Designation: D 5096 – 96

Standard Test Method for Determining the Performance of a Cup Anemometer or Propeller Anemometer[1]

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1. Scope

1.1 This test method covers the determination of the *Starting Threshold*, *Distance Constant*, *Transfer Function*, and *Off-Axis Response* of a cup anemometer or propeller anemometer from direct measurement in a wind tunnel.

1.2 This test method provides for a measurement of cup anemometer or propeller anemometer performance in the environment of wind tunnel flow. Transference of values determined by these methods to atmospheric flow must be done with an understanding that there is a difference between the two flow systems.

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:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

D 3631 Test Methods for Measuring Surface Atmospheric Pressure[2]

D 4430 Practice for Determining the Operational Comparability of Meteorological Instruments[2]

D 4480 Test Method for Measuring Surface Winds by Means of Wind Vanes and Rotating Anemometers[2]

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *starting threshold* (U_o, m/s)—the lowest wind speed at which a rotating anemometer starts and continues to turn and produce a measurable signal when mounted in its normal position. The normal position for cup anemometers is with the axis of rotation vertical, and the normal position for propeller anemometers is with the axis of rotation aligned with the direction of flow. Note that if the anemometer axis is not aligned with the direction of flow, the calculated wind speed component parallel to the anemometer axis is used to determine starting threshold.

3.2.2 *distance constant* (L, m)—the distance the air flows past a rotating anemometer during the time it takes the cup wheel or propeller to reach $(1 - 1/e)$ or 63 % of the equilibrium speed after a step change in wind speed **(1)**.[3] The response of a rotating anemometer to a step change in which wind speed increases instantaneously from $U = 0$ to $U = U_f$ is **(2)**:

$$U_t = U_f[1 - e^{(-t/\Gamma)}] \quad (1)$$

where:
U_t = is the instantaneous indicated wind speed at time t in m/s,
U_f = is the final indicated wind speed, or wind tunnel speed, in m/s,
t = is the elapsed time in seconds after the step change occurs, and
Γ = is the time constant of the instrument.

$$\text{Distance Constant is: } L = U_f\Gamma \quad (2)$$

3.2.3 *transfer function* ($\hat{U}_f = a + bR$, m/s)—the linear relationship between wind speed and the rate of rotation of the anemometer throughout the specified working range. $U_{f|AX}$ is the predicted wind speed in m/s, a is a constant, commonly called zero offset, in m/s, b is a constant representing the wind passage in m/r for each revolution of the particular anemometer cup wheel or propeller, and R is the rate of rotation in r/s. It should be noted that zero offset is not the same as starting threshold. In some very sensitive anemometers the constant a, zero offset, may not be significantly greater than zero. The constants a and b must be determined by wind tunnel measurement for each type of anemometer **(3)**.

3.2.4 *off-axis response* ($U/(U_f \cos \theta)$)—the ratio of the indicated wind speed (U) at various angles of attack (θ) to the indicated wind speed at zero angle of attack (U_f) multiplied by the cosine of the angle of attack. This ratio compares the actual

[1] This test method is under the jurisdiction of ASTM Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.11 on Meteorology.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

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

off-axis response to a cosine response.

3.3 *Symbols:*

a (m/s)	=	zero offset constant
b (m/r)	=	wind passage (apparent pitch) constant or calibration constant
L (m)	=	distance constant
r (none)	=	a shaft revolution
R (r/s)	=	rate of rotation
Γ(s)	=	time constant
t (s)	=	time
U_o(m/s)	=	starting threshold
U (m/s)	=	indicated wind speed (used in off-axis test)
U_f(m/s)	=	final indicated wind speed or wind tunnel speed
U_{max}(m/s)	=	anemometer application range
U_t(m/s)	=	instantaneous indicated wind speed at time *t*
$\hat{U}_f$(m/s)	=	predicted wind speed
θ (deg)	=	off-axis angle of attack

4. Summary of Test Method

4.1 This test method requires a wind tunnel described in Section 6, Apparatus.

4.2 *Starting Threshold* (U_o, m/s) is determined by measuring the lowest speed at which a rotating anemometer starts and continues to turn and produce a measurable signal when mounted in its normal position.

4.3 *Distance Constant* (*L*, m) may be determined at a number of wind speeds but must include 5 m/s, and 10 m/s. It is computed from the time required for the anemometer rotor to accelerate $(1 - 1/e)$ or 63 % of a step change in rotational speed after release from a restrained, non-rotating condition. The final response, U_f, is the wind tunnel speed as indicated by the anemometer. In order to avoid the unrealistic effects of the restrained condition, as shown in Fig. 1, the time measurement should be made from 0.30 of U_f to 0.74 of U_f. This interval in seconds is equal to one time constant (Γ) and is converted to the Distance Constant by multiplying by the wind tunnel speed in meters per second (m/s).

4.4 *Transfer Function* ($\hat{U}_f = a + bR$, m/s) is determined by measuring the rate of rotation of the anemometer at a number of wind speeds throughout the specified working range. In the range of wind speeds where the anemometer response is non-linear (near threshold) a minimum of five data points are recorded. A minimum of five additional data points are recorded within the working range of the anemometer and wind tunnel but above the non-linear threshold region (see Fig. 2). Measurements are recorded for each data point with the wind tunnel speed ascending and descending. The values of *a* and *b* are determined by least-squares linear regression of the individual data points.

4.5 *Off-Axis Response* may be measured at a number of wind speeds but must include 5 m/s, and 10 m/s.

4.5.1 *Cup Anemometers*—A measurement is made of the output signal when the anemometer is inclined into the wind (representing a down-draft) and away from the wind (representing an updraft), while the wind tunnel is running at a steady speed. The output signal is measured with the anemometer axis at 5° intervals from vertical to plus and minus 30° from vertical. The measured signal is then converted to a ratio for each interval by dividing by the normal signal measured with the anemometer axis in the normal, or vertical, position.

4.5.2 *Vane Mounted Propeller Anemometers*—A measurement is made of the output signal when the anemometer's axis of rotation is inclined downward into the wind (representing a down-draft) and inclined upward into the wind (representing an updraft), while the wind tunnel is running at a steady speed. The output signal is measured at 5° intervals from a horizontal axis of rotation to ± 30° from the horizontal. The measured signal is then converted to a ratio for each interval by dividing by the normal signal with the anemometer in the normal, or horizontal position. This test may be conducted either with the vane in place or with the vane removed and the axis of rotation fixed in the down-tunnel direction.

4.5.3 *Fixed Axis Propeller Anemometer*—A measurement is made of the output signal when the anemometer is rotated in the air stream throughout the complete 360° angle of attack. The signal is measured at a number of angles but must include 10° intervals with additional measurements at 85, 95, 265, and 275°. The measured signal for each angle of attack is then converted to a ratio by dividing by the signal measured at 0° angle of attack (axial flow). Additionally, the stall angle of the propeller is measured by orienting the anemometer at 90° and slowly rotating into and away from the air flow until the

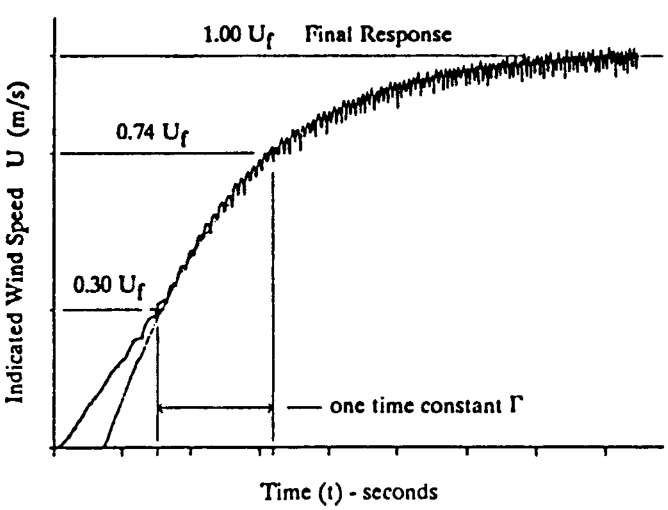

FIG. 1 Typical Anemometer Response Curve

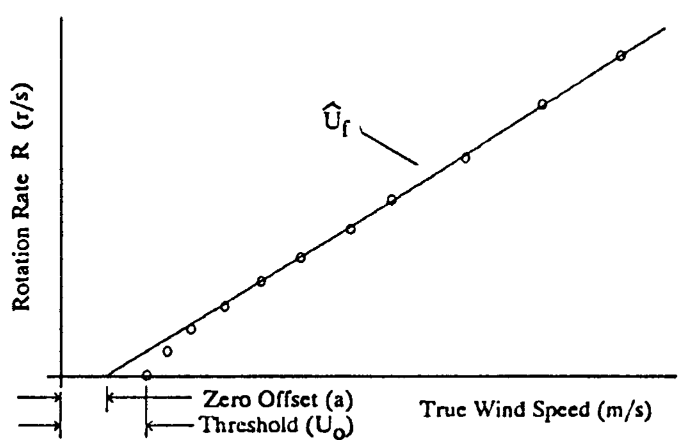

FIG. 2 Typical Anemometer Calibration Curve

propeller starts rotating continuously. Stall angle is the total contained angle within which the propeller does not continuously rotate. The procedure is repeated at 270°.

5. Significance and Use

5.1 This test method will provide a standard for comparison of rotating type anemometers, specifically cup anemometers and propeller anemometers, of different types. Specifications by regulatory agencies **(4-7)** and industrial societies have specified performance values. This standard provides an unambiguous method for measuring *Starting Threshold*, *Distance Constant*, *Transfer Function*, and *Off-Axis Response*.

6. Apparatus

6.1 *Measuring System*:

6.1.1 *Rotation*—The relationship between the rate of rotation of the anemometer shaft and the transducer output must be determined. The resolution of the anemometer transducer limits the measurement. The resolution of the measuring or recording system must represent the indicated wind speed with a resolution of 0.02 m/s.

6.1.2 *Time*—The resolution of time must be consistent with the distance accuracy required. For this reason the time resolution may be changed as the wind tunnel speed is changed. If one wants a distance constant measurement to 0.1 meter resolution one must have a time resolution of 0.05 s at 2 m/s and 0.01 s at 10 m/s. If timing accuracy is based on 50 Hz or 60 Hz power frequency it will be at least an order of magnitude better than the resolution suggested above.

6.1.3 *Angle of Attack*—The resolution of the angle of attack (θ) must be within 0.5°. An ordinary protractor of adequate size with 0.5° markings will permit measurements with sufficient resolution. A fixture should be constructed to permit alignment of the anemometer to the off-axis angles while the wind tunnel is running at a steady speed.

6.2 *Recording Techniques*:

6.2.1 Digital recording systems and appropriate reduction programs will be satisfactory if the sampling rate is at least 100 samples/s. Exercise care to avoid electronic circuits with time constants which limit the proper recording of anemometer performance. Oscilloscopes with memory and hard copy capability may also be used. Another simple technique is to use a fast-response strip chart recorder (flat to 10 Hz or better) with enough gain so that the signal produced by the anemometer when the wind tunnel is running at 2 m/s is sufficient to provide full scale pen deflection on the recorder. The recorder chart drive must have a fast speed of 50 mm/s or more.

6.3 *Wind Tunnel* **(8)**:

6.3.1 *Size*—The wind tunnel must be large enough so that the projection of the cup wheel or propeller, sensor, and support apparatus, is less than 5 % of the cross sectional area of the tunnel test section.

6.3.2 *Speed Range*—The wind tunnel must have a speed control which will allow the flow rate to be varied from 0 to a minimum of 50 % of the application range of the anemometer under test. The speed control should maintain the flow rate within ± 0.2 m/s.

6.3.3 *Calibration*—The mean flow rate must be verified at the mandatory speeds by use of transfer standards which have been calibrated at the National Institute of Standards and Technology or by a fundamental physical method. Speeds below 2 m/s for the threshold determination must be verified by a sensitive anemometer or by some fundamental time and distance technique, such as measuring the transition time of smoke puffs, soap bubbles, or heat puffs between two points separated by known distance. A table of wind tunnel blower rpm or some other index relating method of control to flow rate should be established by this technique for speeds of 2 m/s and below.

6.3.4 The wind tunnel must have a relatively constant profile (known to within 1 %) and a turbulence level of less than 1 % throughout the test section.

6.3.5 Environment (**9-11**). Differences of greater than 3 % in the density of the air within the test environment may result in poor intercomparability of independent measurements of starting threshold (U_o) and distance constant (L) since these values are density dependent. The temperature and pressure of the environment within the wind tunnel test section shall be reported for each independent measurement.

7. Sampling

7.1 *Starting Threshold*—The arithmetic mean on ten consecutive tests is required for a valid starting threshold measurement.

7.2 *Distance Constant*—The arithmetic mean of ten tests is required for a valid measurement at each speed. The results of the measurements at two or more speeds are averaged to a single value for distance constant.

7.3 *Transfer Function*—Two measurements of U_f and R are recorded for each data point, one with the wind tunnel speed ascending and one with the wind tunnel speed descending. The values are then tabulated for each data point.

7.4 *Off-Axis Response*—The results of the measurement at two or more speeds are averaged to a single value for each angle of attack. The averaged values are tabulated for each angle of attack.

8. Procedure

8.1 *Starting Threshold* (U_o):

8.1.1 Provide a mechanical method for holding the anemometer in its normal position (see 3.1) and for releasing the anemometer from a restrained, or non-rotating condition, while the wind tunnel is running at the test speed. Test the release mechanism with the wind tunnel off to verify that the release method does not move the anemometer rotor when activated.

8.1.2 Set the wind tunnel to a speed that is lower than the starting threshold. Slowly increase the wind tunnel speed until the cup wheel or propeller continues to rotate and produce a measurable signal.

8.1.3 Repeat the procedure of 8.1.2 ten times and record the results.

NOTE 1—Vibration caused by the wind tunnel or by other sources can cause erroneous measurements of starting threshold. Care must be exercised to eliminate any vibration in the wind tunnel test section during threshold measurements.

8.2 *Distance Constant* (L):

8.2.1 Set the wind tunnel speed to 5 m/s. Stop the rotation of the cup wheel or propeller and release by method of 8.1.1. Record ten samples.

8.2.2 Repeat procedure of 8.2.1 at 10 m/s.

8.2.3 From the record measure the time in seconds (t) from the point when the rotor speed reaches 0.30 of equilibrium speed (U_f) to the point where the rotor speed reaches 0.74 of equilibrium speed (see Fig. 1). The distance constant (L) is determined by multiplying the time constant (Γ) by the tunnel speed (U_f). This should be done for each of the 10 samples at 5 m/s and at 10 m/s. The average of the 10 samples at each tunnel speed should produce distance constants that are within 10 % of their average. Otherwise the results are invalid and the equipment or testing procedure should be examined.

8.3 *Transfer Function* ($\hat{U}_f = a + bR$):

8.3.1 Set the wind tunnel speed at approximately 2 times threshold (U_o) as determined in 8.1. Record the wind tunnel speed and the anemometer rotation rate. Increase the wind tunnel speed to approximately 3 times U_o and record the measurements. Repeat at 4 times U_o, 5 times U_o and 6 times U_o.

8.3.2 Set the wind tunnel speed at approximately 0.1 times the anemometer application range (U_{max}). Record the wind tunnel speed and the anemometer rotation rate. Increase the wind tunnel speed 0.2 times U_{max} and record the measurements. Repeat at 0.3 times U_{max}, 0.4 times U_{max} and 0.5 times U_{max}. Additional data points may be taken.

8.3.3 Repeat the procedure of 8.3.2 and 8.3.1 with the wind tunnel speed descending.

8.3.4 Use the data recorded in 8.3.2 and 8.3.3 to determine the value of zero offset (a) in m/s and the calibration constant (b) in m/r by least squares linear regression. Do not use the threshold data recorded in 8.3.1 for this calculation.

8.3.5 Using the a and b values calculated in 8.3.4, find the predicted $\hat{U}_f$ for each R measured in 8.3.1. Subtract the predicted $\hat{U}_f$ from the measured U_f. Report the differences in m/s for each tunnel speed used on 8.3.1.

NOTE 2—This test method provides for the determination of transfer function coefficients from measurements within 50 % of the application range of the anemometer under test. Extrapolation of data beyond the range of actual measurement may result in an increase of bias.

NOTE 3—Be sure that the wind tunnel has reached equilibrium at each new speed before taking data. Measure output for 100s at each data point.

8.4 *Off-Axis Response*—cup anemometers:

8.4.1 Set up the off-axis angle fixture for the cup anemometer described in 6.1.3 and align the cup anemometer to its normal (vertical axis of rotation) position. Set the wind tunnel speed to 5 m/s. Take one sample with the anemometer vertical and one sample at each 5° interval inclined into the air flow. Take one additional sample with the anemometer vertical and one sample at each of the 5° intervals inclined away from the air flow. See 4.5.1. Divide each value by the value in the normal position times the cosine of the tilt angle.

$$(U/(U_f \cos \theta)) \quad (3)$$

8.4.2 Repeat the procedure of 8.4.1 at 10 m/s. Tabulate the results by averaging the ratios at each speed for each interval.

8.5 *Off-Axis Response*—vane mounted propeller anemometers:

8.5.1 Set up the off-axis angle fixture, described in 6.1.3, for the vane mounted propeller anemometer and align the propeller axis of rotation to its normal (horizontal) position. Set the wind tunnel speed to 5 m/s. Take one sample with the propeller axis horizontal and one sample at each of the 5° intervals for downdraft (propeller closer to the tunnel floor). Take one additional sample in the normal (horizontal) position and one sample at each of the 5° intervals for updraft (propeller close to the tunnel ceiling). See 4.5.2. Divide each value by the value in the normal position times the cosine of the tilt angle.

$$(U/(U_f \cos \theta)) \quad (4)$$

8.5.2 Repeat the procedure of 8.5.1 at 10 m/s. Tabulate the results by averaging the ratios at each speed for each interval.

8.6 *Off-Axis Response*—fixed axis propeller anemometers:

8.6.1 Set up the off-axis fixture described in 6.1.3 for the propeller anemometer and align the propeller anemometer to its normal (horizontal) position with the axis of the propeller at 0° (align directly into the airflow). Set the wind tunnel speed to 5 m/s. Take one sample with the anemometer at 0° and one sample at each test angle (see 4.5.3). Divide each measurement by the product of the measurement along the axis of the tunnel and the cosine of the test angle.

$$(U/(U_f \cos \theta)) \quad (5)$$

8.6.2 With the wind tunnel continuing to run at 5 m/s rotate the anemometer to 90° (stalled position). Slowly rotate the anemometer into the air flow until the propeller just begins to continuously rotate. Record the angle of attack. Slowly rotate the anemometer away from the air flow, past the stall position, until the propeller just begins to continuously rotate. Record the angle of attack. The contained angle is the stall angle.

8.6.3 Repeat the procedure of 8.6.1 at 10 m/s.

8.6.4 Repeat the procedure of 8.6.2 at 10 m/s.

8.6.5 Tabulate the results by averaging the ratios for each speed for each interval. Include the stall angle determined in 8.6.4 and in the tabulated results.

9. Precision and Bias

9.1 The accuracy of this test method is dependent upon the accuracy of the wind tunnel and its associated test instrumentation. A relative accuracy of 0.1 m/s is required. This must be documented at the wind tunnel facility and be related to measurements at the National Institute of Standards and Technology (NIST) or other internationally recognized standards organization, by a report of calibration on the transfer standard which carries the same or better accuracy limit.

9.1.1 *Precision*—Using this equipment and procedure, an estimate of precision of the method follows.

9.1.1.1 *Starting threshold*—The precision of the speed reported as the threshold relates to the wind tunnel used for this method and the precision of the fundamental time and distance technique employed. A precision of 0.1 m/s is provided by this method.

9.1.1.2 *Distance Constant*—The precision by this test method is 0.2 m or better.

9.1.1.3 *Transfer Function*—The precision by this test method is 0.1 m/s or better.

9.1.1.4 *Off-Axis Response*—The precision by this test method is 0.01 or better.

9.2 *Bias*:

9.2.1 *Starting Threshold*—The bias of this test method is no greater than 0.2 m/s. Documentation of the time and distance measurements for speeds below 2 m/s is required.

9.2.2 *Distance Constant*—The bias of this test method is no greater than 0.2 m.

9.2.3 *Transfer Function*—The bias of this method is no greater than 0.2 m/s.

9.2.4 *Off-Axis Response*—The bias of this test method is no greater than 0.02.

10. Keywords

10.1 anemometer; distance constant; off-axis response; threshold; wind speed

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