2 The test method may require a relatively large amount of site work and survey effort and is therefore most suitable for permanent or semi-permanent installations.

6. Interferences

6.1 *Refraction*—The path taken by an acoustic signal will be bent if the medium through which it is propagating varies significantly in temperature or density. This condition, known as ray bending, is most severe in slow moving streams with poor vertical mixing or tidal (estuaries) with variable salinity. In extreme conditions the signal may be lost. Examples of ray bending are shown in Fig. 4. Beam deflection for various temperatures and specific conductivities are shown in Fig. 5 and Fig. 6.

6.2 *Reflection*—Acoustic signals may be reflected by the water surface or streambed. Reflected signals can interfere with, or cancel, signals propagated along the measurement plane. When thermal or density gradients are present, the placement of transducers with respect to boundaries is most critical. This condition is most critical in shallow streams. A general rule of thumb to prevent reflection interference is to maintain a minimum stream depth to path length ratio of 1 to 100 for path lengths greater than 50 m.

6.3 *Attenuation*—Acoustic signals are attenuated by absorption, spreading, or scattering. Absorption involves the conversion of acoustic energy into heat. Spreading loss is signal weakening as it spreads outward geometrically from its source. Scattering losses are the dominant attenuation factors in streamflow applications. These losses are caused by air bubbles, sediment, or other particle or aquatic materials present in the water column. Table 1 presents tolerable sediment concentrations.

6.4 *Mechanical Obstructions*—Marine growth or waterborne debris may build up on transducers or weed growth, boats, or other channel obstructions may degrade propagation and timing of acoustic signals.

6.5 *Electrical Obstructions*—Nearby radio transmitters, electrical machinery, faulty electrical insulators, or other sources of electromagnetic interference (EMI) can cause failure or sporadic operation of AVMs.

7. Apparatus

7.1 The instrumentation used to measure open-channel flow by acoustic means consists of a complex and integrated electronic system known as an acoustic velocity meter (AVM). Three or four companies presently market AVM systems suitable for measurement of open-channel flow. System configurations range from simple single-path to complex-multi-path systems. Internal computation, transmission, and recording systems vary depending on local requirements. Most AVM

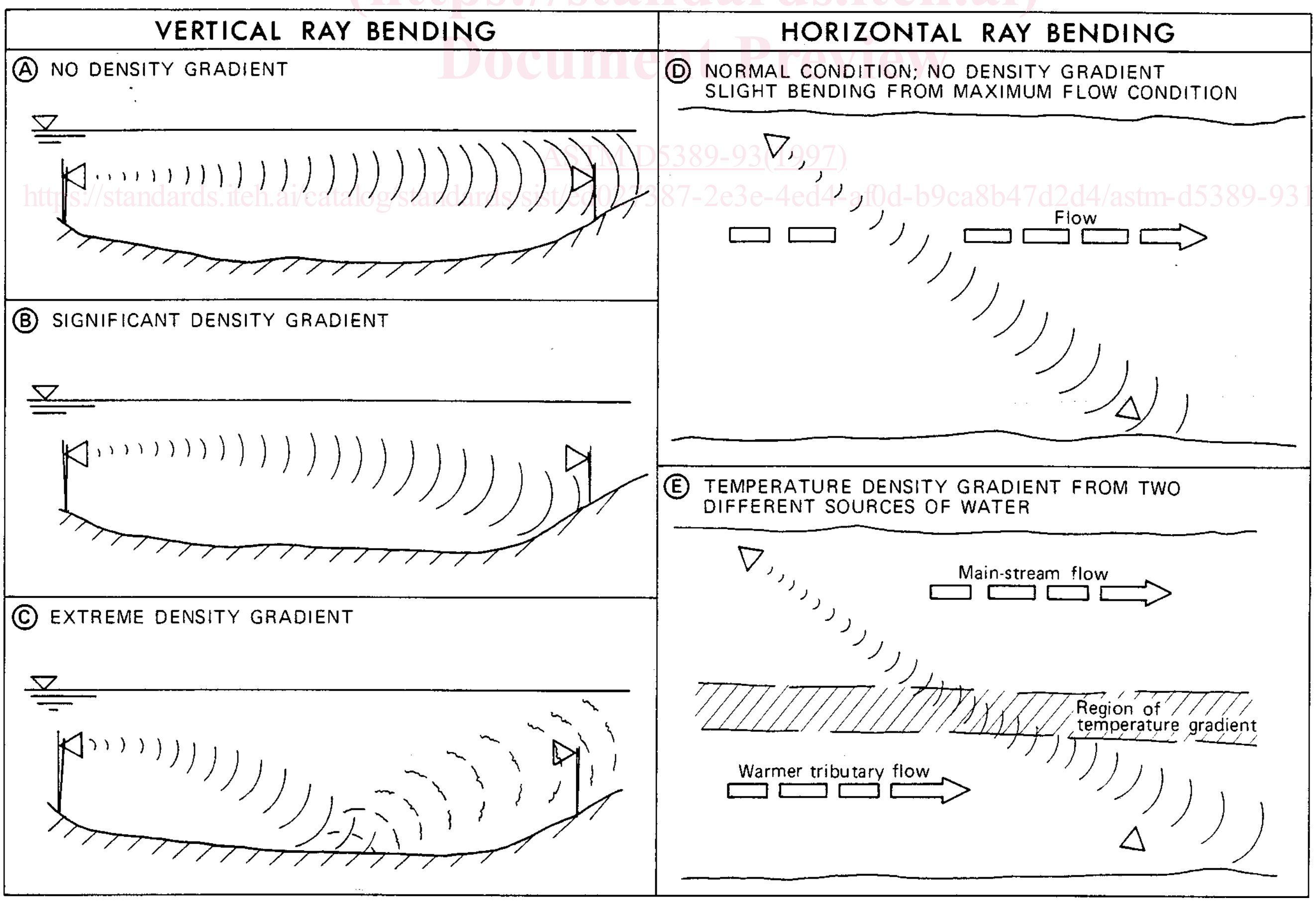
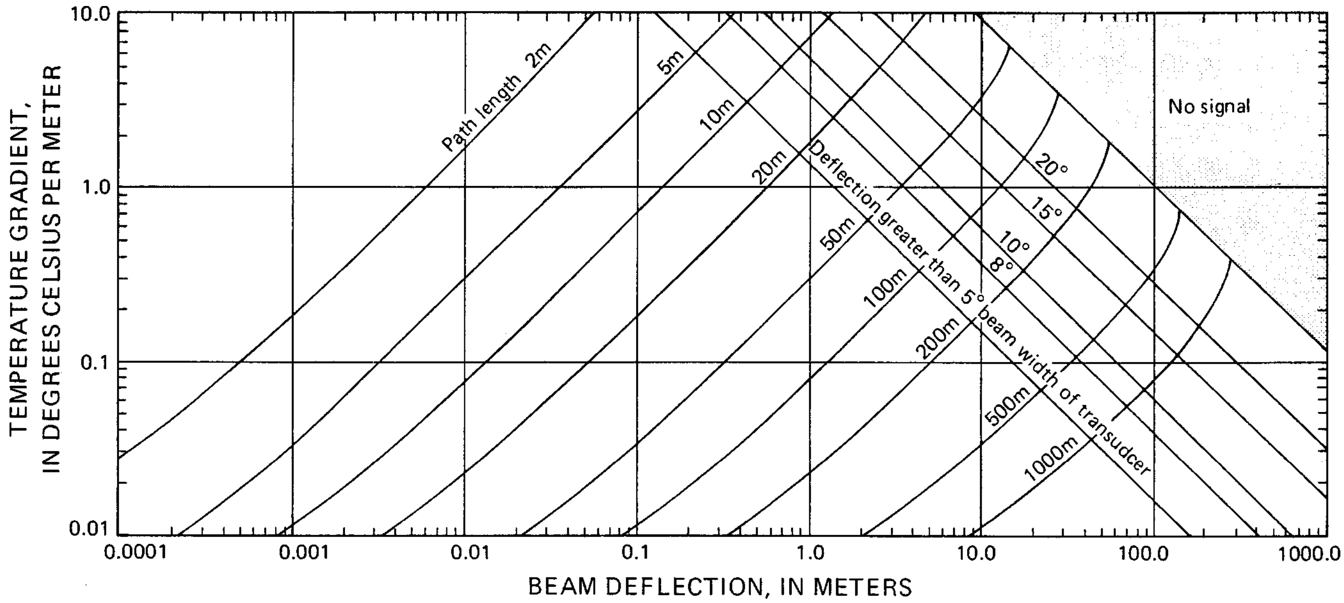
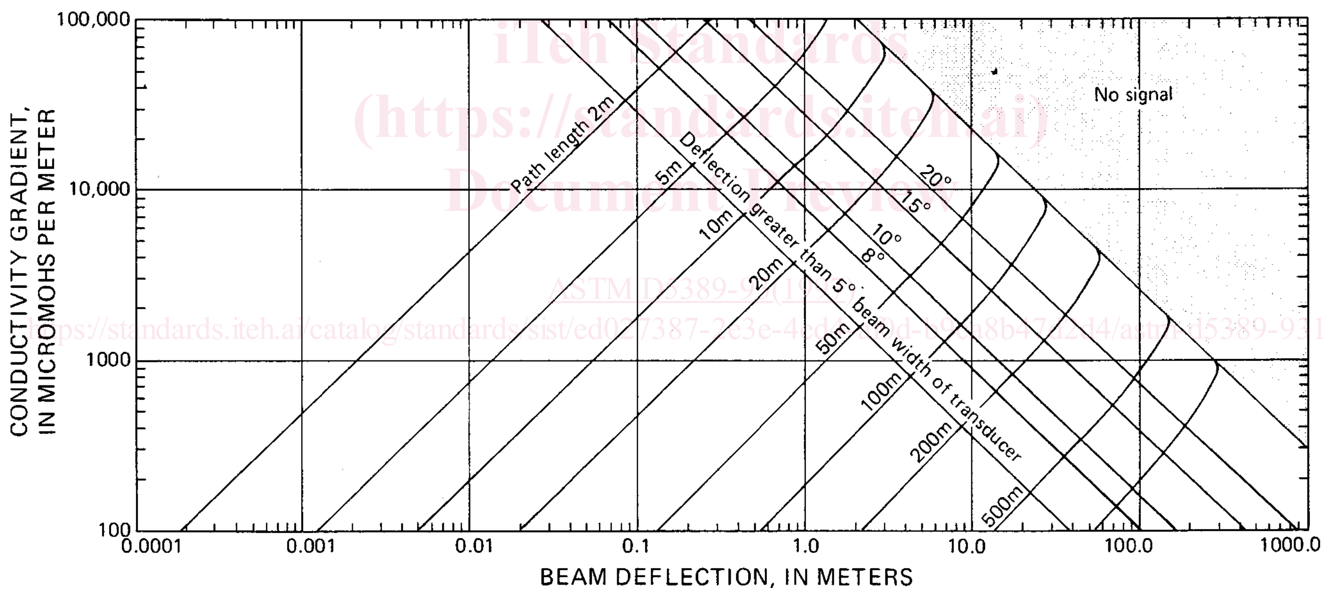


FIG. 4 Signal Bending Caused by Different Density Gradients [4]



NOTE 1—Transducer directivity or beam width determined at the 30-dB level of the transmitted signal pattern. The signal is propagated beyond the beam width but at a weak level. In the shaded area the detection is so great that signals cannot be received directly for any transducer beam width.

FIG. 5 Beam Deflection From Linear Temperature Gradients for Different Path Lengths



NOTE 1—Transducer directivity or beam width determined at the 30-dB level of the transmitted signal pattern. The signal is propagated beyond the beam width but at a weak level. In the shaded area the deflection is so great that signals cannot be received directly for any transducer beam width.

FIG. 6 Beam Deflection From Linear Conductivity Gradients for Different Path Lengths

systems must include the capability to compute an acoustic line velocity from one or more path velocities together with stage (water level) and other information related to channel geometry necessary to calculate a flow rate per unit of time, usually cubic millimetres per second (m^3/s) or cubic feet per second (ft^3/s).

7.1.1 *Electronics Equipment*—There are several methods that are currently being used to implement the electro-acoustic functions and mathematical manipulations required to obtain a line-velocity measurement. Whatever method is used must include internal automatic means for continuously checking the accuracy. In addition, provision must be included to prevent erroneous readings during acoustic interruptions caused by river traffic, aquatic life, or gradual degradation of components.

7.1.2 *Flow Readout Equipment*—This equipment is functionally separated into three subsystems. These subsystems may or may not be physically separable but are discussed separately for clarity.

7.1.3 *Acoustic Tranceiver*—This system generates, receives, and measures the traveltimes of acoustic signals. The acoustic signals travel between the various pairs of acoustic transducers and form the acoustic paths from which line velocities are determined.