STANDARD

# ANSI/AMCA
# Standard 270-23

# Laboratory Methods of Aerodynamic Testing Fan Arrays for Rating

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Air Movement and Control Association International
**AMCA Corporate Headquarters**
30 W. University Drive, Arlington Heights, IL 60004-1893, USA
communications@amca.org ▪ Ph: +1-847-394-0150 ▪ www.amca.org

# ANSI/AMCA Standard 270-23

# Laboratory Methods of Aerodynamic Testing Fan Arrays for Rating

Air Movement and Control Association International
30 West University Drive
Arlington Heights, Illinois
60004

# AMCA Publications

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AMCA International Inc.
30 West University Drive
Arlington Heights, IL 60004-1893
U.S.A.

AMCA International Inc.
European and Middle East Regions
Dubai Association Centre Office
One Central, Building 2, Desk 40
Dubai World Trade Centre Complex
P.O. Box 9292, Dubai, UAE

Asia AMCA Sdn Bhd
No. 7, Jalan SiLC 1/6,
Kawasan Perindustrian SiLC Nusajaya,
Mukim Jelutong, 79200 Nusajaya, Johor
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# Contents

**Laboratory Methods of Aerodynamic Testing Fan Arrays for Rating**

# Laboratory Methods of Aerodynamic Testing Fan Arrays for Rating

## 1. Purpose

The purpose of this standard is to establish a laboratory method for determining the aerodynamic performance of fan arrays. Key performance metrics are airflow rate, pressures, shaft power and electrical power for fan arrays. This standard is an adjunct to ANSI/AMCA Standard 210 to accommodate unique requirements of fan arrays.

## 2. Scope

This standard is limited to testing and reporting aerodynamic performance and fan electrical power (FEP) of fans employing direct-drive transmissions, including:

Optional calculation of fan shaft power based on motor calibration and measurement of electrical input power of individual fans or an overall fan array.

Optional partitions between fans.

Optional appurtenances or design features that affect aerodynamic performance.

Optional speed controllers serving individual fans, groups of fans or all fans of the array.

Exclusions:

Fan arrays using mechanical transmissions, such as belt drives or gear drives.

Fan arrays that control individual fans to different speeds.

Fan arrays using different fan types or sizes.

Fan arrays using individually ducted fan inlets, fan outlets or both.

Fan arrays that cannot directly accept sinusoidal AC electric power or DC power.

## 3. References

ANSI/AMCA Standard 270 contains provisions that, through reference in this text, constitute provisions of ANSI/AMCA Standard 210. At the time of publication, the editions indicated were current. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

AHRI Standard 430 (I-P/2020), *Performance Rating of Central Station Air-handling Unit Supply Fans*, Air-Conditioning, Heating & Refrigeration Institute, Arlington, VA, USA

AMCA Publication 203-90 (R2011) | *Field Performance Measurement of Fan Systems*, Air Movement and Control Association International Inc., Arlington Heights, IL, USA

AMCA Publication 211-13, *Certified Ratings Program Product Rating Manual for Fan Air Performance*, Air Movement and Control Association International Inc., Arlington Heights, IL, USA

ANSI/AMCA Standard 205-19, *Energy Efficiency Classification for Fans*, Air Movement and Control Association International Inc., Arlington Heights, IL, USA

ANSI/AMCA Standard 207-17, *Fan System Efficiency and Fan System Input Power Calculation*, Air Movement and Control Association International Inc., Arlington Heights, IL, USA

ANSI/AMCA Standard 208-18, *Calculation of the Fan Energy Index*, Air Movement and Control Association International Inc., Arlington Heights, IL, USA

ANSI/AMCA Standard 210-16 / ANSI/ASHRAE 51-16 American National Standard, *Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating*, Air Movement and Control Association International Inc., Arlington Heights, IL, USA

# 4. Definitions/Units of Measure/Symbols

## 4.1 Definitions

In general, all references to “fan” in ANSI/AMCA Standard 210 shall be replaced with “fan array” in ANSI/AMCA Standard 270. Examples include:

| Term in ANSI/AMCA Standard 210 | Term in ANSI/AMCA Standard 270 |
|---|---|
| Fan | Fan array |
| Fan inlet area | Fan array inlet area |
| Fan outlet area | Fan array outlet area |
| Fan air density | Fan array air density |
| Fan airflow rate | Fan array airflow rate |
| Fan total pressure | Fan array total pressure |
| Fan static pressure | Fan array static pressure |
| Fan velocity pressure | Fan array velocity pressure |
| Fan input power | Fan array shaft power |
| Fan electrical input power | Fan array electrical power |
| Fan rotational speed | Fan array mean rotational speed |

All definitions used in this standard are defined in ANSI/AMCA Standard 210 with the following additions:

### 4.1.1 Backflow damper

A device intended to prevent air from moving through a non-operating fan. It may close and open due to air pressure, a motor, or manual control.

### 4.1.2 Contained fans

Fans in a fan array within substantially uniform enclosure(s) that extend axially beyond the impeller and do not aerodynamically interact with other fans of the fan array.

### 4.1.3 Fan array

An assembly of two or more identical fans operating in parallel at the same speed and sharing a common inlet plenum, common outlet plenum or both. Fan arrays can be built up using contained or uncontained fans.

### 4.1.4 Fan array air density

The density of the air corresponding to the total pressure and the stagnation (total) temperature of the air at the fan array inlet.

### 4.1.5 Fan array airflow rate

The volumetric airflow rate of the fan array at fan array air density.

### 4.1.6 Fan array electrical power ($W_c$)

The electrical power required to operate the fan array, including losses from motor controllers.

### 4.1.7 Fan array inlet area

If a fan array inlet plenum is present, then it is the product of the internal casing dimensions. If not present, it is the sum of the inlet areas of the individual fans.

### 4.1.8 Fan array input boundary

The interface between a fan and its drive.

### 4.1.9 Fan array mean rotational speed

The mean of the measured fan rotational speeds.

### 4.1.10 Fan array motor electrical power ($W_m$)

The electrical power required by all the operating fans of the array, excluding losses from motor controllers.

### 4.1.11 Fan array outlet area

The gross inside area measured in the planes of the outlet openings.

### 4.1.12 Fan array shaft power

The sum of the individual fan shaft powers required to operate the fan array.

### 4.1.13 Fan array velocity

The average velocity of the air leaving the fan array.

### 4.1.14 Fan array velocity pressure

The difference between the fan array total pressure and the fan array static pressure.

### 4.1.15 Fan motor controller electrical power ($W_{c,i}$)

The electric power required to operate an individual fan with the losses of the motor controller included.

### 4.1.16 Fan motor electrical power ($W_{m,i}$)

The electric power required to operate an individual fan not including losses of the motor controller.

### 4.1.17 Fan shaft power

See definition of fan input power in Section 3 of ANSI/AMCA Standard 210.

### 4.1.18 Identical construction

A fan that has the same manufacturer and model number and is intended to have the same performance under the same conditions. Note: Model numbers may differ if the only difference between the models is something that does not affect performance (e.g., color).

### 4.1.19 Non-operating fan

Any fan that is not energized during a test.

### 4.1.20 Operating fan

Any fan that is energized and rotating during a test.

### 4.1.21 Partially contained fans

Fans in a fan array that are within non-uniform enclosure(s) such that some fans aerodynamically interact with each other within the fan array.

### 4.1.22 Power connection measured power

The power measured at a power connection during a test, in watts.

### 4.1.23 Power connections

One or more points on the exterior and/or interior of the fan array intended for providing electricity from the supply mains to the unit. The points may supply multiple motors or motor controllers.

**4.1.24 Uncontained fans**
Fans in a fan array that aerodynamically interact with each other.

## 4.2 Units of measure

All units used in this standard are defined in ANSI/AMCA Standard 210. The primary units are The International System of Units, also known as Le Systéme International d'Unités (SI), with inch-pound (I-P) units given as the secondary reference.

## 4.3 Symbols and subscripts

**Table 1 — Symbols and Subscripts**

| Symbol | Description | SI Unit | I-P Unit |
|---|---|---|---|
| $A$ | Area of cross section | sq m | sq ft |
| $C$ | Nozzle discharge coefficient | dimensionless | |
| $D$ | Diameter and equivalent diameter | M | ft or in. |
| $H_{i,j}$ | Individual fan shaft power | W | hp |
| $H_{i,A}$ | Fan array shaft power | W | hp |
| $k_f$ | Impact tube array correction factor | dimensionless | |
| $K_p$ | Compressibility coefficient | dimensionless | |
| $l$ | Length | M | in. |
| $M$ | Chamber diameter or equivalent diameter | M | ft |
| $N_A$ | Mean rotational speed | rpm | rpm |
| $n$ | Number of readings | dimensionless | |
| $n_A$ | Number of fans in the fan array | dimensionless | |
| $P_s$ | Fan static pressure | Pa | in. wg |
| $P_{s,A}$ | Fan array static pressure | Pa | in. wg |
| $P_{s,j}$ | Individual fan static pressure | Pa | in. wg |
| $P_{sx}$ | Static pressure at plane $x$ | Pa | in. wg |
| $P_t$ | Fan total pressure | Pa | in. wg |
| $P_{t,A}$ | Fan array total pressure | Pa | in. wg |
| $P_{t,j}$ | Individual fan total pressure | Pa | in. wg |
| $P_{tx}$ | Total pressure at plane $x$ | Pa | in. wg |
| $P_{vA}$ | Fan array velocity pressure | Pa | in. wg |
| $P_{vx}$ | Velocity pressure at plane $x$ | Pa | in. wg |
| $p_b$ | Corrected barometric pressure | Pa | in. Hg |
| $Q$ | Fan airflow rate | $m^3/s$ | cfm, $ft^3/min$ |
| $Q_A$ | Fan array airflow rate | $m^3/s$ | cfm, $ft^3/min$ |
| $Q_j$ | Individual fan airflow rate | $m^3/s$ | cfm, $ft^3/min$ |
| $Q_x$ | Airflow rate at plane $x$ | $m^3/s$ | cfm, $ft^3/min$ |
| $R_Q$ | Airflow rating factor | dimensionless | |
| $R_P$ | Pressure rating factor | dimensionless | |
| $R_H$ | Shaft power rating factor | dimensionless | |

| | | | |
|---|---|---|---|
| $R_W$ | Electrical power rating factor | dimensionless | |
| $V$ | Velocity | m/s | fpm, ft/min |
| $W_A$ | Fan array electrical input power | W | W |
| $W_j$ | Individual fan electrical input power | W | W |
| $W_x$ | Electrical input power, where *x* indicates the input power boundary | W | W |
| $Y$ | Nozzle expansion factor | dimensionless | |
| $y$ | Thickness of airflow straightener element | m | ft |
| $\Delta P$ | Pressure differential | Pa | in. wg |
| $\rho$ | Fan air density | kg/m$^3$ | lbm/ft$^3$ |
| $\rho_x$ | Air density at plane *x* | kg/m$^3$ | lbm/ft$^3$ |

| Subscript | Description |
|---|---|
| *A* | Fan array |
| *A'* | Fan array subset tested |
| *c* | Converted value |
| *j* | Individual fan |
| *m* | Motor |
| *mc* | Motor Controller |
| *x* | Plane 0, 1, 2 … as appropriate |
| *pd* | Discharge plenum |
| *pi* | Inlet plenum |
| 0 | Plane 0 (general test area) |
| 1 | Plane 1 (fan inlet) |
| 2 | Plane 2 (fan outlet) |
| 3 | Plane 3 (pitot traverse station) |
| 4 | Plane 4 (duct piezometer station) |
| 5 | Plane 5 (nozzle inlet station in chamber) |
| 6 | Plane 6 (nozzle discharge station) |
| 7 | Plane 7 (outlet chamber measurement station) |
| 8 | Plane 8 (inlet chamber measurement station) |

# 5. Instruments and Methods of Measurement

All requirements for instruments and methods of measurements in ANSI/AMCA Standard 210 are applicable to testing done in accordance with this standard.

## 5.1 Connection to airflow measurement stations – adaptors

The size of a test array may preclude it from being connected directly to the airflow measurement station. In these circumstances, a discharge or inlet plenum connected to a duct meeting the requirements shall be used.

### 5.1.1 Adaptor size

Adaptor walls at the connection to the fan array shall be at least 0.5 D away from the edge of the array.

#### 5.1.2 Additional pressure taps

The adapter will need to contain a pressure measuring device suitable for the test configuration, according to the requirements in Section 10.

# 6. Test Setups and Equipment

## 6.1 Reference to ANSI/AMCA Standard 210

An adjunct to ANSI/AMCA Standard 210, this standard is used to accommodate unique requirements of fan arrays. Unless otherwise stated, all requirements of ANSI/AMCA Standard 210 shall apply.

### 6.1.1 Test configurations

#### 6.1.1.1 Test setup

All tests shall be conducted using one of the setups described in Section 10.

#### 6.1.1.2 Installation types

ANSI/AMCA Standard 210 defines four installation types depending on the inlet and outlet duct configuration. The individual fans in a fan array are, by definition, not ducted. However, this standard defines four corresponding test configurations (installation types) for fan arrays based on the inclusion of exterior walls around the inlet and outlet plenums.

**Table 2 — Test Configuration Installation Types**

| Test Configuration (Installation Type) | Fan ANSI/AMCA Standard 210 | Fan Array ANSI/AMCA Standard 270 |
|---|---|---|
| A | Free inlet, free outlet | No inlet or outlet plenums |
| B | Free inlet, ducted outlet | No inlet plenum, outlet plenum |
| C | Ducted inlet, free outlet | Inlet plenum, no outlet plenum |
| D | Ducted inlet, ducted outlet | Inlet and outlet plenums |

### 6.1.2 Fan array static pressure

Static pressure shall be measured at the locations shown in the figures in Section 10.

### 6.1.3 Ducts

A duct may be incorporated in a laboratory test setup to provide a measurement plane or to simulate the conditions the fan array is expected to encounter in service. Dimension *D*3 or *D*4 in the test setup figures is the inside diameter of a circular cross-section duct or equivalent diameter of a rectangular cross-section duct with inside traverse dimensions *a* and *b*, where:

$$D = \sqrt{4ab/\pi} \qquad \text{Eq. 6.1}$$

#### 6.1.3.1 Airflow measurement duct

A duct with a measurement plane for airflow determination shall be straight and have a uniform rectangular or circular cross section. A pitot traverse duct shall be sized so that the distance allows for the airflow to become fully developed at the airflow measurement plane, as follows:

- For airflows measured on the fan array discharge: The airflow measurement plane shall be located not less than two equivalent diameters from the start of the duct, and the duct shall extend not less than one equivalent diameter beyond the airflow measurement plane.
- For airflows measured on the fan array inlet: The airflow measurement plane shall be located not less than three equivalent diameters from the start of the duct, and the duct shall extend not less than one equivalent diameter beyond the airflow measurement plane.
- Reference Annex C for information regarding the location of traverse measurement points for circular and rectangular ducts. All methods of determining measurement point locations within Annex C are considered acceptable for volumetric airflow testing.

#### 6.1.3.2 Pressure measurement duct

Pressure measurements and transitions of a fan array shall be through an inlet or discharge plenum. Refer to figure setups in Section 10.

#### 6.1.3.3 Duct area

An outlet or inlet duct used to provide an airflow measurement shall be sized to maintain a velocity sufficient for the measuring devices and shall not be less than 2 m/s (400 ft/min) and not greater than 20 m/s (4,000 ft/min).

#### 6.1.3.4 Airflow straightener

The use of an airflow straightener in ducts is optional.

### 6.2 Chamber or plenum

A chamber or plenum may be incorporated in a laboratory test setup to provide a measurement station to simulate the conditions the fan array is expected to encounter in service or is needed to transition from a measurement duct to the fan array. The chamber may have either a circular or rectangular cross-sectional shape. Dimension *M* in the test setup diagram is the inside diameter of a circular chamber or the equivalent diameter of a rectangular chamber with inside traverse dimensions *a* and *b*, where *a* and *b* are the height and width of the chamber:

$$M = \sqrt{4ab/\pi} \qquad \text{Eq. 6.2}$$

### 6.3 Variable air supply and exhaust system

A means of varying the fan array point of operation shall be provided in a laboratory test setup.

### 6.4 Throttling device

A throttling device may be used to control the fan array point of operation. Such a device shall be located on the end of the test duct or test chamber and shall be symmetrical about the duct or chamber axis.

### 6.5 Auxiliary fan

Auxiliary fans may be used to control the point of test fan operation. They shall provide sufficient pressure at the desired airflow to overcome losses through the test setup. Airflow adjustment means—such as dampers, auxiliary fan blade or auxiliary fan inlet vane pitch control or speed control—may be required. An auxiliary fan shall not surge or pulsate during a test.

### 6.6 Fan array input power boundary

When mechanical input power is reported, the fan array input power boundary is the interface between a fan and its drive, which in this context is a calibrated motor. When electrical input power is reported, the fan array input power boundary is the interface between mains and the drive.

**Table 3 — Input Power Boundary**

| Case | Motor Control | Motor | Transmission | Fan | Boundary | Quantity Measured |
|---|---|---|---|---|---|---|
| 1 | X | X | X | X | Mains/motor control | $W_{cmti}$ |
| 2 |  | X | X | X | Mains/motor | $W_{mti}$ |
| 3 |  | X |  | X | Mains/motor | $W_{mi}$ |
| 4 | X | X |  | X | Mains/motor control | $W_{cmi}$ |
| 5 |  |  | X | X | Calibrated motor | $H_{ti}$ |
| 6 |  |  |  | X | Calibrated motor | $H_i$ |

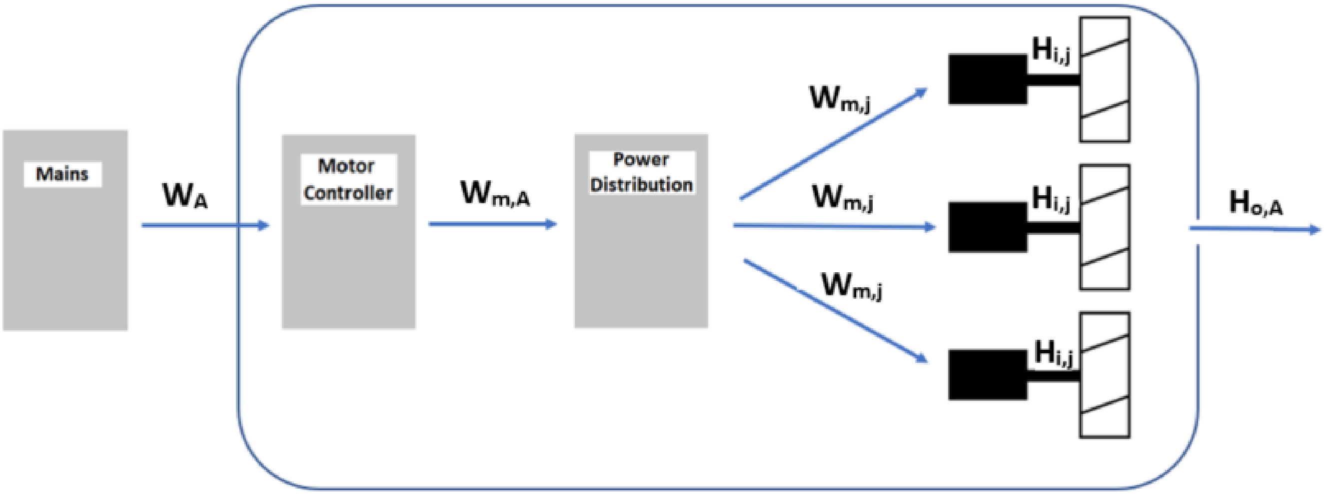


**Figure 6.1 — Input Power Boundary with a Single Controller for the Fan Array**

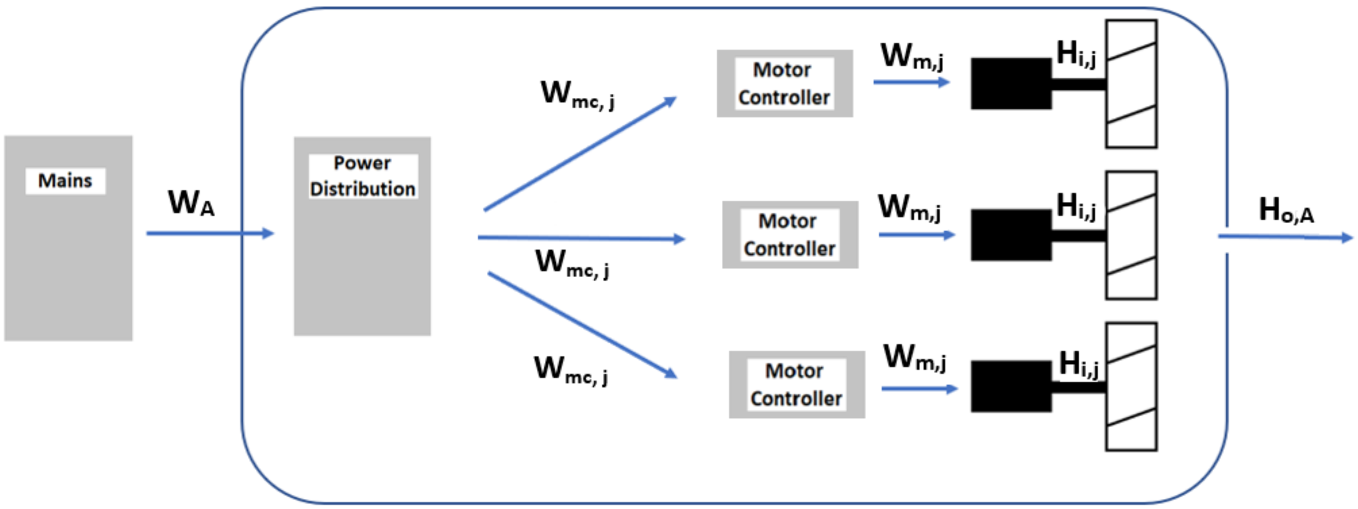


**Figure 6.2** — **Input Power Boundary with a Single Controller for Each Fan**

## 6.7 Fan speed measurement

The minimum number of fans for which fan speed shall be measured is specified in Table 4.

**Table 4 — Number of Fans for Which Fan Speed Shall be Measured**

| Number of Fans in the Fan Array | Number of Motors to be Monitored |
|---|---|
| 2-4 | 2 |
| 5-8 | 3 |
| 9-12 | 4 |
| 13-20 | 5 |
| 21+ | $\geq$ 25% of motors |

**Note:** If a fan array includes a combination of contained fans, partially contained fans and/or uncontained fans, the selection of fans for which fan speed is measured shall be distributed as equally as possible.

## 6.8 Fan array electrical power measurement

### 6.8.1 Non-fan-array system components

Any components that draw power from the same power connection(s) but are not part of the fan array and are not necessary for the operation of the fans shall be turned off.

### 6.8.2 Measurement of fan array electrical power

This section is to be used only if the fan array electrical power ($W_A$) is to be measured and not fan array shaft power ($H_i$). Table 5 shall determine the minimum number of power connections that need to be monitored.

**Table 5 — Minimum Number of Power Connections to be Monitored**

| Number of Power Connections in the Fan Array | Number of Points to be Monitored |
|---|---|
| 1-5 | Equal to number of power connections |
| 6+ | 5 or more |

**Note:** If there are unmonitored power connections, the monitored power connections must be distributed as evenly as possible vertically and horizontally across the fan array. If the fan array includes a combination of contained fans, partially contained fans or uncontained fans, the selection of power connections across these types shall be distributed as equally as possible.

The rated motor controller output current shall be no greater than 200 percent of the sum of the full load amps of the connected motors unless the motor controllers are going to be supplied with the fan array.

#### 6.8.3 Power measurement with motor controllers

If one or more motor controllers is supplied with the fan array, the power measurement shall be taken on the input side of each motor controller.

#### 6.8.4 Motor calibration when fan array shaft power is to be calculated

The minimum number of motors for each fan array shall be calibrated as specified in Table 6. Optionally, motors may be calibrated after air performance testing has been completed. (Refer to ANSI/AMCA Standard 210 for motor calibration information.)

Motor calibrations shall be performed at the same frequency and voltage output as used during the test. When a single controller operates multiple motors, motor input power shall be measured after the motor controller ($W_{m,A}$). When there is one controller per motor, input power shall be measured before the controller ($W_{c,j}$).

Use simple linear regression or a polynomial regression to establish the relationship between output power and input power. (Refer to example in AHRI Standard 430, Appendix D.)

**Table 6 — Minimum Number of Motors to be Calibrated**

| Number of Fans in the Fan Array | Minimum Number of Motors to be Calibrated |
|---|---|
| 2-4 | 2 |
| 5-8 | 3 |
| 9-12 | 4 |
| 13+ | 5 |

**Note**: An equal distribution of contained and uncontained fans must be measured.

# 7. Observations and Conduct of Test

All testing requirements and data recording must be in accordance with ANSI/AMCA Standard 210 except as stated below.

### 7.1 General test requirements

All relevant requirements in ANSI/AMCA Standard 210 that are not modified by this section shall be met.

#### 7.1.1 Backflow dampers

All backflow dampers for non-operating fans, if included in the fan array, shall be closed

### 7.2 Data to be recorded

#### 7.2.1 Test fan

The description of the test fan array, including specific dimensions, shall be recorded. The nameplate data of the individual fans and the total fan array with fan configurations shall be documented.

### 7.2.2 Test setup

The description of the test setup, including specific dimensions, shall be recorded. Reference may be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup may be attached to the recorded data. For setups using nozzles, the nozzle diameters shall be recorded.

**Table 7 — Test Data to be Recorded**

| Item Description | Figure | 10.1 | 10.2, 10.3 | 10.4, 10.5 | 10.6, 10.7 | 10.8 |
|---|---|---|---|---|---|---|
| Barometric pressure | $p_b$ | x | x | x | x | x |
| Rotational speed | $N$ | x | x | x | x | x |
| Input power | $W$ | x | x | x | x | x |
| Velocity pressure | $P_{v3r}$ | x |  | x |  | x |
| Static pressure | $P_{s3r}$ | x |  | x |  | x |
|  | $P_{s4}$ |  |  |  |  |  |
|  | $P_{s5}$ |  | x |  | x |  |
|  | $P_{s7}$ |  | x |  |  |  |
| Total pressure | $P_{t8}$ |  |  | x | x |  |
| Temperature | $t_{d0}$ | x | x | x | x | x |
|  | $t_{w0}$ | x | x | x | x | x |
|  | $t_{d2}$ | x | x | x | x | x |
|  | $t_{d3}$ | x |  | x |  | x |
|  | $t_{d4}$ |  |  |  |  |  |
|  | $t_{d5}$ |  | x |  | x |  |
|  | $t_{d7}$ | x |  |  |  |  |
|  | $t_{d8}$ |  |  | x | x |  |
| Nozzle pressure drop | $\Delta P$ |  | x |  | x |  |

### 7.2.3 Instruments

The instruments and apparatus used in the test shall be listed and recorded, and the manufacturer names, model numbers, serial numbers and calibration information shall be provided, if requested.

### 7.2.4 Test data (review)

The test data that must be recorded varies by setup figure and is shown in Table 7. One reading for each checked parameter is required for each test point with the following exceptions:

1. When environmental conditions vary, a minimum of three readings shall be taken for $t_{d0}$, $t_{w0}$, $t_{d2}$, and $p_b$.
2. One reading for each pitot station shall be recorded for $P_{v3r}$ and $P_{s3r}$.
3. For a test in which $P_s$ is less than 1 kPa (4 in. wg), the temperatures $t_{d3}$, $t_{d4}$, $t_{d5}$, $t_{d7}$ and $t_{d8}$ need not be measured. The value $t_{d0}$ may be used.
4. For setups in Figures 10.2 and 10.3, $t_{d2}$ may be considered equal to $t_{d5}$.
5. A piezometer can be used to measure $P_{s8}$ instead of $P_{t8}$. See Figures 10.4 and 10.6, Note 4, for requirements.

For setup in Figure 10.6, $P_{s5}$ may be calculated. See Figure 10.6, Note 4.

### 7.2.5 Personnel

The names of test personnel shall be listed with the data for which they are responsible.

# 8. Calculations

All calculation requirements other than those described in this section and with the test setup figures in Section 10 must be in accordance with ANSI/AMCA Standard 210, Section 7. Any references to fans in ANSI/AMCA Standard 210, Section 7, Calculations shall be considered applicable to fan arrays.

### 8.1 Compressibility

For increased accuracy, manufacturers may use the compressible (include compressibility coefficient *Kp*) or incompressible (exclude compressibility coefficient *Kp*) conversion formulae to calculate performance as follows (from AMCA Publication 211, Annex I):

1. Include *Kp* for tests in which fan array static pressures exceed 10 in. wg (2.5 KPa).
2. Include *Kp* for performance ratings calculations (see Annex B) for other speeds and sizes when fan array static pressures exceed 10 in. wg (2.5 kPa).

### 8.2 Air velocity and velocity pressure

Fan array velocity pressure is defined as the calculated velocity pressure based on the average velocity across the fan array outlet. Fan array total pressure is the sum of the fan array static pressure and the fan array velocity pressure.

1. Fan array velocity shall be calculated by dividing airflow by the area of the fan array inlet or outlet when the fan array includes an integral casing or is composed of fans that each have an integral casing. Divide the total airflow by the fan array casing internal dimensions (*a* x *b*).
2. The velocity through an inlet or discharge plenum shall be calculated in the same manner and could differ from the fan array velocity if the plenum internal dimensions differ from that of the fan array.

$$V_A = \frac{Q_A}{A_A} \qquad \text{Eq. 8.1}$$

Fan array velocity pressure is the fan array velocity multiplied by the air density:

$$P_{vA} = P_{vA2} = \left(\frac{Q_{A2}}{\sqrt{2}A_2}\right)^2 \rho_2 \qquad \text{SI} \qquad \text{Eq. 8.2}$$

Or

$$P_{vA} = P_{vA2} = \left(\frac{Q_{A2}}{1097.8A_2}\right)^2 \rho_2 \qquad \text{IP} \qquad \text{Eq. 8.3}$$

### 8.3 Mean fan speed

The mean rotational speed of the array ($N_A$) shall be the average speed of the monitored motors.

$$N_A = \frac{\sum_{j=1}^{n} N_j}{n} \qquad \text{Eq. 8.4}$$

Where:

$N_A$ is the mean rotational speed of the fan array.

$j$ is one of the individual fans for which rotational speed was measured.

$N_j$ is the measured rotational speed of the individual fan.

$n$ is the number of fans monitored.

## 8.4 Calculation of fan array electrical power

### 8.4.1 Monitored power connections

If all the fan array's power connections are monitored, the electrical input power is the sum of all the measured power values of the power connections.

### 8.4.2 Unmonitored power connections

If any power connections are unmonitored and the requirements of Table 5 are met, the fan electrical power of the fan array shall be calculated per the requirements below.

If the highest power measurement is not more than 3 percent greater than the lowest power measurement, the mean of all the power measurements shall represent the power of a single fan. The fan array electrical power shall be the product of the mean measured power and the number of operating fans.

Otherwise, record the power for each monitored power connection. Repeat the test with the previously unmonitored power connections until there is a measured power for each power connection, then add the values. For each repeat of the test, the fan array speed shall match the first test, and the fan array static pressure shall be +/-3 percent of the fan array static pressure at standard air density of the first test.

## 8.5 Calculation of fan array shaft power

The fan shaft power of fan arrays may optionally be calculated. All the requirements of Section 6.8.4 must be met except where they conflict with requirements in this section.

### 8.5.1 Motor calibration

Use one of the following methods to determine the composite motor calibration:

Use simple linear regression or a polynomial regression to establish the relationship between output power and input power. (Refer to example in AHRI Standard 430, Appendix D.)

### 8.5.2 Calculation of fan shaft power

#### 8.5.2.1 Motor controllers with more than one fan each or no motor controllers

When there is more than one fan for each motor controller or there is no motor controller, fan array shaft power is calculated as shown below:

1. Divide the fan array motor electrical power by the number of operating fans.

$$W_{m,j} = \frac{W_{m,A}}{n_A} \qquad \text{Eq. 8.5}$$

Where:

$n_A$ is the number of fans in the fan array.

$W_{m,j}$ is the fan motor electrical power.

$W_{m,A}$ is the fan array motor electrical power.

2. Determine the shaft power per fan using the composite motor calibration data.

$$H_{ij} = f\left(W_{m,j}\right) \qquad \text{Eq. 8.6}$$

Where:

$f(W_{m,j})$ is the function to determine fan shaft power based on fan motor controller electrical power and rotational speed determined in accordance with Section 6.8.4.

$W_{m,j}$ is the fan electrical power determined in accordance with Section 6.8.2.

$H_{i,j}$ is the fan shaft power.

**3.** Multiply the shaft power per fan by the number of fans to get the total unit shaft power.

$$H_{i,A} = H_{i,j} \times n_A \qquad \text{Eq. 8.7}$$

Where:

$H_{i,A}$ is the fan array shaft power.

$H_{i,j}$ is the fan shaft power.

$n_A$ is the number of fans in the fan array.

**8.5.2.2 One motor controller for each fan**
Fan array shaft power when there is one motor controller for each fan is calculated as shown below:

**1.** Divide the total input power by the number of operating fans.

$$W_{mc,j} = \frac{W_A}{n_A} \qquad \text{Eq. 8.8}$$

Where:

$n_A$ is the number of fans in the fan array.

$W_{mc,j}$ is the fan motor controller electrical power.

$W_A$ is the fan array electrical power.

**2.** Determine the shaft power per fan using the composite motor calibration data.

$$H_{i,j} = f(W_{mc,j}) \qquad \text{Eq. 8.9}$$

Where:

$f(W_{mc,j})$ is the function to determine fan shaft power based on fan electrical power and rotational speed determined in accordance with Section 6.8.4.

$W_{mc,j}$ is the fan motor controller electrical power determined in accordance with Section 6.8.2.

$H_{i,j}$ is the fan shaft power.

**3.** Multiply the shaft power per fan by the number of fans to get the total unit shaft power.

$$H_{i,A} = H_{i,j} \times n_A \qquad \text{Eq. 8.10}$$

Where:

$H_{i,A}$ is the fan array shaft power.

$H_{i,j}$ is the fan shaft power.

$n_A$ is the number of fans in the fan array.

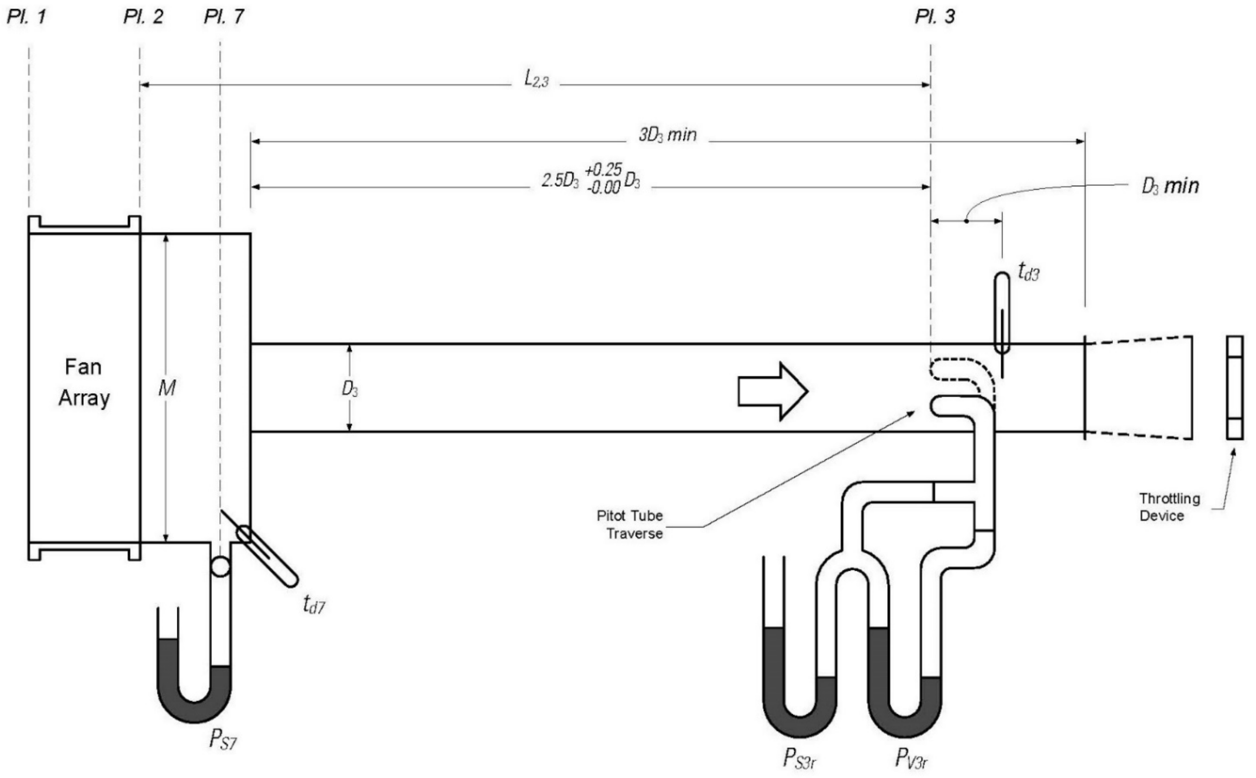
# 9. Report and Results of Test

The results of the fan tests shall be presented as tables or plots. ANSI/AMCA Standard 210 defines typical tabular and plotting conventions. Descriptions of the test fan, test instruments and personnel must be reported as outlined in ANSI/AMCA Standard 210, Section 8, Report and Results of Test. The laboratory shall be identified by name and location.

In addition to ANSI/AMCA Standard 210, the following fan array testing reporting requirements shall be included:

1. Number of fans for which fan speed shall be measured.
2. Number of power connections monitored.
3. Number of motors calibrated, if fan shaft power is calculated.
4. Test data from Table 7.
5. Motor controller if supplied by the lab.
6. All dimensions of any inlet or discharge plenums or ducts that are not part of the fan array.
7. Measurement plane and traverse grid as outlined in Annex C.

# 10. Figures



**(Derived from ANSI/AMCA Standard 210, Figure 7)**

**Notes:**

1. Dotted lines on the outlet indicate a diffuser cone that may be used to approach more nearly free delivery.
2. The minimum fan (array) static pressure for which this test can be applied is the sum of the entrance loss to the duct and the minimum pressure drop over the throttling device at the tested airflow.

**Flow and pressure formulae:**

$$** \, \mathrm{P_{V3}} = \left(\frac{\sum\sqrt{\mathrm{P_{v3r}}}}{\mathrm{n}}\right)^2 \qquad \mathrm{Q_3 = V_3A_3} \qquad \mathrm{P_v} = \mathrm{P_{v3}}\left(\frac{\mathrm{A_3}}{\mathrm{A_2}}\right)^2\left(\frac{\rho_3}{\rho_2}\right) \qquad \mathrm{P_s = P_{s7} - P_{t1}}$$

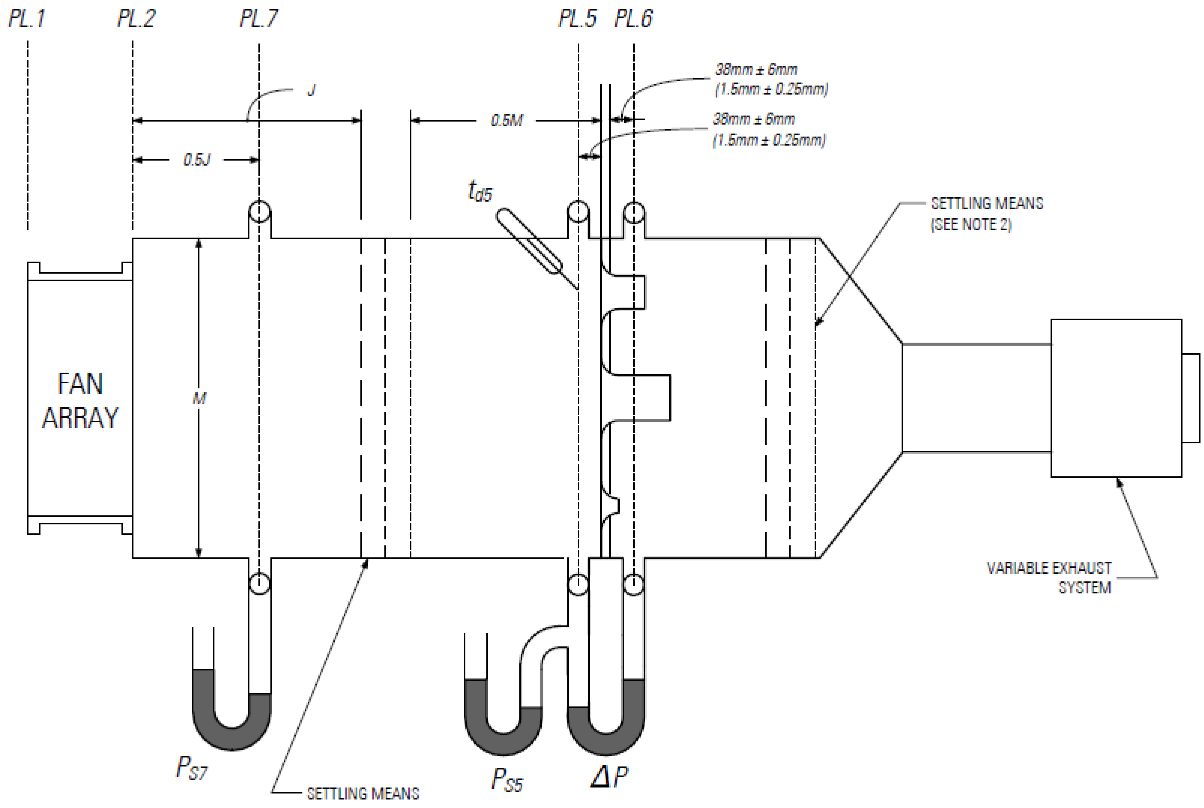
$$* \, \mathrm{V_3} = \sqrt{2}\sqrt{\frac{\mathrm{P_{v3}}}{\rho_3}} \qquad \mathrm{Q} = \mathrm{Q_3}\left(\frac{\rho_3}{\rho}\right) \qquad \mathrm{P_{t1}} = 0 \qquad \mathrm{P_t = P_s + P_v}$$

$$\mathrm{P_{s3}} = \frac{\sum \mathrm{P_{s3r}}}{\mathrm{n}}$$

*These formulae are the same in both SI and I-P systems, except for $V_3$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.
**In lieu of a traverse of individual pressure measurements at Plane 3, a manifolded system can be used to measure average values of $P_{t3}$ and $P_{s3}$ to calculate $P_{v3}$:

$$P_{v3} = P_{t3} - P_{s3}$$

**Figure 10.1 — Outlet Duct Setup – Pitot Tube Traverse**



**(Derived from ANSI/AMCA Standard 210, Figure 7)**

**Notes:**

1. The variable exhaust system may be an auxiliary fan or a throttling device.
2. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
3. Dimension *J* shall allow the chamber to meet the criteria of ANSI/AMCA Standard 210, Annex A.
4. To calculate the density at Plane 5 only, $P_{s5}$ may be considered equal to $P_{s7}$.

**Flow and pressure formulae:**

$$* \, Q_5 = \sqrt{2} Y \sqrt{\frac{\Delta P}{\rho_5}} \sum (CA_6)$$

$$* \, P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2 \rho_2$$

$$P_s = P_{s7} - P_{t1}$$

$$Q = Q_5 \left(\frac{\rho_5}{\rho}\right)$$

$$P_v = P_{v2}$$

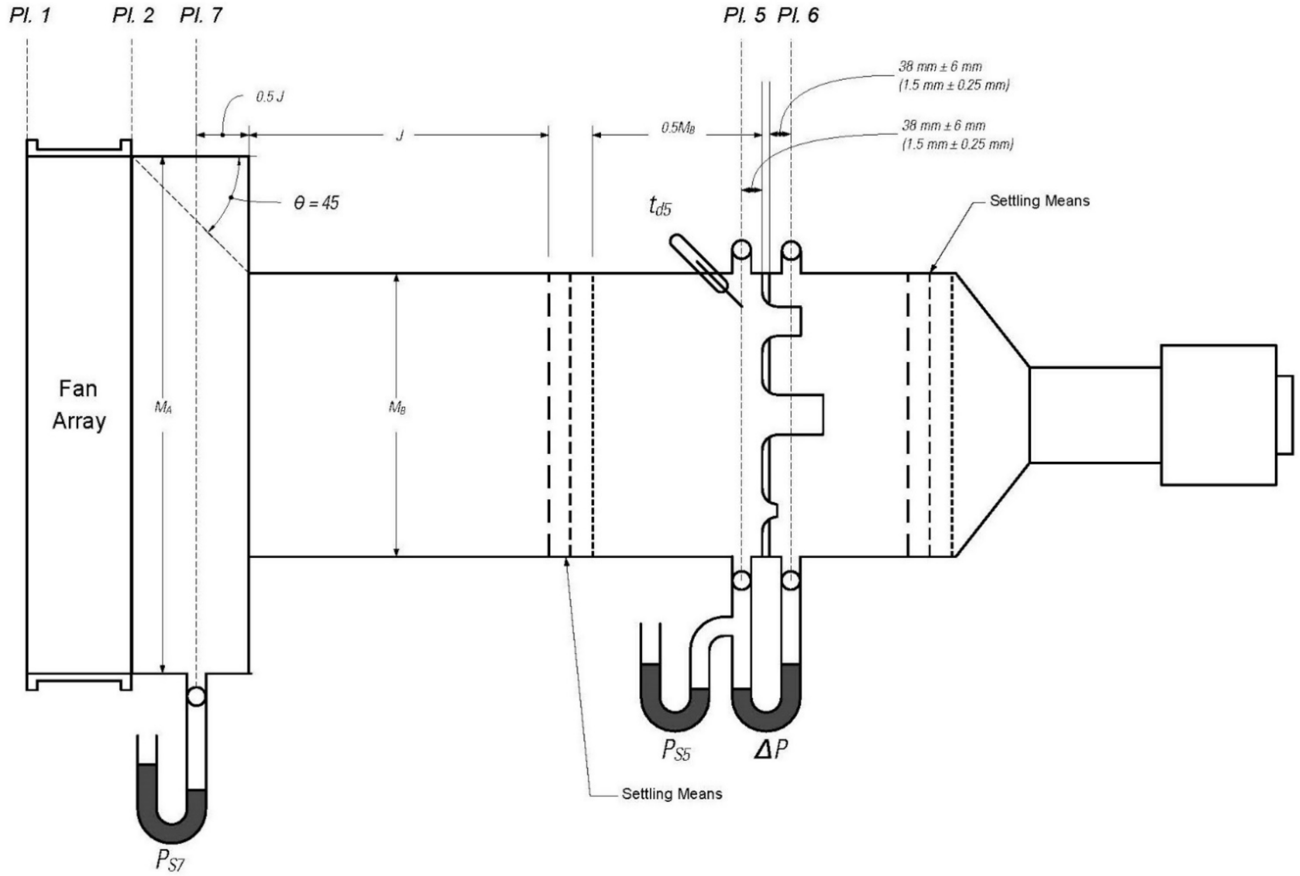
$$P_t = P_s + P_v$$

$$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right)$$

$$P_{t1} = 0$$

*These formulae are the same in both the SI and the I-P systems, except for $Q_5$ and $P_{v2}$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

**Figure 10.2 — Outlet Chamber Setup – Multiple Nozzles in Chamber (No Discharge Plenum Required)**



**(Derived from ANSI/AMCA Standard 210, Figure 12)**

**Notes:**

1. The variable exhaust system may be an auxiliary fan or a throttling device.
2. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
3. Dimension *J* shall allow the chamber to meet the criteria of ANSI/AMCA Standard 210, Annex A.
4. Eliminate the fixed dimension fan.
5. To calculate the density at Plane 5 only, $P_{s5}$ may be considered equal to $P_{s7}$.

**Flow and pressure formulae:**

$$* \, Q_5 = \sqrt{2} Y \sqrt{\frac{\Delta P}{\rho_5}} \sum (CA_6)$$

$$* \, P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2 \rho_2$$

$$P_s = P_{s7} - P_{t1}$$

$$Q = Q_5 \left(\frac{\rho_5}{\rho}\right)$$

$$P_v = P_{v2}$$

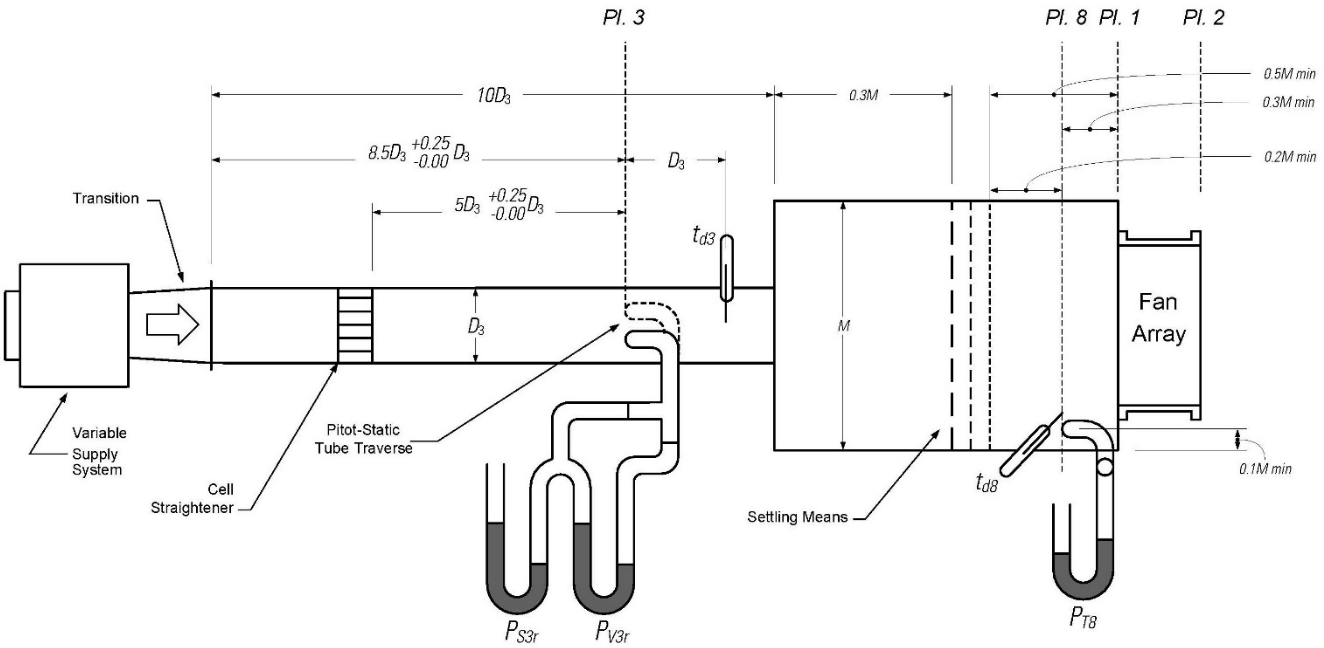
$$P_t = P_s + P_v$$

$$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right)$$

$$P_{t1} = 0$$

*These formulae are the same in both the SI and the I-P systems, except for $Q_5$ and $P_{v2}$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

**Figure 10.3 — Outlet Chamber Setup – Multiple Nozzles in Chamber (Discharge Plenum Required)**



**(Derived from ANSI/AMCA Standard 210, Figure 13)**

**Notes:**

1. Dotted lines on the fan array outlet indicate an optional discharge plenum.
2. Additional ductwork of any size, including elbows, may be used to connect between the chamber and the exit of the 10*D* minimum test duct.
3. The variable supply system may be an auxiliary fan or a throttling device.
4. In lieu of a total pressure tube, a piezometer ring can be used to measure static pressure at Plane 8. If this alternative arrangement is used, and the calculated Plane 8 velocity is greater than 2 m/s (400 ft/min), then the calculated Plane 8 velocity pressure shall be added to the measured static pressure.

**Flow and pressure formulae:**

$$** \mathrm{P_{V3}} = \left(\frac{\sum\sqrt{\mathrm{P_{v3r}}}}{\mathrm{n}}\right)^2 \qquad Q = Q_3\left(\frac{\rho_3}{\rho}\right) \qquad \mathrm{P_{s2}} = 0$$

$$* \mathrm{V_3} = \sqrt{2}\sqrt{\frac{\mathrm{P_{v3}}}{\rho_3}} \qquad \mathrm{P_v} = \mathrm{P_{v3}}\left(\frac{\mathrm{A_3}}{\mathrm{A_2}}\right)^2\left(\frac{\rho_3}{\rho_2}\right) \qquad \mathrm{P_s} = \mathrm{P_{s2}} - \mathrm{P_{t1}}$$

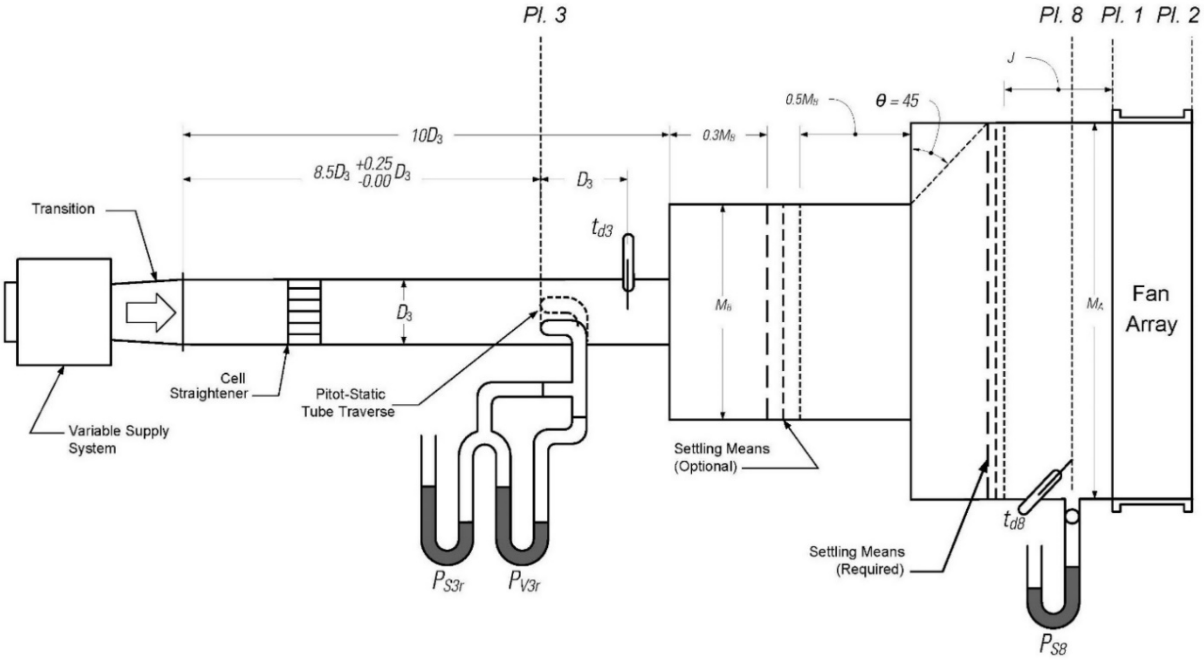
$$\mathrm{Q_3} = \mathrm{V_3}\mathrm{A_3} \qquad \mathrm{P_{t1}} = \mathrm{P_{t8}} \qquad \mathrm{P_t} = \mathrm{P_s} + \mathrm{P_v}$$

*These formulae are the same in both SI and I-P systems, except for $V_3$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

**In lieu of a traverse of individual pressure measurements at Plane 3, a manifolded system can be used to measure average values of $P_{t3}$ and $P_{s3}$. *P* calculate $P_{v3}$:

$$P_{v3} = P_{t3} - P_{s3}$$

**Figure 10.4 — Inlet Chamber Setup – Pitot Tube Traverse in Duct (No Inlet Plenum)**



**(Derived from ANSI/AMCA Standard 210, Figure 13)**

**Notes:**

1. Dotted lines on the fan array outlet indicate an optional discharge plenum.
2. Additional ductwork of any size, including elbows, may be used to connect the chamber and the exit of the 10*D* minimum test duct.
3. The variable supply system may be an auxiliary fan or a throttling device.
4. *J* shall not be less than 0.61 m (2 ft).
5. θ is a 45º angle from the end of the duct to the beginning of the settling means.

**Flow and pressure formulae:**

$$** \mathrm{P_{V3}} = \left(\frac{\sum\sqrt{\mathrm{P_{v3r}}}}{\mathrm{n}}\right)^2$$

$$Q = Q_3\left(\frac{\rho_3}{\rho}\right)$$

$$\mathrm{P_{s2}} = 0$$

$$* \mathrm{V_3} = \sqrt{2}\sqrt{\frac{\mathrm{P_{v3}}}{\rho_3}}$$

$$\mathrm{P_v} = \mathrm{P_{v3}}\left(\frac{\mathrm{A_3}}{\mathrm{A_2}}\right)^2\left(\frac{\rho_3}{\rho_2}\right)$$

$$\mathrm{P_s} = \mathrm{P_{s2}} - \mathrm{P_{t1}}$$

$$\mathrm{Q_3} = \mathrm{V_3}\mathrm{A_3}$$

$$\mathrm{P_{v8}} = \mathrm{P_{v3}}\left(\frac{\mathrm{A_3}}{\mathrm{A_8}}\right)^2\left(\frac{\rho_3}{\rho}\right)$$

$$\mathrm{P_t} = \mathrm{P_s} + \mathrm{P_v}$$

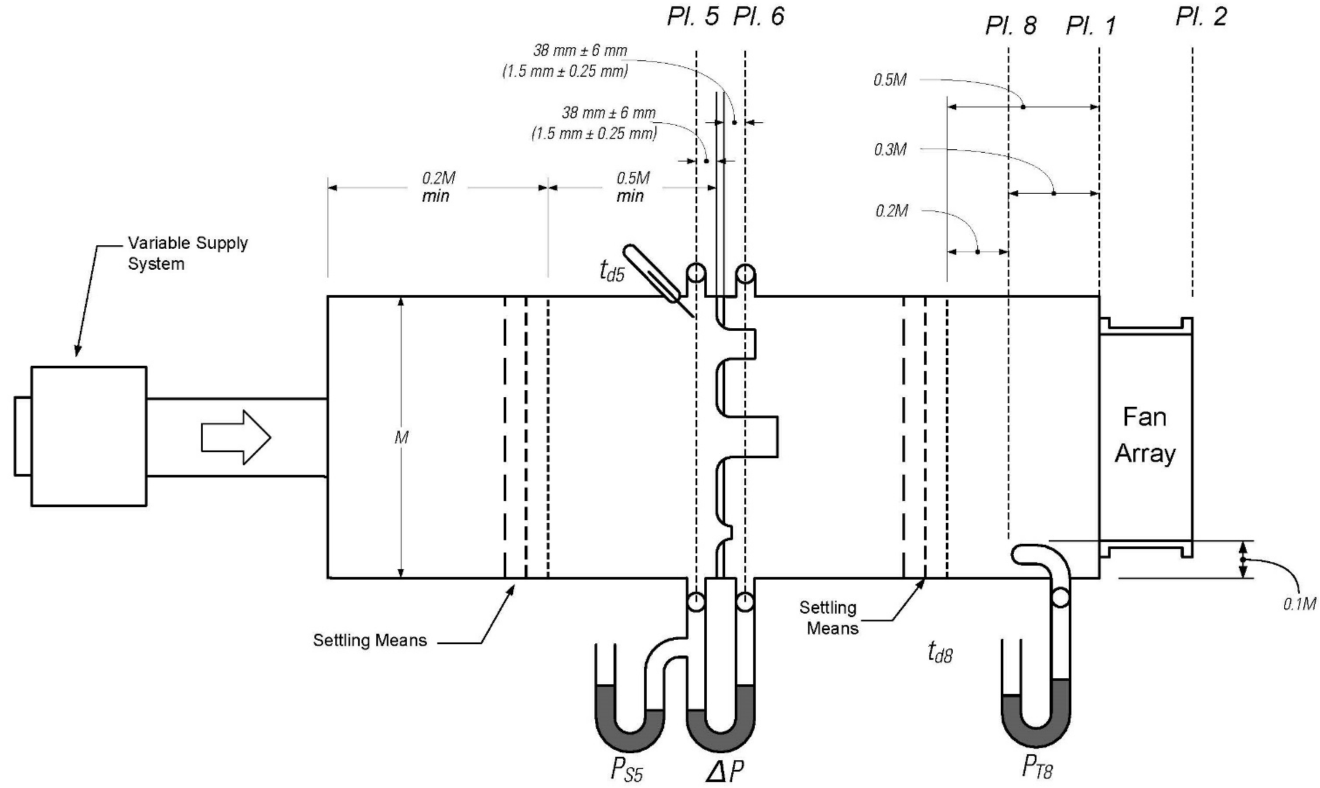
$$\mathrm{P_{t1}} = \mathrm{P_{s8}} + \mathrm{P_{v8}}$$

*These formulae are the same in both SI and I-P systems, except for $V_3$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

**In lieu of a traverse of individual pressure measurements at Plane 3, a manifolded system can be used to measure average values of $P_{t3}$ and $P_{s3}$. *P* calculate $P_{v3}$:

$$P_{v3} = P_{t3} - P_{s3}$$

**Figure 10.5 — Inlet Chamber Setup – Pitot Traverse in Duct with Inlet Plenum**



**(Derived from Figure 15, ANSI/AMCA Standard 210)**

**Notes:**

1. Dotted lines on the fan array outlet indicate an optional discharge plenum.
2. The variable supply system may be an auxiliary fan or throttling device.
3. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
4. To calculate the density at Plane 5 only, $P_{s5}$ may be considered equal to $(P_{t8} + \Delta P)$.
5. In lieu of a total pressure tube, a piezometer ring can be used to measure static pressure at Plane 8. If this alternative arrangement is used, and the calculated Plane 8 velocity is greater than 2 m/s (400 ft/min), then the calculated Plane 8 velocity pressure shall be added to the measured static pressure.

**Flow and pressure formulae:**

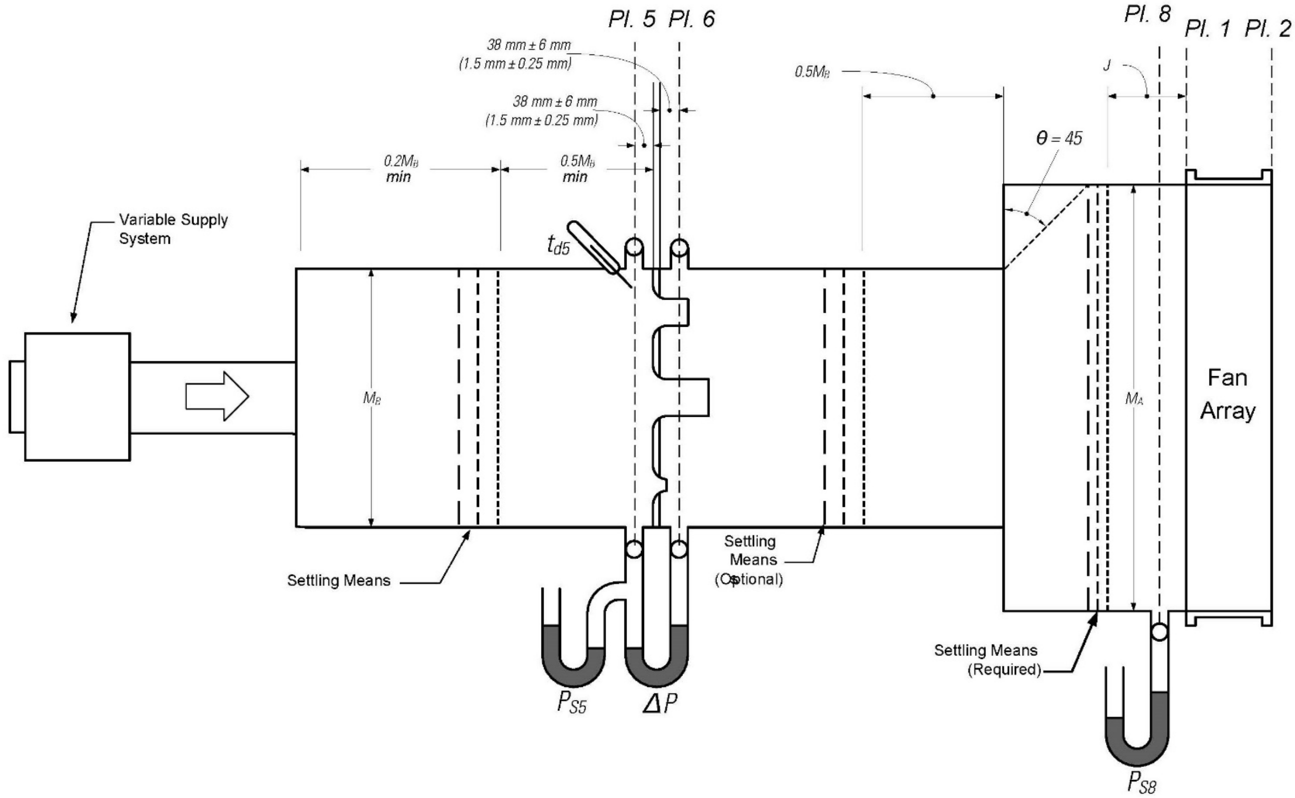
$$* \, Q_5 = \sqrt{2} Y \sqrt{\frac{\Delta P}{\rho_5}} \sum(CA_6) \qquad * \, P_{v2} = \left(\frac{V_2}{\sqrt{2}}\right)^2 \rho_2 \qquad P_{s2} = 0$$

$$Q = Q_5 \left(\frac{\rho_5}{\rho}\right) \qquad P_{t1} = P_{t8} \qquad P_s = P_{s2} - P_{t1}$$

$$V_2 = \left(\frac{Q}{A_2}\right)\left(\frac{\rho}{\rho_2}\right) \qquad P_v = P_{v2} \qquad P_t = P_s + P_v$$

*These formulae are the same in both the SI and the I-P systems, except for $Q_5$ and $P_{v2}$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

**Figure 10.6 — Inlet Chamber Setup – Multiple Nozzles in Chamber (No Plenum Required)**



**(Derived from Figure 15, ANSI/AMCA Standard 210)**

**Notes:**

1. The variable supply system may be an auxiliary fan or throttling device.
2. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
3. To calculate the density at Plane 5 only, $P_{s5}$ may be considered equal to $(P_{t8} + \Delta P)$.
4. *J* shall not be less than 0.61 m (2 ft).
5. θ is a 45° angle from the end of the duct to the beginning of the settling means.

**Flow and pressure formulae:**

$$* \mathrm{Q_5} = \sqrt{2}\mathrm{Y}\sqrt{\frac{\Delta \mathrm{P}}{\rho_5}}\sum(\mathrm{CA_6}) \qquad * \mathrm{P_{v2}} = \left(\frac{\mathrm{V_2}}{\sqrt{2}}\right)^2 \rho_2 \qquad \mathrm{P_{s2}} = 0$$

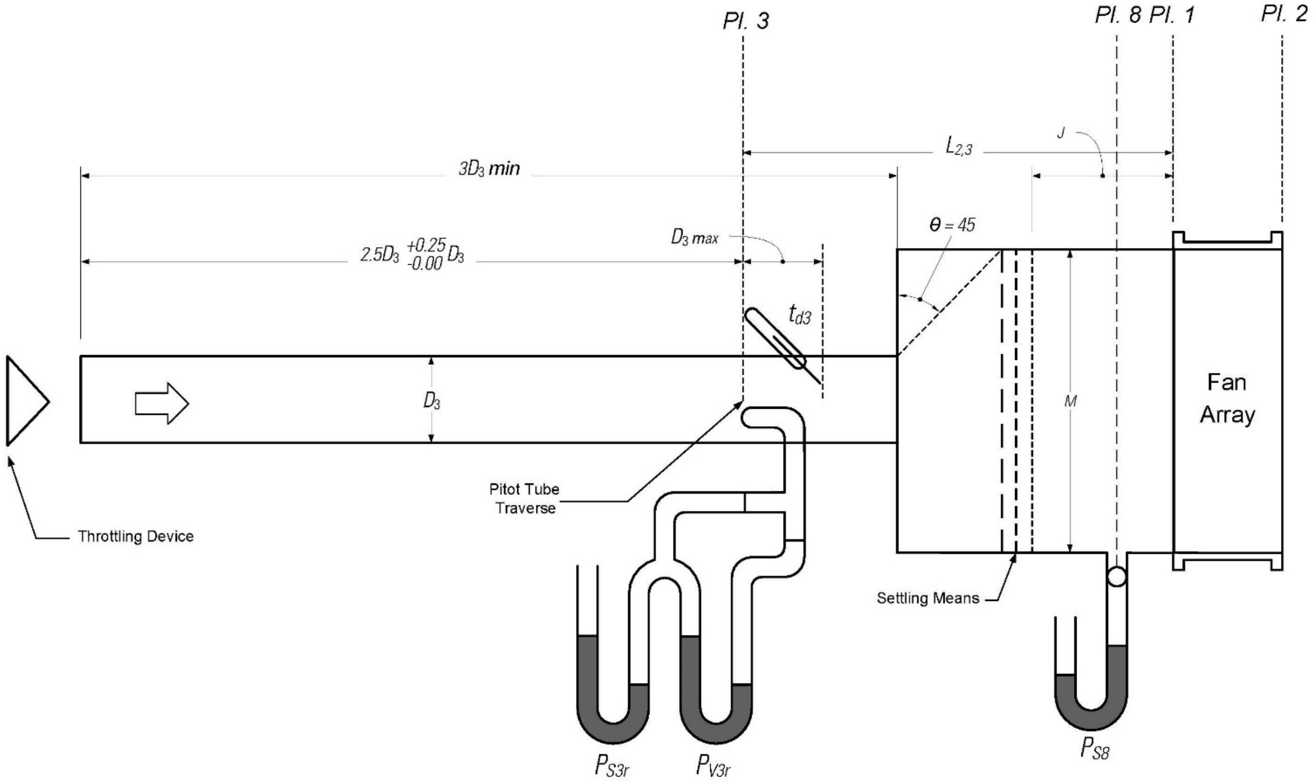
$$\mathrm{Q} = \mathrm{Q_5}\left(\frac{\rho_5}{\rho}\right) \qquad \mathrm{P_v} = \mathrm{P_{v2}} \qquad \mathrm{P_s} = \mathrm{P_{s2}} - \mathrm{P_{t1}}$$

$$\mathrm{V_2} = \left(\frac{\mathrm{Q}}{\mathrm{A_2}}\right)\left(\frac{\rho}{\rho_2}\right) \qquad \mathrm{P_{v8}} = \mathrm{P_{v2}}\left(\frac{\mathrm{A_2}}{\mathrm{A_8}}\right)^2\left(\frac{\rho_2}{\rho}\right) \qquad \mathrm{P_t} = \mathrm{P_s} + \mathrm{P_v}$$

$$\mathrm{P_{t1}} = \mathrm{P_{s8}} + \mathrm{P_{v8}}$$

* These formulae are the same in both the SI and the I-P systems, except for $Q_5$ and $P_{v2}$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8.

**Figure 10.7 — Inlet Chamber Setup – Multiple Nozzles in Chamber (Inlet Plenum Required)**



**(Derived from Figure 16, ANSI/AMCA Standard 210)**

**Notes:**

1. Dotted lines on the fan array outlet indicate an optional discharge plenum.
2. *J* shall not be less than 0.61 m (2 ft).
3. θ is a 45º angle from the end of the duct to the beginning of the settling means.

**Flow and pressure formulae:**

$$** \; P_{V3} = \left(\frac{\sum \sqrt{P_{v3r}}}{n}\right)^2 \qquad Q = Q_3\left(\frac{\rho_3}{\rho}\right) \qquad P_{s2} = 0$$

$$* \; V_3 = \sqrt{2}\sqrt{\frac{P_{v3}}{\rho_3}} \qquad P_v = P_{v3}\left(\frac{A_3}{A_2}\right)^2\left(\frac{\rho_3}{\rho_2}\right) \qquad P_s = P_{s2} - P_{t1}$$

$$Q_3 = V_3 A_3 \qquad P_{t1} = P_{t8} \qquad P_t = P_s + P_v$$

*These formulae are the same in both SI and I-P systems, except for $V_3$; in the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.8

**In lieu of a traverse of individual pressure measurements at Plane 3, a manifolded system can be used to measure average values of $P_{t3}$ and $P_{s3}$. *P* calculate $P_{v3}$:

$$P_{v3} = P_{t3} - P_{s3}$$

**Figure 10.8 — Inlet Duct – Pitot Tube Traverse in Inlet Duct**

# Annex A
# Guidance on ANSI/AMCA Standard 270 (Informative)

(This annex is available to the public through AMCA International Inc. at no cost.)

## A.1 Purpose

This annex guides manufacturers and fan specifiers on the appropriate use of this standard.

## A.2 Appropriate uses of ANSI/AMCA Standard 270

This standard is a laboratory method of test for fan arrays to determine only the aerodynamic performance for a given fan array that is a unique combination of:

- Fan type
- Fan size
- Fan speed
- Quantity of fans
- Fan arrangement
- Spacing between fans
- Motor speed controller(s), if included
- The number of operating fans
- The use or non-use of partitions between fan inlets or fan outlets
- The inclusion of appurtenances, such as backflow dampers and safety screens

Each of these values is determined by the person specifying the test. Typically, a given fan array will be tested at multiple operating conditions.

### A.2.1 Use by manufacturers

#### A.2.1.1 Individual tests

Manufacturers should only use ANSI/AMCA Standard 270 to specify the laboratory test requirements of a unique fan array as described previously. Manufacturers may extrapolate that fan array's aerodynamic performance to other speeds using the methods described in Annex B.

#### A.2.1.2 Tests of multiple fan arrays to create application data

Manufacturers may test many different fan arrays. Each test should be performed per the requirements of this standard. Manufacturers may use results from those tests to calculate the expected performance of untested fan arrays per Annex B. Manufacturers may use other methods to calculate the performance of untested fan arrays.

### A.2.2 Fan specifiers

The only time it is appropriate for a fan specifier to list ANSI/AMCA Standard 270 by itself is when the specifier requires a particular fan array to be laboratory tested. For example: "Each fan array shall be serialized, laboratory tested per ANSI/AMCA Standard 270 and furnished with an individual test report."

## A.3 Inappropriate uses of ANSI/AMCA Standard 270

This section describes possible misapplications of ANSI/AMCA Standard 270 and explains why they are inappropriate.

### A.3.1 Determining a single fan's performance

Data collected via testing under ANSI/AMCA Standard 270 cannot predict the aerodynamic performance of an individual fan. Individual fans should be tested per the requirements of ANSI/AMCA Standard 210. This exclusion applies even if a fan array is tested with only a single operating fan.

Test data from a fan array often will not provide the same results for an individual fan because the installation conditions in a fan array will be different than those required by ANSI/AMCA Standard 210.The differences may include:

- Interaction between the discharge flows of multiple fans.
- Inlet system effects: ANSI/AMCA Standard 210 tests typically are performed with a completely free inlet. For fan arrays, the inlets of neighboring fans may create airflow patterns that affect inlet conditions.
- System effects or pressure loss created by backflow dampers that likely are not included in a single-fan test.
- Air recirculation through non-operating fans: Even if the non-operating fans have dampers, there will be some leakage.
- Air recirculation through the assembly: When multiple fans are assembled as a fan array, there likely will be some, possibly significant, air leakage back to the inlet side through the assembly. That leakage does not exist in a test performed under ANSI/AMCA Standard 210.
- Pressure loss from other appurtenances.

### A.3.2 Inappropriate testing claims

ANSI/AMCA Standard 270 includes a test method for a particular fan array as described in Section A.1. While often a different and untested configuration will have the same performance, it is not appropriate to claim that the configuration was tested per ANSI/AMCA Standard 270. Annex B provides methods to develop performance data for untested fan arrays.

For example: A fan array using contained fans that is three fans high by four fans wide is tested. Likely, an array using those same fans but arranged four fans high by three fans wide will have the same aerodynamic performance. Nevertheless, a manufacturer must not claim that arrangement was tested per ANSI/AMCA Standard 270.

### A.3.3 Inappropriate statements for untested arrays

Annex B is an informative section of this standard. Therefore, specifiers should not require that fan array performance be determined per Annex B.

## A.4 The use of other AMCA standards

### A.4.1 Sound per ANSI/AMCA Standard 300, Reverberant Room Method for Sound Testing of Fans

ANSI/AMCA Standard 270 does not address sound.

### A.4.2 Fan Energy Index (FEI) per ANSI/AMCA Standard 208, Calculation of the Fan Energy Index

Fan Energy Index (FEI) should always be calculated per the method in ANSI/AMCA Standard 208, Annex C. This method uses the total airflow of the fan array as the reference airflow used for the FEI calculation.

It is inappropriate to calculate the FEI based on an individual fan. If FEI is calculated this way, the reference fan input power for arrays with different numbers of fans would not be the same, and the resulting FEIs would not be comparable.

### A.4.3 Fan Efficiency Grade (FEG) per ANSI/AMCA Standard 205, Energy Efficiency Classification for Fans

Fan arrays and fans tested only wire-to-air are out of the scope of ANSI/AMCA Standard 205.

The FEG energy-efficiency classification includes the velocity pressure at the individual fan’s outlet. However, fan arrays in the scope of this standard do not use fans with individual outlet ducts. Velocity pressure of a fan without an outlet duct is immediately lost when the airflow exits the fan and cannot contribute useful work.

# Annex B
# Calculation of Fan Array Performance from Tests (Informative)

Array configuration and fan geometry are key factors in performance losses. In some instances, these losses may be adequately defined using the comparable effect of a fan enclosure. It is incumbent on the manufacturer to ensure that the performance obtained from rating factors results in accurate calculated performance.

## B.1 General

In some cases, the exact configuration of a fan array can be tested. However, the variety of possible fan array sizes and configurations creates a need for the conversion of aerodynamic performance test results from a tested fan array to performance data of another fan array. This annex provides standardized methods of calculating fan array performance data from tests.

### B.1.1 Backflow dampers

Fan arrays are commonly applied with a backflow damper on each fan. Backflow dampers can be motorized or non-motorized (gravity) and can cause a significant performance reduction. Fan array performance calculated according to this annex shall be identified as to whether it includes the effects of backflow dampers and, if so, shall be based on tests with backflow dampers.

### B.1.2 Fan array shaft power vs. electrical power

Fan array shaft power is defined as the total of all shaft power values of individual fans in a fan array. Calculation of fan shaft power from tests to other sizes or speeds should be done according to AMCA Publication 211, Annex I.

Fan array electrical power is defined as the total of all electrical power values of individual fans in a fan array; however, each individual motor must have a motor controller. If a single motor controller is used for multiple motors, electrical power must be measured going into the controller and cannot be used to calculate the electrical power for individual fans.

### B.1.3 Use of ANSI/AMCA Standard 207

If fan shaft power is measured according to ANSI/AMCA Standard 210 or calculated according to AMCA Publication 211, Annex I, ANSI/AMCA Standard 207 can be used to determine the electrical input power for individual fans and, when they are combined, fan array electrical power.

### B.1.4 Motor controller sizing

If a fan array includes a motor controller for each individual motor, the electrical power for individual fans can be combined to determine fan array electrical power.

### B.1.5 Combining performance from individual tests

Sections B.2 through B.6 standardize calculation methods for fan array performance from tests of individual fans or modules. Fan arrays are comprised of multiple fans between common inlet and outlet spaces with a common static pressure differential between the two spaces. The calculation methods provided use the concept of adding fans in parallel at values of constant fan static pressure. At each fan static pressure value, airflow rates and power values of all fans are added.

Section B.2 is used for arrays of contained fans while sections B.3 to B.6 are used for arrays of uncontained fans. Impeller rotation direction is not that critical for contained fans. However, for uncontained fans, it is recommended that rotation direction remain consistent between small array tests and the performance calculation of larger arrays: clockwise remains clockwise and counterclockwise remains counterclockwise. If the fan rotation directions are alternating in the small array test, they shall be alternating in the larger array.

## B.2 Fan arrays using contained fans

### B.2.1 Requirements

Performance data for a fan array made up of contained fans shall be based on tests of the individual contained fans according to ANSI/AMCA Standard 210. Performance data for untested fan sizes and speeds can include calculations found in AMCA Publication 211, Annex I, provided the requirements of that annex are met.

Fan electrical power for individual fans can be measured during an ANSI/AMCA Standard 210 test, calculated from tests using AMCA Publication 211, Annex I, or calculated from shaft power using ANSI/AMCA Standard 207.

### B.2.2 Calculations

Symbols used in this section:

| Quantity | Tested Contained Fan | Calculated Fan Array |
|---|---|---|
| Number of fans | 1 | $n_A$ |
| Airflow | $Q_j$ | $Q_A$ |
| Pressure | $P_{s,j}$ or $P_{t,j}$ | $P_{s,A}$ or $P_{t,A}$ |
| Power | $H_{i,j}$ or $W_j$ | $H_{i,A}$ or $W_A$ |

The fan array airflow is the sum of airflow values from individual fans in the array:

$$Q_A = n_A \times Q_j$$

The fan array static pressure is equal to the fan static pressure of each individual fan:

$$P_{s,A} = P_{s,j}$$

The fan array total pressure includes the fan array velocity pressure:

$$P_{t,A} = P_{s,A} + P_{v,A}$$

The fan array shaft power is the sum of shaft power values from all individual fans:

$$H_{i,A} = n_A \times H_{i,j}$$

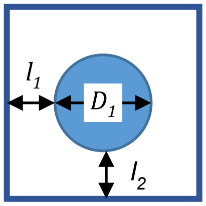
The fan array electrical power is the sum of electrical power values from all individual fans:

$$W_A = n_A \times W_j$$

**Example 1 for Section B.2: Fan array using contained fans**

The base fan is tested in accordance with ANSI/AMCA Standard 210. In this case, an 18-in. diameter fan is tested with 9-in. spacing to each wall of its enclosure:

Individual contained fan:



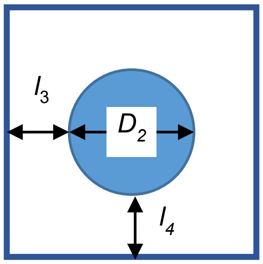
$D_1$ = 18 in.
$l_1$ = 9 in.
$l_2$ = 9 in.
$N$ = 1750 rpm

Tested performance:
$Q_1$ = 4000 cfm
$P_{s,1}$ = 2 in. wg
$H_{i,1}$ = 1.80 hp
$W_1$ = 1.65 kW

**Figure B.1 — Tested Performance of Individual Contained Fan**

The results of this test can be scaled to other fan sizes or speeds using the requirements in AMCA Publication 211, Annex I. The spacing from the impeller to the enclosure wall must be equal to or greater than the proportions from the base fan tested.

Individual contained fan scaled from base fan:



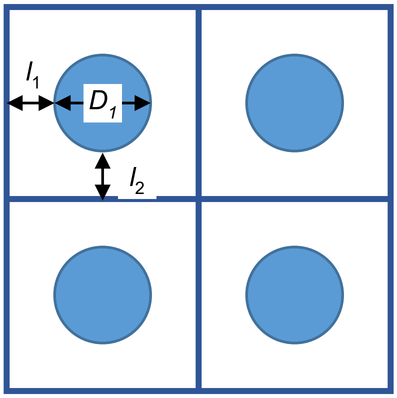
$D_2$ = 24 in.
$l_3$ = 12 in.
$l_4$ = 12 in.
$N$ = 1750 rpm

Scaled performance:
$Q_2$ = 9481 cfm
$P_{s,2}$ = 3.56 in. wg
$H_{i,2}$ = 7.59 hp

**Figure B.2 — Calculated Performance of Larger Contained Fan**

The performance of a fan array can be calculated from the performance of a single fan test.

Fan array made up of multiple contained fans:



$D_1$ = 18 in.
$l_1$ = 9 in.
$l_2$ = 9 in.
$N$ = 1750 rpm
$n_A$ = 4 fans

Performance of four-fan array:
$Q_A$ = 4 x 4000 = 16,000 cfm
$P_{s,A} = P_{s,1}$ = 2 in. wg
$H_{i,A}$ = 4 x 1.8 = 7.2 hp
$W_A$ = 4 x 1.65 = 6.60 kW

**Figure B.3 — Calculated Performance of Fan Array**

## B.3 Fan arrays using modules of uncontained fans

A module is a smaller subsection of a fan array that may be made up of uncontained fans but is itself contained in that on all sides it has partitions that prevent aerodynamic interaction with adjacent modules in the array. These modules often are provided as individual assemblies that are combined by stacking in a field erected fan array.

### B.3.1 Requirements

Performance data for a fan array made up of modules of uncontained fans shall be based on tests of the individual modules according to this standard. Performance data for untested fan sizes and speeds can include calculations found in AMCA Publication 211, Annex I, provided the requirements of that annex are met.

Fan electrical power for individual modules can be measured during an ANSI/AMCA Standard 270 test, calculated from tests using AMCA Publication 211, Annex I, or calculated from fan shaft power using ANSI/AMCA Standard 207.

### B.3.2 Calculations

Symbols used in this section:

| Quantity | Tested Fan Array Module | Calculated Fan Array |
|---|---|---|
| Number of modules | 1 | $n_A$ |
| Airflow | $Q_{A'}$ | $Q_A$ |
| Pressure | $P_{s,A'}$ or $P_{t,A'}$ | $P_{s,A}$ or $P_{t,A}$ |
| Power | $H_{i,A'}$ or $W_{A'}$ | $H_{i,A}$ or $W_A$ |

The fan array airflow is the total airflow from all modules:

$$Q_A = n_A \times Q_{A'}$$

The fan array static pressure is equal to the static pressure of each module:

$$P_{s,A} = P_{s,A'}$$

The fan array total pressure includes the fan array velocity pressure:

$$P_{t,A} = P_{s,A} + P_{v,A}$$

The fan array shaft power is the total shaft power from all modules:

$$H_{i,A} = n_A \times H_{i,A'}$$

The fan array electrical power is the total electrical power from all modules:

$$W_A = n_A \times W_{A'}$$

If a fan array includes modules containing different numbers of fans, each different module size shall be tested and the above equations modified to include each module size (where $Q_{a,1}$, $Q_{a,2}$, etc., are at the same fan static pressure):

$$Q_A = n_{A,1} \times Q_{A',1} + n_{A,2} \times Q_{A',2} + \cdots$$

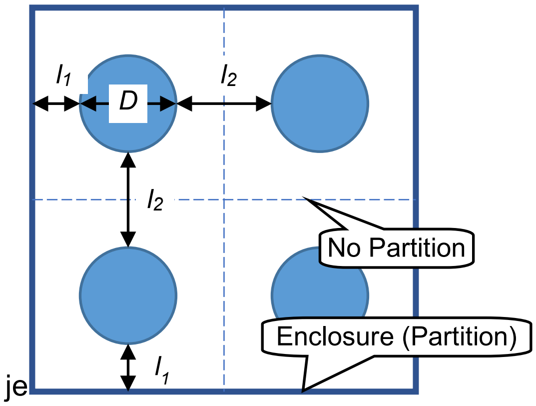
$$H_{i,A} = n_{A,1} \times H_{i,A',1} + n_{A,2} \times H_{i,A',2} + \cdots$$

$$W_A = n_{A,1} \times W_{A',1} + n_{A,2} \times W_{A',2} + \cdots$$

### Example 2 for Section B.3: Fan array using modules of uncontained fans

The base fan module is tested in accordance with this standard. In this case, a module of four 18-in. diameter fans is tested with an 18-in. spacing between impellers and a 9-in. spacing from impellers to the outer partitions.

Base fan module tested per this standard:



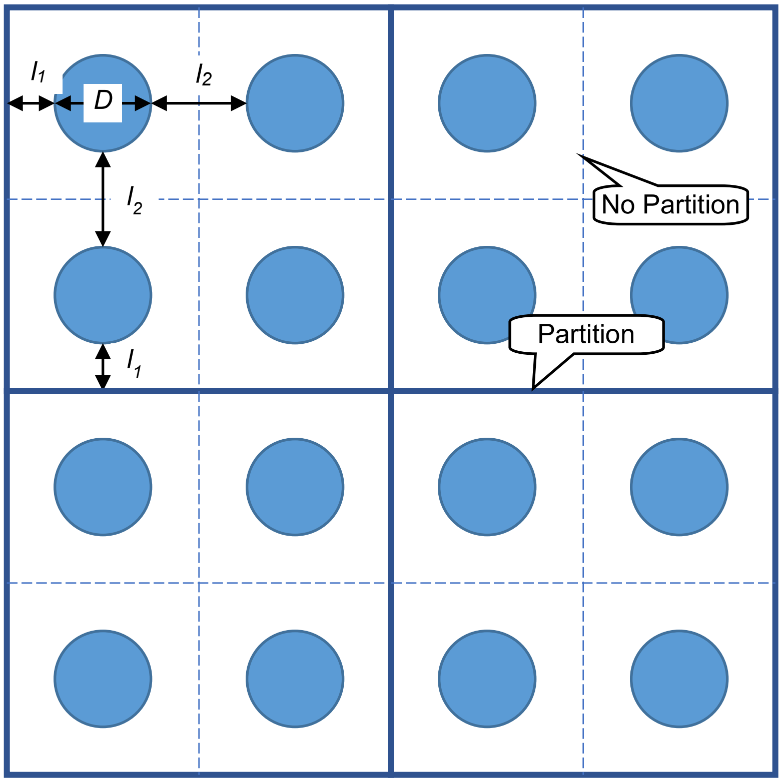
$D$ = 18 in.
$l_1$ = 9 in.
$l_2$ = 18 in.
$N$ = 1750 rpm

Tested module performance:
$Q_{A'}$ = 16,000 cfm
$P_{s,A'}$ = 2.00 in. wg
$H_{i,A'}$ = 7.20 hp
$W_{A'}$ = 6.60 kW

**Figure B.4 — Tested Performance of Individual Fan Module**

The performance of a fan array can be calculated from the performance of a fan array module test.

Fan array made up of multiple modules:



$D$ = 18 in.
$l_1$ = 9 in.
$l_2$ = 18 in.
$N$ = 1750 rpm
$n_A$ = 4 modules

Performance of a four-module array:
$Q_A$ = 4 x 16,000 = 64,000 cfm
$P_{s,A}$ = $P_{s,A}$ = 2.00 in. wg
$H_{i,A}$ = 4 x 7.20 = 28.80 hp
$W_a$ = 4 x 6.60 = 26.40 kW

**Figure B.5 — Calculated Performance of Fan Array Using Modules**

## B.4 Fan arrays using uncontained fans – model test method

This method uses a model test of a fan array with a minimum number of fans to establish the performance of individual fans within the array. Once the performance of an individual fan is established, it is used to calculate the performance of a similar fan array with a different number of fans.

### B.4.1 Requirements

Performance data for a fan array made up of any number of uncontained fans shall be based on a model test of a fan array having at least four fans.

For the model test, the performance of an individual fan should be representative of its performance in a larger fan array and the radial distance from the outer impellers to the enclosure must be half of the distance between impellers. For the calculated fan array, the spacings between impellers or between impellers and outer walls shall be greater than or equal to the corresponding spacing of the model test fan array.

Performance data for untested fan sizes and speeds can include calculations found in AMCA Publication 211, Annex I, provided the requirements of that annex are met. This includes spacing between fans and spacing from outer fans to walls. These calculations shall be done at the individual fan level.

Fan electrical power for individual fans can be determined during the ANSI/AMCA Standard 270 test, calculated from tests using AMCA Publication 211, Annex I, or calculated from individual fan shaft power using ANSI/AMCA Standard 207.

### B.4.2 Calculations

Symbols used in this section:

| Quantity | Tested Fan Array | Calculated Individual Fan | Calculated Fan Array |
|---|---|---|---|
| Number of fans | $n_{A'}$ (≥4) | 1 | $n_A$ |
| Airflow | $Q_{A'}$ | $Q_j$ | $Q_A$ |
| Pressure | $P_{s,A'}$ or $P_{t,A'}$ | $P_{s,j}$ or $P_{t,j}$ | $P_{s,A}$ or $P_{t,A}$ |
| Power | $H_{i,A'}$ or $W_{A'}$ | $H_{i,j}$ or $W_j$ | $H_{i,A}$ or $W_A$ |

The fan array airflow is the total airflow of all the individual fans in the array:

$$Q_j = Q_{A'}/n_{A'}$$

$$Q_A = n_A \times Q_j$$

The fan array static pressure is equal to the static pressure of each fan:

$$P_{s,j} = P_{s,A'}$$

$$P_{s,A} = P_{s,j}$$

The fan array total pressure includes the fan array velocity pressure:

$$P_{t,A} = P_{s,A} + P_{v,A}$$

The fan array shaft power is the total shaft power from all individual fans:

$$H_{i,j} = H_{A'}/n_{A'}$$

$$H_{i,A} = n_A \times H_{i,j}$$

The fan array electrical power is the total electrical power from all individual fans:

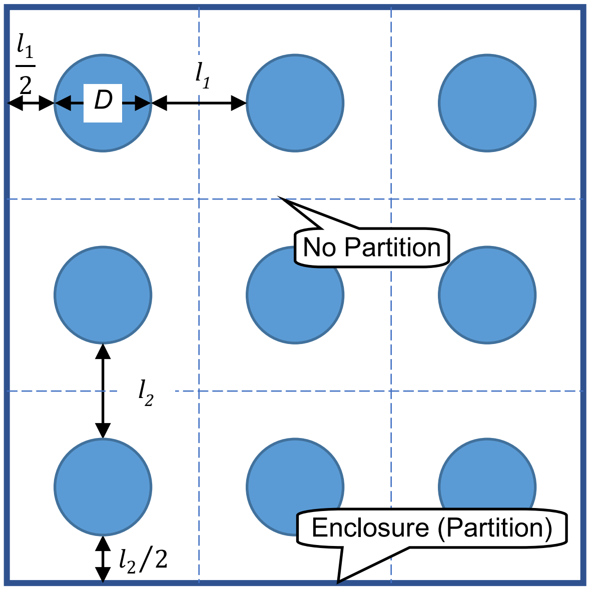
$$W_j = W_{A'}/n_{A'}$$

$$W_A = n_A \times W_j$$

**Example 3 for Section B.4: Fan array using uncontained fans – model test method**

The model test is conducted in accordance with this standard. In this case, nine 18-in. diameter fans are tested with an 18-in. spacing between impellers and a 9-in. spacing from impellers to the outer partitions.

Model test on fan array per this standard:



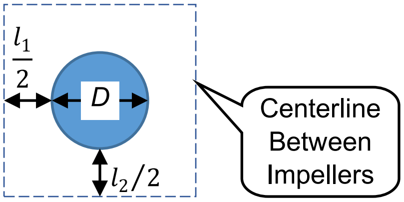
$D$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1750 rpm
$n_{A'}$ = 9 fans

Model test performance:
$Q_{A'}$ = 36,000 cfm
$P_{s,A'}$ = 2.00 in. wg
$H_{i,A'}$ = 16.20 hp
$W_{A'}$ = 14.85 kW

**Figure B.6 — Tested Performance of Model Fan Array**

The performance of an individual fan within this array is then determined from this model test.

Individual fan calculated from model test:



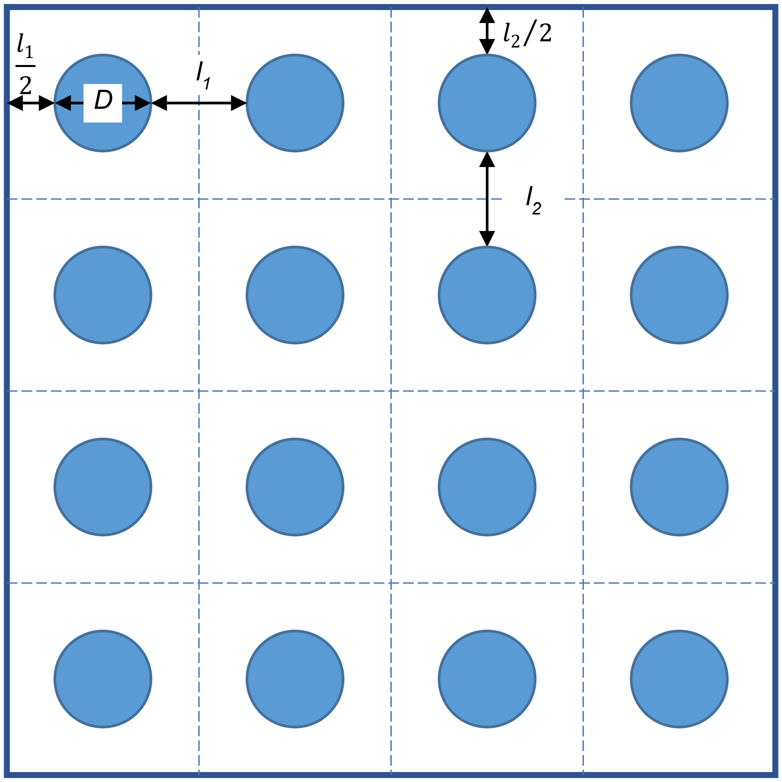
$D$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1750 rpm

Individual fan performance:
$Q_j$ = 36,000 / 9 = 4,000 cfm
$P_{s,j}$ = $P_{s,A}$ = 2.00 in. wg
$H_{i,j}$ = 16.20 / 9 = 1.80 hp
$W_j$ = 14.85 / 9 = 1.65 kW

**Figure B.7 — Calculated Performance of Individual Fan from Model Fan Array**

The individual fan performance is then used to determine fan array performance with a different number of fans.

Fan array made up of many individual fans:



$D$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1750 rpm
$n_A$ = 16 fans

Fan array performance:
$Q_A$ = 16 x 4,000 = 64,000 cfm
$P_{s,A} = P_{s,j}$ = 2.00 in. wg
$H_{i,A}$ = 16 x 1.80 = 28.8 hp
$W_A$ = 16 x 1.65 = 26.4 kW

**Figure B.8 — Calculated Performance of Fan Array from Model Testing**

## B.5 Fan arrays using uncontained fans – rating factor method applied to a single uncontained fan

This method uses a test of a fan array with a minimum number of fans along with an ANSI/AMCA Standard 210 test of an individual fan to establish rating factors that account for installation effects. Once the rating factors are established, they can be applied to other fan sizes and speeds to calculate the performance of a similar fan array with a larger number of fans.

### B.5.1 Requirements

Performance data for a fan array made up of any number of uncontained fans shall be based on a test of a fan array with at least four fans. The spacing between fans and spacing from outer fans to walls (in both directions) of the larger calculated fan array shall be greater than or equal to the corresponding spacing of the smaller tested fan array. Performance data for untested fan sizes and speeds can include calculations found in AMCA Publication 211, Annex I, provided the requirements of that annex are met. This includes spacing between fans and spacing from outer fans to walls. Fan electrical power for individual fans can be determined during an ANSI/AMCA Standard 270 test, calculated from tests using AMCA Publication 211, Annex I, or calculated from fan shaft power using ANSI/AMCA Standard 207.

### B.5.2 Calculations

Symbols used in this section:

| Quantity | Tested Fan Array | Tested Individual Fan | Rating Factor | Calculated Fan Array |
|---|---|---|---|---|
| Number of fans | $n_{A'}$ (≥4) | $1$ | - | $n_A$ |
| Airflow | $Q_{A'}$ | $Q_j$ | $R_Q$ | $Q_A$ |
| Pressure | $P_{s,A'}$ or $P_{t,A'}$ | $P_{s,j}$ or $P_{t,j}$ | $R_P$ | $P_{s,A}$ or $P_{t,A}$ |
| Power | $H_{i,A'}$ or $W_{A'}$ | $H_{i,j}$ or $W_j$ | $R_H$ or $R_W$ | $H_{i,A}$ or $W_A$ |

The fan array airflow is the total airflow from individual fans modified by the rating factor:

$$R_Q = \frac{(Q_{A'}/n_{A'})}{Q_j}$$

$$Q_A = n_A \times \left(Q_j \times R_Q\right)$$

The fan array static pressure is equal to the static pressure of the individual fans modified by the rating factor:

$$R_P = P_{s,A'}/P_{s,j}$$

$$P_{s,A} = P_{s,j} \times R_P$$

The fan array total pressure includes the fan array velocity pressure:

$$P_{t,A} = P_{s,A} + P_{v,A}$$

The fan array shaft power is the total shaft power from individual fans modified by the rating factor:

$$R_H = \left(H_{i,A'}/n_{A'}\right)/H_{i,j}$$

$$H_{i,A} = n_A \times \left(H_{i,j} \times R_H\right)$$

The fan array electrical power is the total electrical power from individual fans modified by the rating factor:

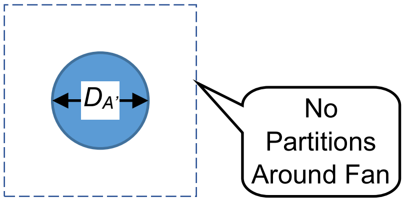
$$R_W = (W_{A'}/n_{A'})/W_j$$

$$W_A = n_A \times \left(W_j \times R_W\right)$$

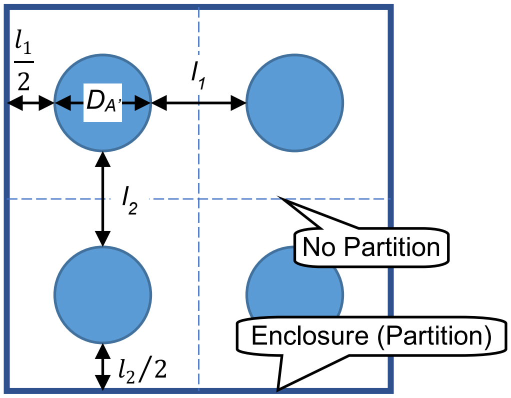
### Example 4 for Section B.5: Fan array using uncontained fans – rating factor method applied to a single uncontained fan

Rating factors are determined from the comparison between a test of an individual fan per ANSI/AMCA Standard 210 and a test of a fan array per this standard. In this case, an 18-in. individual fan is tested along with an array of four 18-in. diameter fans with an 18-in. spacing between impellers and a 9-in. spacing from impellers to the outer partitions.

Test of individual fan per ANSI/AMCA Standard 210:



Test of fan array per this standard:



$D_{A'}$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1750 rpm
$n_{A'}$ = 4 fans

Individual fan test performance:
$Q_j$ = 4,400 cfm
$P_{s,j}$ = 2.40 in. wg
$H_{i,j}$ = 2.20 hp
$W_j$ = 2.01 kW

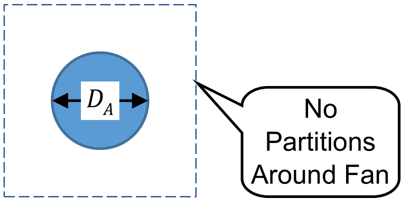
Fan array test performance:
$Q_{A'}$ = 16,000 cfm
$P_{s,A}$ = 2.00 in. wg
$H_{i,A'}$ = 7.20 hp
$W_{A'}$ = 6.60 kW

Rating factors:
$R_Q$ = (16000 / 4) / 4400 = 0.91
$R_P$ = (2.00 / 2.40) = 0.83
$R_H$ = (7.20 / 4) / 2.20 = 0.82
$R_W$ = (6.60 / 4) / 2.01 = 0.82

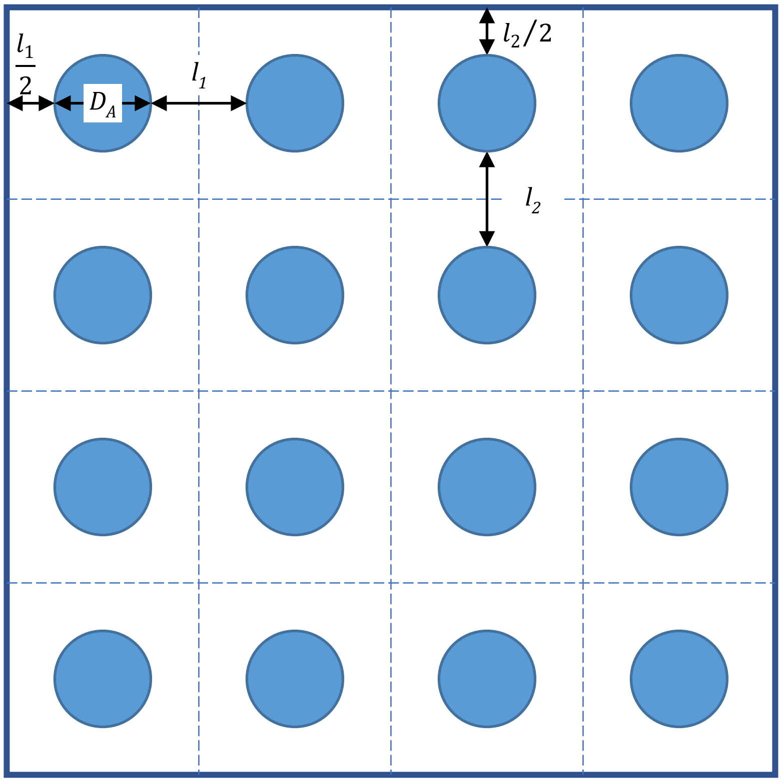
**Figure B.9 — Rating Factors Developed from Testing**

The rating factors are then used along with a test of an individual fan to determine fan array performance with a different number of fans.

Test of individual fan per ANSI/AMCA Standard 210:



Fan array made up of many individual fans:



$D_A$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1750 rpm
$n_A$ = 16 fans

Individual fan test performance:
$Q_j$ = 4,400 cfm
$P_{s,j}$ = 2.40 in. wg
$H_{i,j}$ = 2.20 hp
$W_j$ = 2.01 kW

Rating factors:
$R_Q$ = 0.91
$R_P$ = 0.83
$R_H$ = 0.82
$R_W$ = 0.82

Fan array performance:
$Q_A$ = 16 x (4,400 x 0.91) = 64,000 cfm
$P_{s,A}$ = 2.40 x 0.83 = 2.00 in. wg
$H_{i,A}$ = 16 x (2.20 x 0.82) = 28.8 hp
$W_A$ = 16 x (2.01 x 0.82) = 26.4 kW

**Figure B.10 — Calculated Performance of Fan Array Based on Rating Factors**

## B.6 Fan arrays using uncontained fans – rating factor method applied to a single contained fan

This method uses an ANSI/AMCA Standard 210 test of an individual fan, both contained and uncontained, to establish rating factors that account for installation effects if that same fan is used uncontained in a fan array. Once the rating factors are established, they can be applied to other fan speeds to calculate the performance of a fan array having several uncontained fans.

### B.6.1 Requirements

Performance data for a fan array made up of any number of uncontained fans shall be based on two tests of a given fan, one with the fan contained and one with it uncontained. The spacing between fans and spacing from outer fans to walls (in both directions) in the calculated fan array shall be greater than or equal to the corresponding spacing of the contained fan in its enclosure. In addition, the spacing to any fan shall be no less than the average outer impeller diameter, $D$, and the spacing to any wall, no less than half the average outer impeller diameter, $D$.

Performance data for untested speeds can include calculations found in AMCA Publication 211, Annex I, provided the requirements of that annex are met. Fan electrical power for the contained fan can be determined during an ANSI/AMCA Standard 210 test, calculated from tests using AMCA Publication 211, Annex I, or calculated from fan shaft power using ANSI/AMCA Standard 207.

### B.6.2 Calculations

Symbols used in this section:

| Quantity | Tested Contained Fan | Tested Uncontained Fan | Rating Factor | Calculated Fan Array |
|---|---|---|---|---|
| Number of fans | 1 | 1 | - | $n_A$ |
| Airflow | $Q_1$ | $Q_2$ | $R_Q$ | $Q_A$ |
| Pressure | $P_{s,1}$ or $P_{t,1}$ | $P_{s,2}$ or $P_{t,2}$ | $R_P$ | $P_{s,A}$ or $P_{t,A}$ |
| Power | $H_{i,1}$ or $W_1$ | $H_{i,2}$ or $W_2$ | $R_H$ or $R_W$ | $H_A$ or $W_A$ |

The fan array airflow is the total airflow from individual fans modified by the rating factor:

$$R_Q = \frac{Q_1}{Q_2}$$

$$Q_A = n_A \times \left(Q_2 \times R_Q\right)$$

The fan array static pressure is equal to the static pressure of the individual fans modified by the rating factor:

$$R_P = P_{s,1}/P_{s,2}$$

$$P_{s,A} = P_{s,2} \times R_P$$

The fan array total pressure includes the fan array velocity pressure:

$$P_{t,A} = P_{s,A} + P_{v,A}$$

The fan array shaft power is the total shaft power from individual fans modified by the rating factor:

$$R_H = H_{i,1}/H_{i,2}$$

$$H_{i,A} = n_A \times \left(H_{i,j} \times R_H\right)$$

The fan array electrical power is the total electrical power from individual fans modified by the rating factor:

$$R_W = W_1/W_2$$

$$W_A = n_A \times (W_2 \times R_W)$$

### Example 5 for Section B.6: Fan array using uncontained fans – rating factor method applied to single contained fan

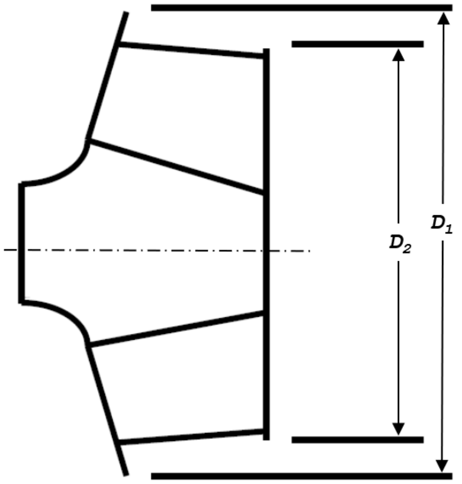
Rating factors are determined from the comparison between two ANSI/AMCA Standard 210 tests of an individual fan operating contained and uncontained. In this case, an individual centrifugal or mixed-flow fan with an 18-in. average impeller diameter is tested with and without partitions.

$$D = \frac{D_1 + D_2}{2}$$

$$l_1 \geq D$$

and

$$l_2 \geq D$$

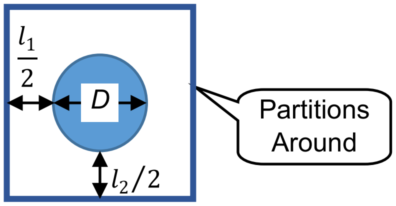


$D$ = Average outer impeller diameter

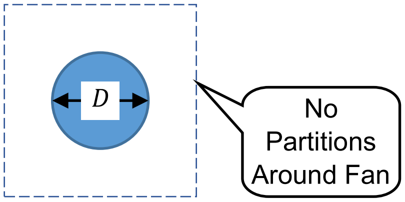
$D_1$ = Outer diameter of impeller rim

$D_2$ = Outer diameter of impeller backplate

Test of individual contained fan per ANSI/AMCA Standard 210:



Test of individual uncontained fan per ANSI/AMCA Standard 210:



$D$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1,750 rpm

Contained fan test performance:
$Q_1$ = 4,004 cfm
$P_{s,1}$ = 1.992 in. wg
$H_{i,1}$ = 1.804 hp
$W_1$ = 1.648 kW

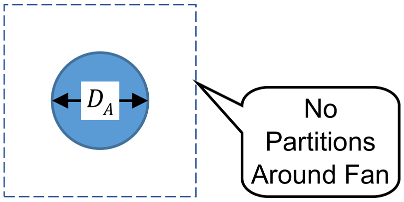
Uncontained fan test performance:
$Q_2$ = 4,400 cfm
$P_{s,2}$ = 2.40 in. wg
$H_{i,2}$ = 2.20 hp
$W_2$ = 2.01 kW

Rating factors:
$R_Q$ = 4,004 / 4,400 = 0.91
$R_P$ = 1.992 / 2.40) = 0.83
$R_H$ = 1.804 / 2.20 = 0.82
$R_W$ = 1.648 / 2.01 = 0.82

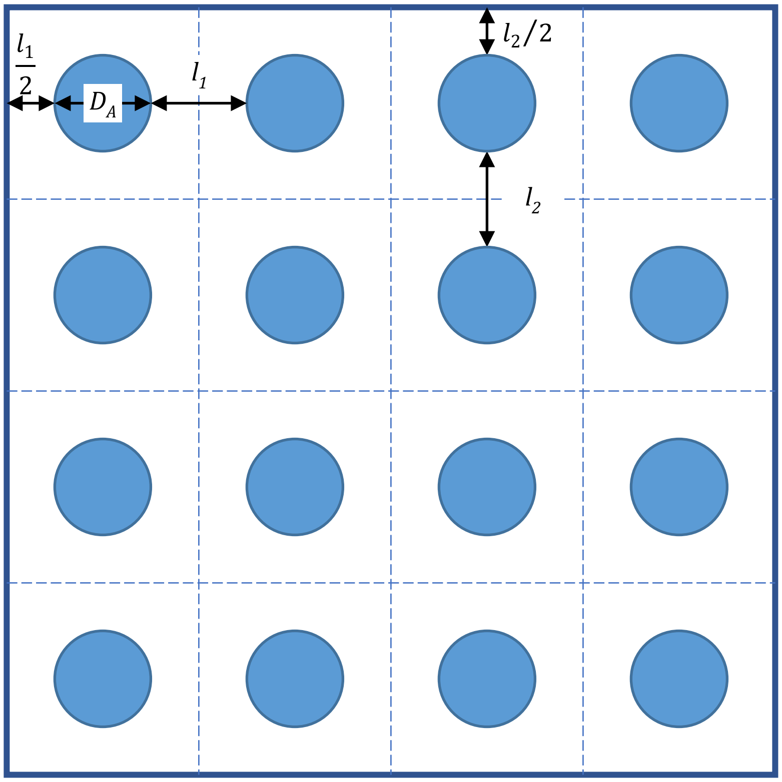
**Figure B.11 — Rating Factors Developed from ANSI/AMCA Standard 210 Testing**

The rating factors are then used along with a test of an individual fan to determine fan array performance with the desired number of fans.

Test of individual fan per ANSI/AMCA Standard 210:



Calculated fan array made up of many individual fans:



$D_A$ = 18 in.
$l_1$ = 18 in.
$l_2$ = 18 in.
$N$ = 1750 rpm
$n_A$ = 16 fans

Uncontained fan test performance:
$Q_2$ = 4,400 cfm
$P_{s,2}$ = 2.40 in. wg
$H_{i,2}$ = 2.20 hp
$W_2$ = 2.01 kW

Rating factors:
$R_Q$ = 0.91
$R_P$ = 0.83
$R_H$ = 0.82
$R_W$ = 0.82

Fan array performance:
$Q_A$ = 16 x (4,400 x 0.91) = 64,000 cfm
$P_{s,A}$ = 2.40 x 0.83 = 2.00 in. wg
$H_{i,A}$ = 16 x (2.20 x 0.82) = 28.8 hp
$W_A$ = 16 x (2.01 x 0.82) = 26.4 kW

**Figure B.12 — Calculated Performance of Fan Array Based on Rating Factors**

# Annex C
# Fan Array Performance Measurements (Normative)

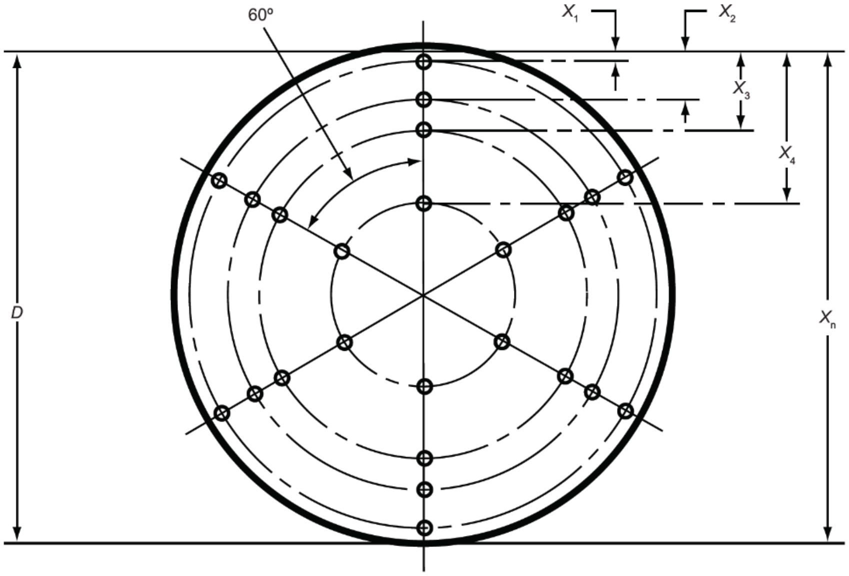
## C.1 Distribution of pitot traverse points

### C.1.1 General

This annex provides information on the distribution of traverse points for circular and rectangular ducts. It also describes the methodology of common piping for total pressure measurements and accuracy of measuring static pressure in turbulent environments.

### C.1.2 Distribution of traverse points in a circular duct

To obtain a representative average velocity in a duct, it is necessary to locate each traverse point accurately. It is recommended that the number of traverse points increase with increasing duct size. The distributions of traverse points for circular ducts, as indicated below, are based on a log-linear pitot traverse method.



$$X_a = D \times K_a$$

Where:

*D* is the inside diameter of the duct.
$K_a$ is the factor corresponding to the duct size and traverse point location as indicated in the table below.

| Inside Diameter of Duct | Number of Traverse Points in Each of Three Diameters | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | $K_7$ | $K_8$ | $K_9$ | $K_{10}$ | $K_{11}$ | $K_{12}$ | $K_{13}$ | $K_{14}$ | $K_{15}$ | $K_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| < 8 ft | 8 | 0.021 | 0.117 | 0.184 | 0.345 | 0.655 | 0.816 | 0.883 | 0.979 | — | — | — | — | — | — | — | — |
| 8 ft-12 ft | 12 | 0.014 | 0.075 | 0.114 | 0.183 | 0.241 | 0.374 | 0.626 | 0.759 | 0.817 | 0.886 | 0.925 | 0.986 | — | — | — | — |
| > 12 ft | 16 | 0.010 | 0.055 | 0.082 | 0.128 | 0.166 | 0.225 | 0.276 | 0.391 | 0.609 | 0.724 | 0.775 | 0.834 | 0.872 | 0.918 | 0.945 | 0.990 |

**Figure C.1 — Distribution of Traverse Points for Circular Ducts**

### C.1.3 Distribution of traverse points in a rectangular duct using the equal area method

The recommended minimum number of traverse points for rectangular ducts is indicated below in Figure C.3. For rectangular ducts with cross-sectional areas of 24 sq ft and less, the recommended minimum number is 24. For cross-sectional areas greater than 24 sq ft, the minimum number of points increases as indicated in Figure C.3. The points are to be located in the centers of equal areas as square as practical (see Figure C.2). If the flow conditions at the traverse plane are less than satisfactory, the accuracy of the determination of flow rate may be improved by using more than the recommended minimum number of points. Fewer points may be used if the flow is very uniform; however, the maximum area covered per point should not exceed 3 sq ft.

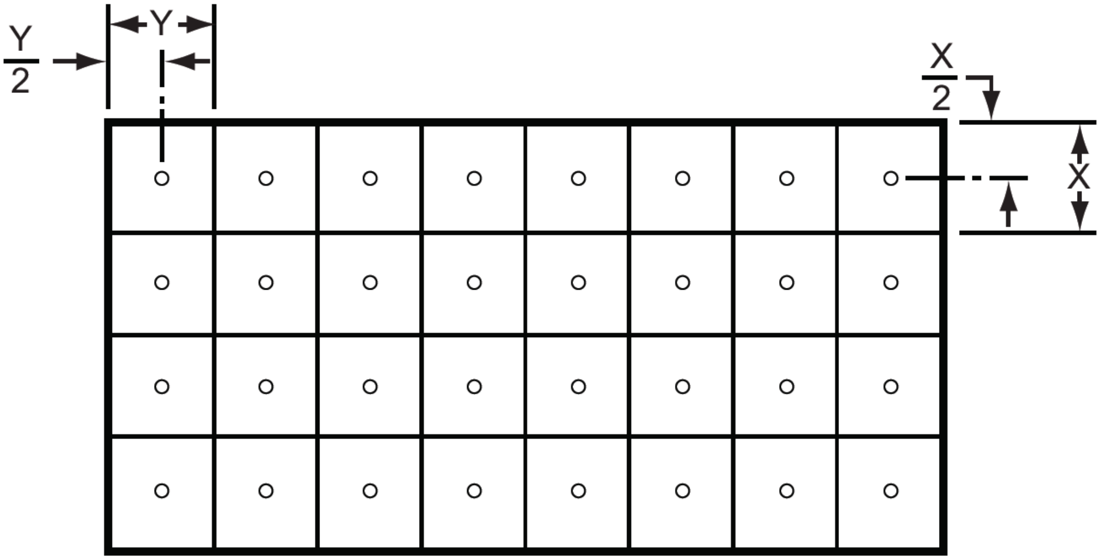


**Figure C.2 — Distribution of Traverse Points for Rectangular Duct**

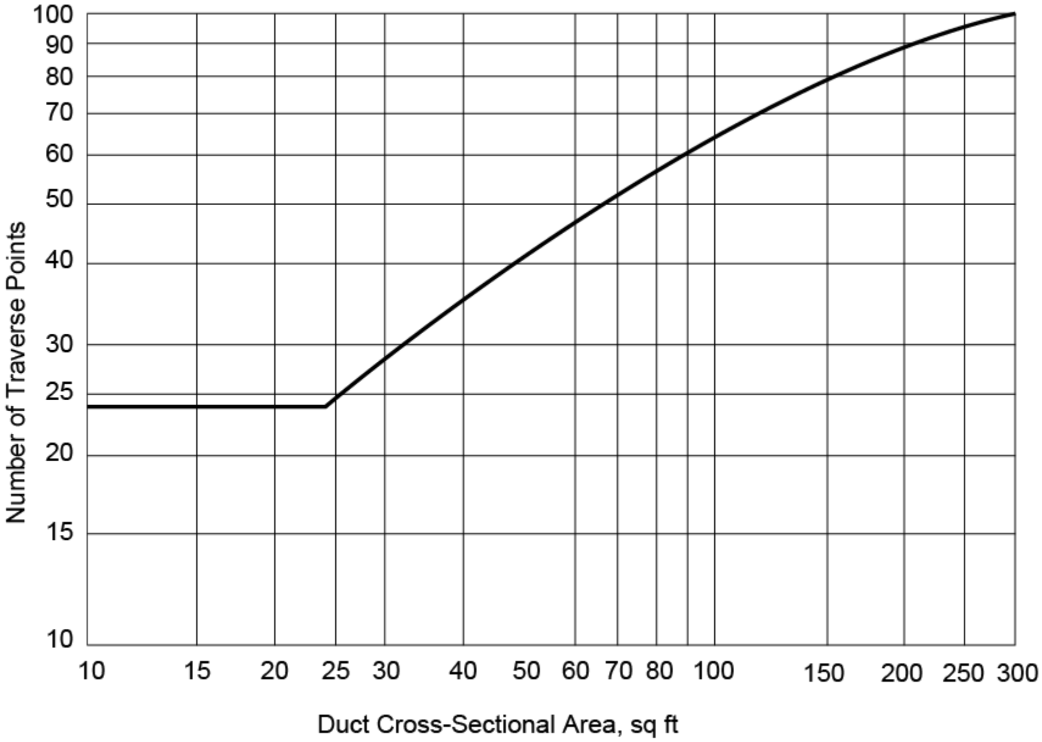
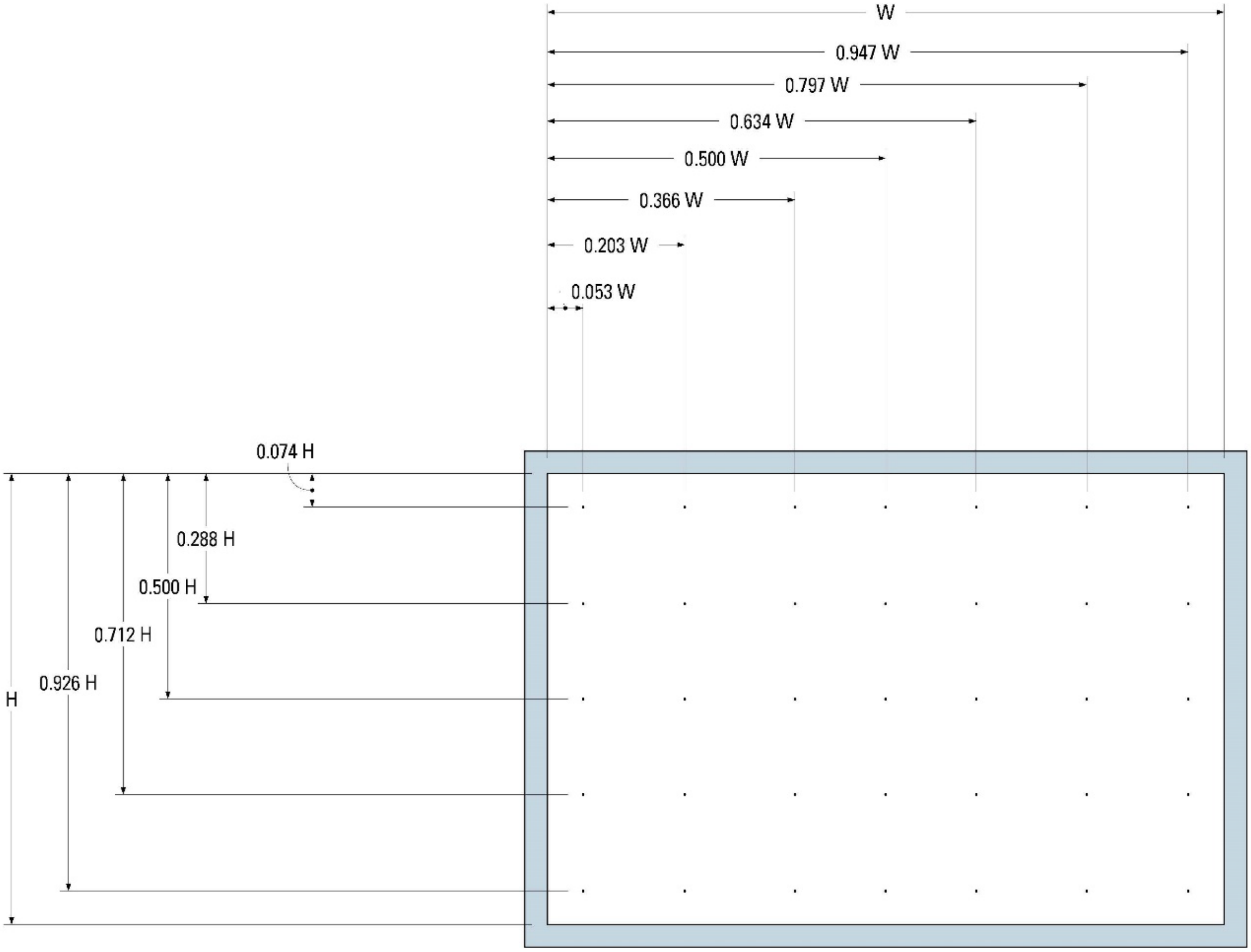


**Figure C.3 — Recommended Minimum Number of Traverse Points for Rectangular Ducts**

### C.1.4 Distribution of traverse points in a rectangular duct using the log-Tchebycheff method

Measurement points using the log-Tchebycheff method are located to consider the duct wall's impact upon the airflow. Ducts will have five to seven gridlines per side, depending on duct size. A 30 in. (762 mm) or smaller duct will have five traverse lines. Ducts between 30 and 36 in. (762-914.4 mm) will have six traverse lines. Ducts larger than 36 in. (914.4 mm) will have seven traverse lines. Where traverse lines from the two perpendicular sides intersect, a measurement point location is defined. A measurement duct will have a minimum of 25 and maximum of 49 measurement points. See the table below for traverse line locations, defined by a distance from the inner wall and determined by a proportion of the duct side length. Figure C.4 shows locations of measurement points for a duct that is less than 30-in. tall and greater than 36-in. wide, which is a five-by-seven traverse line configuration, resulting in 35 traverse measurement points.

| Number of Traverse Lines per Side of Duct | Location of Traverse Lines (Multipliers per Duct Side Length) |
|---|---|
| 5 | 0.074, 0.288, 0.500, 0.712, 0.926 |
| 6 | 0.061, 0.235, 0.437, 0.563, 0.765, 0.939 |
| 7 | 0.053, 0.203, 0.366, 0.500, 0.634, 0.797, 0.947 |



Location of Measuring Points for
Traversing a Rectangular Duct
Using log-Tchebycheff Method

**Figure C.4 — Log-Tchebycheff Total Pressure Tubes Measurement Positions**

### C.1.5 Common piping method for total pressure tube averaging

The method described in the following subsections can expedite total pressure measurements for fan arrays.

#### C.1.5.1 Common piping for total pressure tube pressure averaging

Referencing Figures C.1, C.2 and C.4, place the total pressure tubes parallel to the airflow with the pressure ports facing into the air stream and connect each total pressure tube in parallel via barbed tips and flexible tubing per Figure C.5. The tubing shall be free of dust or moisture. Combining the appropriate number of total pressure tubes into a common pipe configuration will allow the average total pressure of the air stream to be measured. Best practices for plumbing the total pressure tubes together include minimizing the length and bends in the flexible tubing. The diameter of the common tubing connecting all the total pressure tubes to the measuring device shall not exceed 1.5 times the diameter of the total pressure tubes. The total pressure tubes and common piping must be calibrated prior to testing. Before the common piping calibration is conducted, ensure that the tubing connections are tight and free of leaks.

##### C.1.5.1.1 Calibration

After the total pressure tube array has been constructed and piped, the measurement readings it produces must be validated. With a separate, certified and calibrated air-measuring instrument, the velocity pressure needs to be measured and compared with the readings of the total pressure tube array at the same duty point. After these two separate sets of velocity pressures are compared, a total pressure tube correction factor ($k_f$) can be applied to the array for future testing. To minimize error, the calibration process shall be conducted at a velocity greater than 2000 ft/min (10.16 m/s). A minimum of two duty points are required to calibrate the total pressure tube array. However, three-point calibration is preferred.

$$V = \sqrt{\frac{2 \times k_f P_{vx}}{\rho_x}} \qquad \text{SI} \qquad \text{Eq. C.1}$$

$$V = 1097.8 \times \sqrt{\frac{k_f P_{vx}}{\rho_x}} \qquad \text{I-P} \qquad \text{Eq. C.2}$$

Where:

$V$ = Velocity, m/s or ft/min
1097.8 = Unit conversion factor (imperial)
$k_f$ = Total pressure tube array correction factor
$P_{vx}$ = Velocity pressure, Pa or in. wg
$\rho_x$ = Density of air, kg/m$^3$ or lbm/ft$^3$

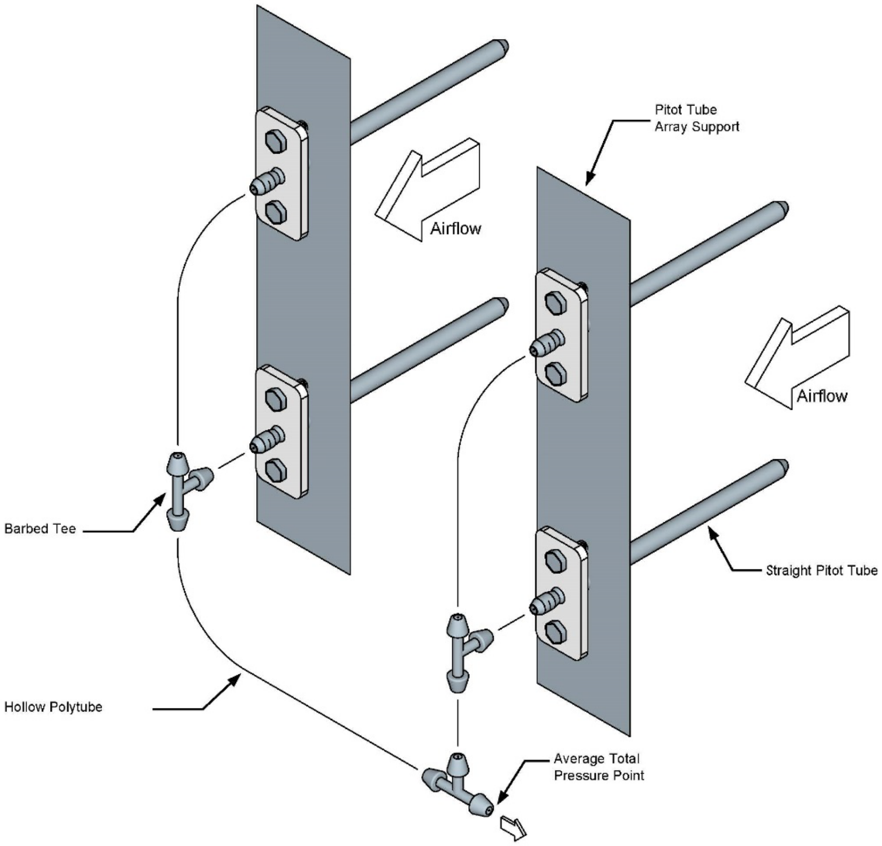


**Figure C.5 — Common Piping Method for Total Pressure Measurement**

### C.1.6 Static pressure measurement assembly for turbulent environments

Some testing configurations require measurements within inlet or discharge plenums. These measurements often can be inaccurate due to a turbulent environment within the plenums. To help mitigate influences upon the static pressure reading, the total pressure tube shall be shielded from this turbulence. Yet, the total pressure tube also must be buffered enough to take a proper static pressure reading.

Figure C.6 shows an assembly that could be used in turbulent environments to read the static pressure within a given area. The assembly is comprised of two PVC caps, a length of PVC pipe and a straight total pressure tube installed through one of the caps. The total free area of the holes within the pipe shall be approximately 0.5 sq in. per 1 ft of pipe length. The recommended hole size is 0.125 in.

For example, the calculation for a 2-ft section of pipe is:

- $2 \text{ ft x } (0.5 \text{ in}^2/1 \text{ ft}) = 1 \text{ in}^2$
- $\pi\ (0.125/2)^2 = 0.0123^2$
- $1 \text{ in}^2\ /\ 0.0123^2 = 82 \text{ holes (round up) } / \ 2 \text{ ft} = 41 \text{ holes } / \ 1 \text{ ft of pipe}$

The static pressure measuring assembly is omnidirectional, which allows for a vertical or horizontal application. Pipe length is determined by the application and size of the area it serves. It is recommended that the pipe be sized to span more than 50 percent of the plane length or height. When a pipe length is more than 3 ft, a second total pressure tube shall be installed in the opposing cap and averaged with the original total pressure tube.

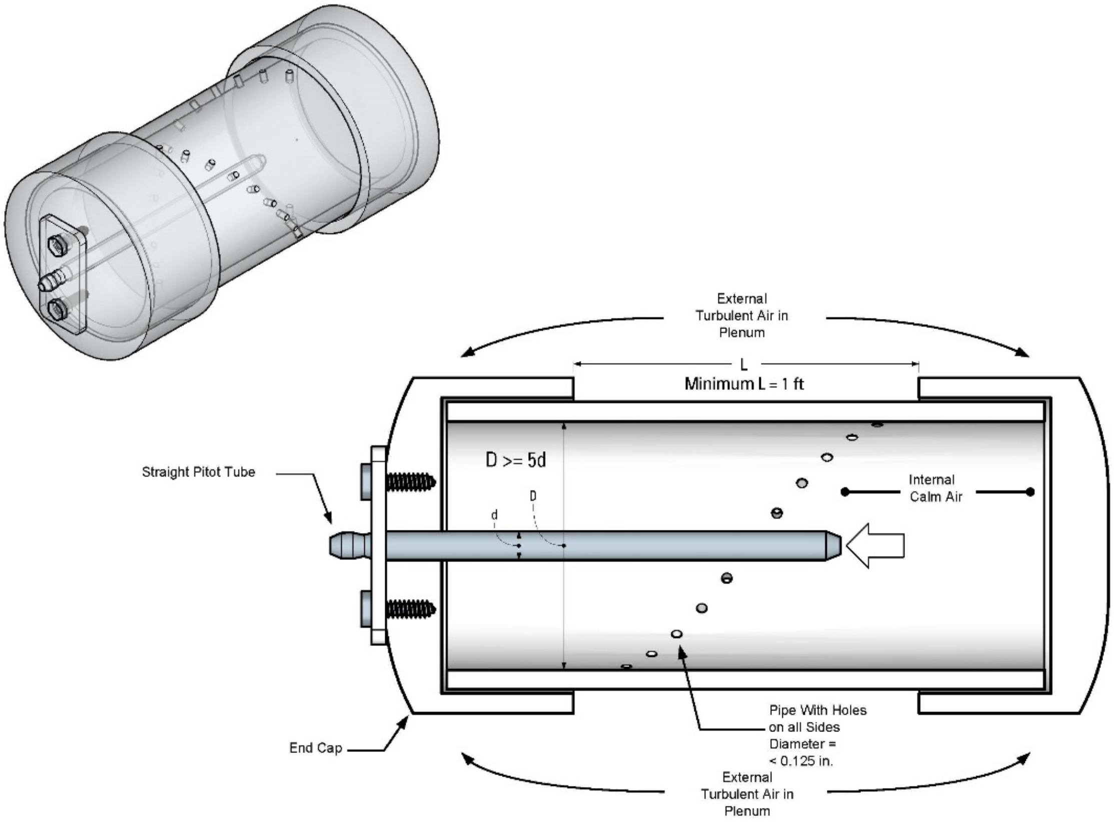


**Figure C.6 — Static Pressure Measurement Assembly for Turbulent Environments**

## C.2 Accuracy and uncertainty of measurements

### C.2.1 Introduction

Instrumentation accuracy and measurement uncertainties are critical aspects to consider in fan array testing. For practical reasons related to size and test setups, this standard (ANSI/AMCA Standard 270) clearly identifies the variations from ANSI/AMCA Standard 210 testing. In test chamber measurements, ANSI/AMCA Standard 270 complies with ANSI/AMCA Standard 210 in accuracy and uncertainty. However, in duct flow measurements using a pitot traverse, there are some key differences as outlined in Table C.1:

**Table C.1 — Variations in Pitot Traverse Method Between ANSI/AMCA Standard 210 and ANSI/AMCA Standard 270**

| | Parameter description | ANSI/AMCA Standard 210 | ANSI/AMCA Standard 270 |
|---|---|---|---|
| 1. | Test duct velocity, *V* (ft/min) | V >= 2400 | 400 <= V <= 4000* |
| 2. | Inclusion of duct friction losses | Yes | No |
| 3. | Inclusion of duct straightener | Yes | Optional |
| 4. | Accuracy of measurement | ~1% | AMCA Publication 203, Annex T, basis - see below sections |
| 5 | Uncertainty of measurements | ~2% | AMCA Publication 203, Annex T, basis - see below sections |

*If the airflow is measured using a pitot traverse, the average velocity at the traverse plane shall be greater than or equal to 1500 ft/min.

### C.2.2 Measurement instrumentation accuracy for pitot traverse

Accuracy of instruments measuring variables related to flow, pressure and power shall be within +/-3 percent of a primary instrument, the calibration of which is traceable to NIST standards.

### C.2.3 Measurement uncertainties for pitot traverse

To determine the range of uncertainties likely to be encountered in fan array testing, a statistical uncertainty analysis was undertaken. Maximum and minimum uncertainties were assigned to each quantity to be measured based on the degree of difficulty in measuring the quantity, the previously specified instrument accuracy and the conditions expected to be encountered in fan array testing. These individual maximum and minimum uncertainties were combined statistically to arrive at the probable range of overall uncertainties for the fan array flow rate, static pressure and input power. It would be unlikely, however, that any particular fan array setup would have all minimum or all maximum uncertainties occurring simultaneously. Therefore, prior to testing, the parties should establish an agreement regarding acceptable measurement tolerances for a given test setup.

This analysis assumes that fan array performance can be treated as a statistical quantity and the performances derived from repeated tests would have a normal distribution. The most probable performance would be the mean results based on repeated observations at each point of operation. Only one set of observations is specified in this standard. Therefore, this analysis deals with the probable uncertainty of results obtained from a single set of observations.

The results of a fan array performance test for a single point of operation are a combination of variables that normally are presented graphically. Test results shall be the fan array static pressure vs. flow rate and fan array input power vs. flow rate. The uncertainty in results shall be expressed in terms of fan array flow rate, static pressure and input power.

The accuracies specified in this standard are based on two standard deviations. This means there is a 95 percent probability that the actual uncertainties will be less than the specified value.

This applies only to random uncertainties. Systematic uncertainties should be eliminated using properly calibrated test instruments. This analysis considers only the uncertainties inherent in testing.

This standard specifies uncertainties in percent. These are, of course, per unit uncertainties, multiplied by 100. Absolute uncertainties, which bear the units of the quantity being measured or calculated, are equal to the per unit uncertainty multiplied by the measured or calculated quantity. Because the tolerance on measured values is specified based on 95 percent confidence limits, the actual deviations in results will be less than the calculated deviations 95 percent of the time.

For the purposes of a fan array test, an uncertainty range shall be defined with minimum and maximum values. This range of possible uncertainty is necessary to cover the varying degrees of difficulty encountered in performing tests in various setups.

### C.2.3.1 Symbols

In the analysis that follows, certain symbols and notations are used.

| **Symbol** | **Quantity** |
|---|---|
| $e_x$ | Per unit uncertainty in $X$ |
| $\Delta X$ | Absolute uncertainty in $X$ |
| $R$ | Gas constant (SI - J/kgHK) (I-P ft-lb/lbmH°$R$) |

| **Subscript** | **Description** |
|---|---|
| $A$ | Area |
| $B$ | Barometric pressure |
| $D$ | Dry-bulb temperature |
| $F$ | Velocity pressure |
| $G$ | Static pressure |
| $H$ | Input power OR Fan array input power |
| $N$ | Fan array speed |
| $P$ | Fan array static pressure |
| $Q$ | Fan array flow rate |
| $W$ | Wet-bulb depression |
| $X$ | Generalized quantity ($A$, $b$, $\rho$) |
| $X_c$ | Converted quantity from site data ($Q$, $P$, $H$) |
| $\rho$ | Density |

### C.2.3.2 Instrumentation uncertainty ranges

The various measurement uncertainty ranges for various instruments used in this standard are listed below.

#### C.2.3.2.1 Barometric pressure

The estimated uncertainty in measuring barometric pressure is between 0.3 percent minimum and 0.7 percent maximum.

$e_b$ = 0.003 (min) to 0.007 (max)

Barometric pressure generally is obtained by portable aneroid barometer, onsite barometer (mercury or aneroid) or from a nearby airport. The uncertainty range above is estimated based on the use of portable or onsite instrumentation and applicable corrections.

#### C.2.3.2.2 Dry-bulb temperature

The estimated uncertainty in measuring dry-bulb temperature is between 0.5 percent of absolute temperature minimum and 2.0 percent of absolute temperature maximum.

$$e_d = 0.005 \text{ (min) to } 0.02 \text{ (max)}$$

The estimated uncertainty range is based on a broad temperature range and the likelihood of stratification.

#### C.2.3.2.3 Wet-bulb depression

The estimated uncertainty in measuring wet-bulb depression is between 3°C (5°F) minimum and 6°C (10°F) maximum.

$$e_w = 3/(t_d - t_w) \text{ (min) to } 6/(t_d - t_w) \text{ (max) SI}$$

$$e_w = 5/(t_d - t_w) \text{ (min) to } 10/(t_d - t_w) \text{ (max) I-P}$$

The estimated uncertainty range is based on a broad temperature range with the associated difficulties in determining wet-bulb readings at high or low temperatures and the likelihood of stratification.

### C.2.3.2.4 Fan array mean rotational speed

The estimated uncertainty in measuring fan array mean rotational speed is between 0.5 percent minimum and 1 percent maximum.

$e_N$ = 0.005 (min) to 0.01 (max)

The uncertainty range in fan array speed is estimated based on portable instrumentation accuracy and an allowance for fluctuation in fan array speed.

### C.2.3.2.5 Fan array input power

The estimated uncertainty in measuring input power is between 3 percent minimum and 7 percent maximum.

$e_h$ = 0.03 (min) to 0.07 (max)

The estimated uncertainty range is based on the various measurement methods and their respective accuracies, estimated drive losses and the broad horsepower range encountered in the field.

### C.2.3.2.6 Fan array pitot traverse

A properly performed field traverse is estimated to have an accuracy between 1.5 percent minimum and 7.5 percent maximum.

$e_c$ = 0.015 (min) to 0.075 (max)

The uncertainty range in the pitot traverse is estimated based on traverse location, broad range of duct sizes, non-uniform velocity profiles and turbulence.

### C.2.3.2.7 Fan array flow measurement area

The estimated uncertainty in the flow measurement area is between 1 percent minimum and 2 percent maximum.

$e_A$ = 0.010 (min) to 0.020 (max)

The estimated uncertainty is based on a broad range of duct sizes, accessibility and the rigidity of ducts under pressure.

### C.2.3.2.8 Fan array velocity pressure

An allowance between 2.0 percent minimum and 5.0 percent maximum of the reading is estimated for the mental averaging performed on a fluctuating reading. An allowance between 1.0 percent minimum and 2.0 percent maximum of the reading is estimated for calibrated manometer uncertainty and relocation of the instrument after calibration. In addition, an allowance between 0.5 percent minimum and 10.0 percent maximum of the reading is estimated for instrument precision. No allowance is included for yaw on the assumption that the pitot-static tube is aligned within 10 degrees of streamlines. A combined uncertainty can be written as:

$$\begin{aligned} e_f(\min) &= [(0.02)^2 + (0.01)^2 + (0.005)^2]^{0.5} \\ &= 0.0229 \end{aligned}$$

$$\begin{aligned} e_f(\max) &= [(0.05)^2 + (0.02)^2 + (0.10)^2]^{0.5} \\ &= 0.1136 \end{aligned}$$

### C.2.3.2.9 Fan array static pressure

An allowance between 1.0 percent minimum and 5.0 percent maximum of the reading is estimated for the mental averaging performed on a fluctuating reading. An allowance between 1.0 percent minimum and 2.0 percent maximum of the reading is estimated for calibrated manometer uncertainty and relocation of the instrument after. In addition, a tolerance between 10 percent minimum and 20.0 percent maximum of the fan array velocity pressure should cover the influence of pitot-static tube yaw or velocity influence on static pressure taps and other possible effects. A combined uncertainty can be written as:

$$e_g\,(\text{min}) = \{(0.01)^2 + (0.01)^2 + (0.005)^2 + [0.1\ P_V/(P_{s2} - P_{s1})]^2\}^{0.5}$$
$$= \{0.000225 + [0.1\ P_V/(P_{s2} - P_{s1})]^2\}^{0.5}$$

$$e_g\,(\text{max}) = \{(0.05)^2 + (0.02)^2 + (0.02)^2 + [0.2\ P_V/(P_{s2} - P_{s1})]^2\}^{0.5}$$
$$= \{0.0033 + [0.2\ P_V/(P_{s2} - P_{s1})]^2\}^{0.5}$$

Where the denominator in the final term in each equation will involve $P_{s2}$ or $P_{s5}$ and $P_{s1}$ or $P_{s4}$, whichever are measured.

The estimated uncertainty range is based on an allowance for fluctuation in the fan array system operation, lack of ideal measurement locations, turbulence and the relocation of instrumentation after calibration.

### C.2.3.3 Fan array combined uncertainties

The uncertainties in the test performance are the result of using various values, each of which contains a probable uncertainty. The combined uncertainty for each of the fan array performance variables is given below.

#### C.2.3.3.1 Fan array density

Air density involves the various psychrometric measurements and the approximate formula:

$$\rho = \frac{p_b V}{R(t_d + 273.15)}$$

$$\rho = \frac{70.73 p_b V}{R(t_d + 459.67)}$$

Where:

$$V = 1.0 - 0.378\left\{(p_e/p_b) - \left[\frac{(t_d - t_w)}{1{,}500}\right]\right\}$$

$$V = 1.0 - 0.378\ \{(p_e/p_b) - [(t_d - t_w)/2{,}700]\}$$

For random and independent uncertainties in products, the combined uncertainty is determined as follows:

$$Dr/r = \{(Dp_b/p_b)^2 + (DV/V)^2 + (DR/R)^2 + [Dt_d/(t_d + 273.15)]^2\}^{0.5}$$

$$Dr/r = \{(\text{D}70.73/70.73)^2 + (Dp_b/p_b)^2 + (DV/V)^2 + (DR/R)^2 + [Dt_d/(t_d + 459.67)]^2\}^{0.5}$$

Assuming $\Delta 70.73$ and $\Delta R$ are both zero:

$$e_r = (e_b^2 + e_V^2 + e_d^2)^{0.5}$$

It can be shown that:

$$e_V = [(0.00002349\ t_w - 0.0003204)\ \text{D}(t_d - t_w)]$$

$$e_V = [(0.00000725\ t_w - 0.0000542)\ \text{D}(t_d - t_w)]$$

Where:

$\Delta(t_d - t_w)$ = Absolute uncertainty in wet-bulb depression.

Other methods for determining density are assumed to have equal accuracy.

### C.2.3.3.2 Fan array flow rate

Fan array flow rate directly involves the area at the flow measuring station, pitot traverse, square root of the pressure measurement for flow and square root of the density. Uncertainties in fan array speed will produce a first-power uncertainty in flow rate when making the fan law conversions. Combining:

$$e_Q = [e_c^2 + e_A^2\ (e_f/2)^2 + (e_r/2)^2 + e_N^2]^{0.5}$$

### C.2.3.3.3 Fan array static pressure

Fan array static pressure directly involves static pressure measurements. Uncertainties in density will produce a first-power uncertainty in fan array static pressure while uncertainties in fan array speed will produce a second-power uncertainty in fan array static pressure when making fan law conversions. Combining:

$$e_p = [e_g^2 + e_r^2 + (2e_N)^2]^{0.5}$$

**Table C.2 — Minimum and Maximum Measurement Uncertainties Per Unit**

| Measurement | Minimum | Maximum |
|---|---|---|
| $e_b$ | 0.003 | 0.007 |
| $e_d$** | 0.005 | 0.020 |
| $e_W$ | 5/($t_d$ - $t_w$) (Rankin) | 10/($t_d$ - $t_w$) (Rankin) |
| | 3/($t_d$ - $t_w$) (Kelvin) | 6/($t_d$ - $t_w$) (Kelvin) |
| $e_N$ | 0.005 | 0.010 |
| $e_h$ | 0.030 | 0.070 |
| $e_c$ | 0.015 | 0.075 |
| $e_A$ | 0.010 | 0.020 |
| $e_f$ | 0.0229 | 0.1136 |
| $e_g$ | $\{0.000225 + [0.1\ P_v/(P_{s2} - P_{s1})]^2\}^{0.5}$ | $\{0.0033 + [0.2\ P_v/(P_{s2} - P_{s1})]^2\}^{0.5}$ |

NOTE: These uncertainties do not account for the effect of swirl at the fan array inlet. Swirl at the fan array inlet must be corrected to produce acceptable fan array system performance (see Section 5).
**Based on absolute temperature.

To simplify the application of this uncertainty analysis to the results of field tests, the above equation was developed based on tests in which static pressure measurements are made at a single plane, as would be the case in which a fan array is ducted on one side only. However, the equation is reasonably accurate for all other fan array system configurations.

Although in most cases the determination of fan array static pressure involves $P_{v1}$, the uncertainty in determining $P_{v1}$ is not included in the above equation on the basis that it normally has a very small effect on the overall uncertainty in fan array static pressure.

For purposes of this standard, $e_P$ is applied directly to $P_{sc}$, which may include system effect factors.

### C.2.3.3.4 Fan array input power

Fan array input power directly involves the power measurement; in addition, when making fan law conversions, density has a first-power effect and speed has a third-power effect on fan array input power. Combining:

$$e_H = [e_h^2 + e_r^2 + (3e_N)^2]^{0.5}$$

### C.2.3.4 Summary

The minimum and maximum measurement uncertainties were defined earlier in Section C.2.3. Summarizing, the per unit uncertainties are as shown in Table C.2.

The uncertainty calculations lead to absolute uncertainties in fan array flow rate, static pressure and input power that can be applied directly to the corresponding test results. The uncertainty results can then be plotted as rectangles around the test point. Intersection of the rectangles with the quoted fan array performance are within the limitations of a fan array test. See the examples in the following Section C.2.3.5.

### C.2.3.5 Examples

Two examples of the calculation of uncertainties and the method of comparison with the quoted fan array curve are included in this section. Though more context of each fan setup can be found in AMCA Publication 203, all the necessary quantities to perform an uncertainty analysis are provided. Example 1 utilizes all minimum uncertainty tolerances. Example 2 utilizes all maximum uncertainty tolerances.

**Example 1: Calculation of Uncertainties in Test Results Based on Minimum Measurement Uncertainty**
(Reference: Example 2B from Appendix A of AMCA Publication 203)

**Test Values (SI)**

Designed Fan Operating Point:
$N_c$ = 2075 rpm
$r_c$ = 1.20 kg/m3

**Site Measurements**

$t_d$ = 32.9°C
$t_w$ = 21.3°C
= 294.45°K
$P_{s1}$ = -2840 Pa
$P_{s2}$ = 24.9 Pa
$P_{v3}$ = 309 Pa
N = 2120 rpm
$A_2$ = 0.130 sq m
$A_3$ = 0.146 sq m
$r_1$ = 0.0700 kg/m$^3$
$r_2$ = 1.14 kg/m$^3$
$r_3$ = 1.13 kg/m$^3$
H = 14.026 kW

**Measurement Uncertainties**

$e_b$ = 0.003
$e_d$ = 0.005
$e_W$ = $3/(t_d - t_w)$
$e_N$ = 0.005
$e_h$ = 0.030
$e_c$ = 0.015
$e_A$ = 0.010
$e_f$ = 0.0229
$e_g$ = $\{0.000225 + [0.1\ P_v/(P_{s2} - P_{s1})]^2\}^{0.5}$

**Converted Results from Site Data**

$Q_c = Q \times (N_c / N)$
$Q_c = 3.43 \times (2075 / 2120)$
$Q_c = 3.36$ m$^3$/s

**Test Values (I-P)**

Designed Fan Operating Point:
$N_c$ = 2075 rpm
$r_c$ = 0.075 lbm/ft3

**Site Measurements**

$t_d$ = 91.3°F
$t_w$ = 70.4°F
= 530.07°R
$P_{s1}$ = -11.4 in. wg
$P_{s2}$ = 0.1 in. wg
$P_{v3}$ = 1.24 in. wg
N = 2120 rpm
$A_2$ = 1.40 sq ft
$A_3$ = 1.57 sq ft
$r_1$ = 0.0700 lbm/ft$^3$
$r_2$ = 0.0713 lbm/ft$^3$
$r_3$ = 0.0705 lbm/ft$^3$
H = 18.81 hp

**Measurement Uncertainties**

$e_b$ = 0.003
$e_d$ = 0.005
$e_W$ = $5/(t_d - t_w)$
$e_N$ = 0.005
$e_h$ = 0.030
$e_c$ = 0.015
$e_A$ = 0.010
$e_f$ = 0.0229
$e_g$ = $\{0.000225 + [0.1\ P_v/(P_{s2} - P_{s1})]^2\}^{0.5}$

**Converted Results from Site Data**

$Q_c = Q \times (N_c / N)$
$Q_c = 7268 \times (2075 / 2120)$
$Q_c = 7114$ cfm

$P_{sc} = P_s \times (N_c / N)^2 \times (r_c / r_1)$
$P_{sc} = 2772 \times (2075 / 2120)^2 \times (1.20 / 1.12)$
$P_{sc} = 2{,}846$ Pa

$H_c = H \times (N_c / N)^3 \times (r_c / r_1)$
$H_c = 14.027 \times (2075 / 2120)^3 \times (1.20 / 1.12)$
$H_c = 14.09$ kW

### Calculations

$P_v = P_{v2}$
$= P_{v3} \times (A_3/A_2)^2 \times (r_3/r_2)$
$= 309 \times (0.146/0.130)^2 \times (1.13/1.14)$
$= 386$ Pa
$e_g = \{0.000225 + [0.1\, P_v/(P_{s2} - P_{s1})]^2\}^{0.5}$
$= \{0.000225 + [(0.1 \times 386)/(24.9 + 2840)]^2\}^{0.5}$
$= 0.02016$

*Using Degrees Kelvin,*

$e_v = [(0.00002349\, t_w - 0.0003204)\, \Delta(t_d - t_w)]$
$= [(0.00002349 \times 294.45 - 0.0003204) \times 3]$
$= 0.01979$

$e_r = [e_b^2 + e_v^2 + e_d^2)^{0.5}$
$= (0.003^2 + 0.01979^2 + 0.005^2)^{0.5}$
$= 0.02064$

$e_P = [e_g^2 + e_r^2 + (2e_N)^2]^{0.5}$
$= [0.02016^2 + 0.02064^2 + (2 \times 0.005)^2]^{0.5}$
$= 0.0305$

$e_Q = [e_c^2 + e_A^2 + (e_f/2)^2 + (e_r/2)^2 + e_N^2]^{0.5}$
$= [0.015^2 + 0.010^2 + (0.0229/2)^2 +$
$(0.02064/2)^2 + 0.005^2]^{0.5}$
$= 0.0242$

$e_H = [e_h^2 + e_r^2 + (3e_N)^2]^{0.5}$
$= [0.030^2 + 0.02064^2 + (3 \times 0.005)^2]^{0.5}$
$= 0.0394$

$DP = e_P P_{sc}$
$= 0.0305 \times 2846$
$= 87$ Pa

$P_{sc} + DP = 2847 + 87$
$= 2934$ Pa

$P_{sc} - DP = 2847 - 87$
$= 2760$ Pa

$DQ = e_Q Q_c$
$= 0.0242 \times 3.36$
$= 0.0813$ m$^3$/s

$P_{sc} = P_s \times (N_c / N)^2 \times (r_c / r_1)$
$P_{sc} = 11.13 \times (2075/ 2120)^2 \times (.075 / 0.0700)$
$P_{sc} = 11.42$ in. wg

$H_c = H \times (N_c / N)^3 \times (r_c / r_1)$
$H_c = 18.81 \times (2075 / 2120)^3 \times (.075 / 0.0700)$
$H_c = 18.90$ hp

### Calculations

$P_v = P_{v2}$
$= P_{v3} \times (A_3/A_2)^2 \times (r_3/r_2)$
$= 1.24 \times (1.57/1.40)^2 \times (0.0705/0.0713)$
$= 1.54$ in. wg
$e_g = \{0.000225 + [0.1\, P_v/(P_{s2} - P_{s1})]^2\}^{0.5}$
$= \{0.000225 + [(0.1 \times 1.54)/(0.1 + 11.4)]^2\}^{0.5}$
$= 0.02011$

*Using Degrees Rankin,*

$e_v = [(0.00000725\, t_w - 0.0000542)\, \Delta(t_d - t_w)]$
$= [(0.00000725 \times 530.07 - 0.0000542) \times 5]$
$= 0.01894$

$e_r = [e_b^2 + e_v^2 + e_d^2)^{0.5}$
$= (0.003^2 + 0.01894^2 + 0.005^2)^{0.5}$
$= 0.01982$

$e_P = [e_g^2 + e_r^2 + (2e_N)^2]^{0.5}$
$= [0.02011^2 + 0.01982^2 + (2 \times 0.005)^2]^{0.5}$
$= 0.0300$

$e_Q = [e_c^2 + e_A^2 + (e_f/2)^2 + (e_r/2)^2 + e_N^2]^{0.5}$
$= [0.015^2 + 0.010^2 + (0.0229/2)^2 +$
$(0.01982/2)^2 + 0.005^2]^{0.5}$
$= 0.0241$

$e_H = [e_h^2 + e_r^2 + (3e_N)^2]^{0.5}$
$= [0.030^2 + 0.01982^2 + (3 \times 0.005)^2]^{0.5}$
$= 0.0390$

$DP = e_P P_{sc}$
$= 0.0300 \times 11.42$
$= 0.34$ in. wg

$P_{sc} + DP = 11.42 + 0.34$
$= 11.76$ in. wg

$P_{sc} - DP = 11.42 - 0.34$
$= 11.08$ in. wg

$DQ = e_Q Q_c$
$= 0.0241 \times 7114$
$= 171$ cfm

$$\begin{aligned} Q_c + DQ &= 3.36 + 0.0813 \\ &= 3.44 \text{ m}^3\text{/s} \end{aligned}$$

$$\begin{aligned} Q_c - DQ &= 3.36 - 0.0813 \\ &= 3.28 \text{ m}^3\text{/s} \end{aligned}$$

$$\begin{aligned} DH &= e_H H_c \\ &= 0.0394 \times 14.09 \\ &= 0.56 \text{ kW} \end{aligned}$$

$$\begin{aligned} H_c + DH &= 14.09 + 0.56 \\ &= 14.15 \text{ kW} \end{aligned}$$

$$\begin{aligned} H_c - DH &= 14.09 - 0.56 \\ &= 13.53 \text{ kW} \end{aligned}$$

$$\begin{aligned} Q_c + DQ &= 7114 + 171 \\ &= 7285 \text{ cfm} \end{aligned}$$

$$\begin{aligned} Q_c - DQ &= 7114 - 171 \\ &= 6943 \text{ cfm} \end{aligned}$$

$$\begin{aligned} DH &= e_H H_c \\ &= 0.0390 \times 18.90 \\ &= 0.74 \text{ hp} \end{aligned}$$

$$\begin{aligned} H_c + DH &= 18.9 + 0.74 \\ &= 19.64 \text{ hp} \end{aligned}$$

$$\begin{aligned} H_c - DH &= 18.9 - 0.74 \\ &= 18.16 \text{ hp} \end{aligned}$$

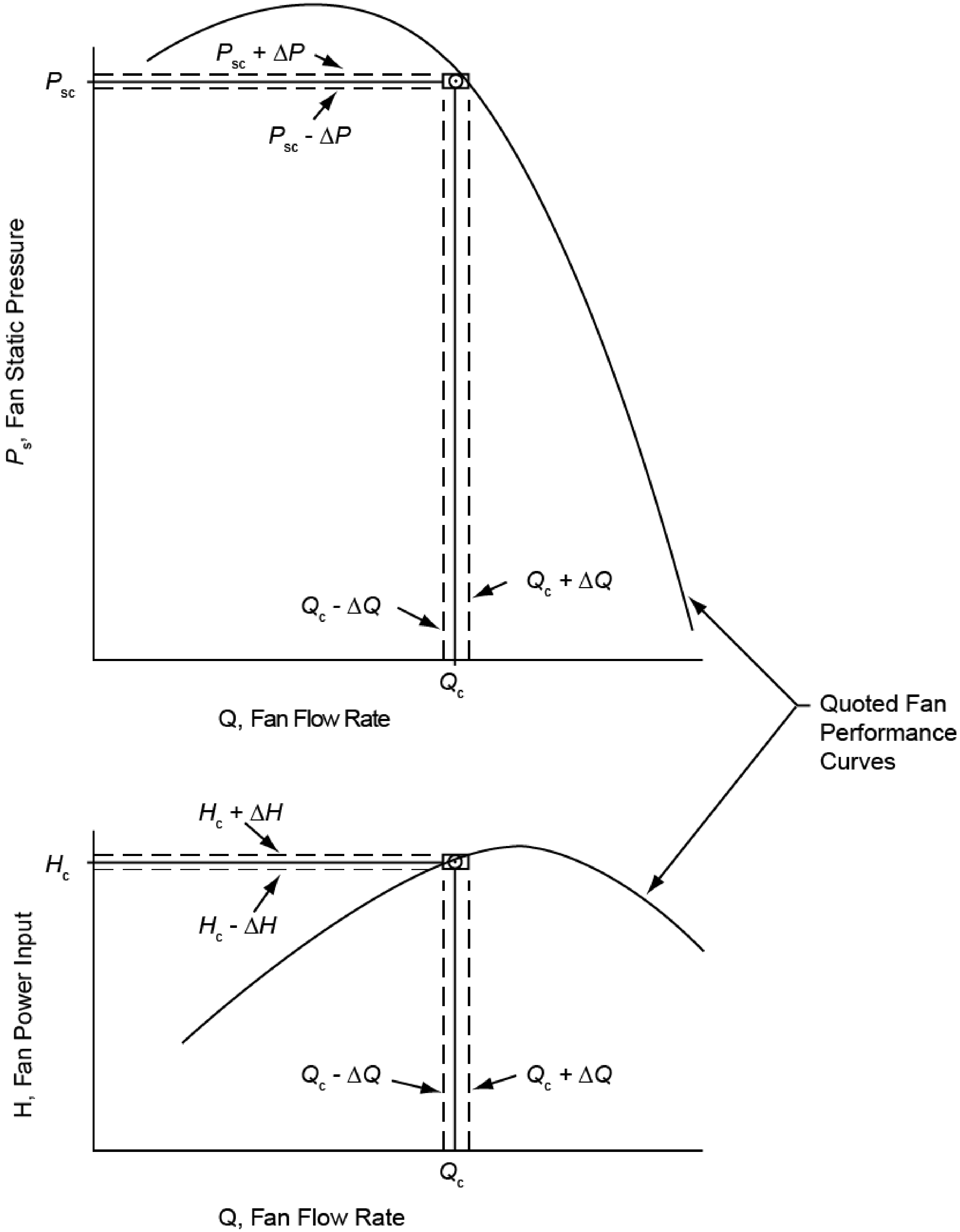


**Figure C.7 — Graphical Presentation - Example 1**

**Example 2: Calculation of Uncertainties in Test Results Based on Maximum Measurement Uncertainty**
(Reference: Example 2C from Appendix A of AMCA Publication 203)

**Test Values (SI)**

Designed Fan Operating Point:
$N_c$ = 1580 rpm
$r_c$ = 1.105 kg/m$^3$

**Site Measurements**

$t_d$ = 30.3°C
$t_w$ = 24.2°C
= 297.35°K
$P_{s4}$ = -391 Pa
$P_{s5}$ = 304 Pa
$P_{v2}$ = 154 Pa
N = 1590
$\rho_4$ = 1.107 kg/m$^3$

**Converted Results from Site Data**

$Q_c = Q \times (N_c / N)$
$Q_c = 12.33 \times (1580 / 1590)$
$Q_c$ = 12.25 m$^3$/s

$P_{sc} = P_s \times (N_c / N)^2 \times (\rho_c / \rho_4)$
$P_{sc} = 643 \times (1580/1590)^2 \times (.0690 / 0.0691)$
$P_{sc}$ = 633 Pa

$H_c = H \times (N_c / N)^3 \times (\rho_c / \rho_4)$
$H_c = 13.09 \times (1580/1590)^3 \times (.0690 / 0.0691)$
$H_c$ = 12.83 kW

**Measurement Uncertainties**

$e_b$ = 0.007
$e_d$ = 0.020
$e_W = 6/(t_d - t_w)$
$e_N$ = 0.010
$e_h$ = 0.070
$e_c$ = 0.075
$e_A$ = 0.020
$e_f$ = 0.1136
$e_g = \{0.0033 + [0.2\ P_v/(P_{s5} - P_{s4})]^2\}^{0.5}$

**Calculations**

$e_g = \{0.0033 + [0.2\ P_v/(P_{s5} - P_{s4})]^2\}^{0.5}$
$= \{0.0033 + [(0.2 \times 154)/(304 + 391)]^2\}^{0.5}$
= 0.07255

**Test Values (I-P)**

Designed Fan Operating Point:
$N_c$ = 1580 rpm
$r_c$ = 0.069 lbm/ft$^3$

**Site Measurements**

$t_d$ = 86.5°F
$t_w$ = 75.5°F
= 535.17°R
$P_{s4}$ = -1.57 in. wg
$P_{s5}$ = 1.22 in. wg
$P_{v2}$ = 0.61 in. wg
N = 1590
$\rho_4$ = 0.0691 lbm/ft$^3$

**Converted Results from Site Data**

$Q_c = Q \times (N_c / N)$
$Q_c = 26128 \times (1580 / 1590)$
$Q_c$ = 25,964 cfm

$P_{sc} = P_s \times (N_c / N)^2 \times (\rho_c / \rho_4)$
$P_{sc} = 2.58 \times (1580/1590)^2 \times (.0690 / 0.0691)$
$P_{sc}$ = 2.54 in. wg

$H_c = H \times (N_c / N)^3 \times (\rho_c / \rho_4)$
$H_c = 17.56 \times (1580/1590)^3 \times (.0690 / 0.0691)$
$H_c$ = 17.21 hp

**Measurement Uncertainties**

$e_b$ = 0.007
$e_d$ = 0.020
$e_W = 10/(t_d - t_w)$
$e_N$ = 0.010
$e_h$ = 0.070
$e_c$ = 0.075
$e_A$ = 0.020
$e_f$ = 0.1136
$e_g = \{0.0033 + [0.2\ P_v/(P_{s5} - P_{s4})]^2\}^{0.5}$

**Calculations**

$e_g = \{0.0033 + [0.2\ P_v/(P_{s5} - P_{s4})]^2\}^{0.5}$
$= \{0.0033 + [(0.2 \times 0.61)/(1.22 + 1.57)]^2\}^{0.5}$
= 0.07219

*Using Degrees Kelvin,*

$$\begin{aligned}
e_v &= [(0.00002349\ t_w - 0.0003204)\ \Delta(t_d - t_w)]^2 \\
&= [(0.00002349 \times (297.35) - 0.0003204) \times 6] \\
&= 0.040 \\
e_\rho &= (e_b^2 + e_v^2 + e_d^2)^{0.5} \\
&= (0.007^2 + 0.04^2 + 0.020^2)^{0.5} \\
&= 0.0453
\end{aligned}$$

$$\begin{aligned}
e_P &= [e_g^2 + e_\rho^2 + (2e_N)^2]^{0.5} \\
&= [0.07255^2 + 0.0453^2 + (2 \times 0.010)^2]^{0.5} \\
&= 0.135
\end{aligned}$$

$$\begin{aligned}
e_Q &= [e_c^2 + e_A^2 + (e_f/2)^2 + (e_\rho/2)^2 + e_N^2]^{0.5} \\
&= [0.075^2 + 0.020^2 + (0.0453/2)^2 + \\
&\quad (0.02466/2)^2 + 0.010^2]^{0.5} \\
&= 0.099
\end{aligned}$$

$$\begin{aligned}
e_H &= [e_h^2 + e_\rho^2 + (3e_N)^2]^{0.5} \\
&= [0.070^2 + 0.0453^2 + (3 \times 0.010)^2]^{0.5} \\
&= 0.089
\end{aligned}$$

$$\begin{aligned}
\Delta P &= e_P P_{sc} \\
&= 0.135 \times 633 \\
&= 85\ \text{Pa}
\end{aligned}$$

$$\begin{aligned}
P_{sc} + \Delta P &= 633 + 85 \\
&= 718\ \text{Pa}
\end{aligned}$$

$$\begin{aligned}
P_{sc} - \Delta P &= 633 - 85 \\
&= 548\ \text{Pa}
\end{aligned}$$

$$\begin{aligned}
\Delta Q &= e_Q Q_c \\
&= 0.099 \times 12.25 \\
&= 1.21\ \text{m}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_c + \Delta Q &= 12.25 + 1.21 \\
&= 13.5\ \text{m}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_c - \Delta Q &= 12.25 - 1.21 \\
&= 11.04\ \text{m}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
\Delta H &= e_H H_c \\
&= 0.089 \times 12.83 \\
&= 1.14\ \text{kW}
\end{aligned}$$

$$\begin{aligned}
H_c + \Delta H &= 12.83 + 1.14 \\
&= 13.97\ \text{kW}
\end{aligned}$$

$$\begin{aligned}
H_c - \Delta H &= 12.83 - 1.14 \\
&= 11.69\ \text{kW}
\end{aligned}$$

*Using Degrees Rankin,*

$$\begin{aligned}
e_v &= [(0.00000725\ t_w - 0.0000542)\ \Delta(t_d - t_w)] \\
&= [(0.00000725 \times (535.17) - 0.0000542) \times 10] \\
&= 0.0383 \\
e_\rho &= (e_b^2 + e_v^2 + e_d^2)^{0.5} \\
&= (0.007^2 + 0.0383^2 + 0.020^2)^{0.5} \\
&= 0.0437
\end{aligned}$$

$$\begin{aligned}
e_P &= [e_g^2 + e_\rho^2 + (2e_N)^2]^{0.5} \\
&= [0.07219^2 + 0.0437^2 + (2 \times 0.010)^2]^{0.5} \\
&= 0.087
\end{aligned}$$

$$\begin{aligned}
e_Q &= [e_c^2 + e_A^2 + (e_f/2)^2 + (e_\rho/2)^2 + e_N^2]^{0.5} \\
&= [0.075^2 + 0.020^2 + (0.0437/2)^2 + (0.02439/2)^2 \\
&\quad + 0.010^2]^{0.5} \\
&= 0.099
\end{aligned}$$

$$\begin{aligned}
e_H &= [e_h^2 + e_\rho^2 + (3e_N)^2]^{0.5} \\
&= [0.070^2 + 0.0437^2 + (3 \times 0.010)^2]^{0.5} \\
&= 0.088
\end{aligned}$$

$$\begin{aligned}
\Delta P &= e_P P_{sc} \\
&= 0.087 \times 2.54 \\
&= 0.22\ \text{in. wg}
\end{aligned}$$

$$\begin{aligned}
P_{sc} + \Delta P &= 2.54 + 0.22 \\
&= 2.76\ \text{in. wg}
\end{aligned}$$

$$\begin{aligned}
P_{sc} - \Delta P &= 2.54 - 0.22 \\
&= 2.32\ \text{in. wg}
\end{aligned}$$

$$\begin{aligned}
\Delta Q &= e_Q Q_c \\
&= 0.099 \times 25{,}964 \\
&= 2570\ \text{cfm}
\end{aligned}$$

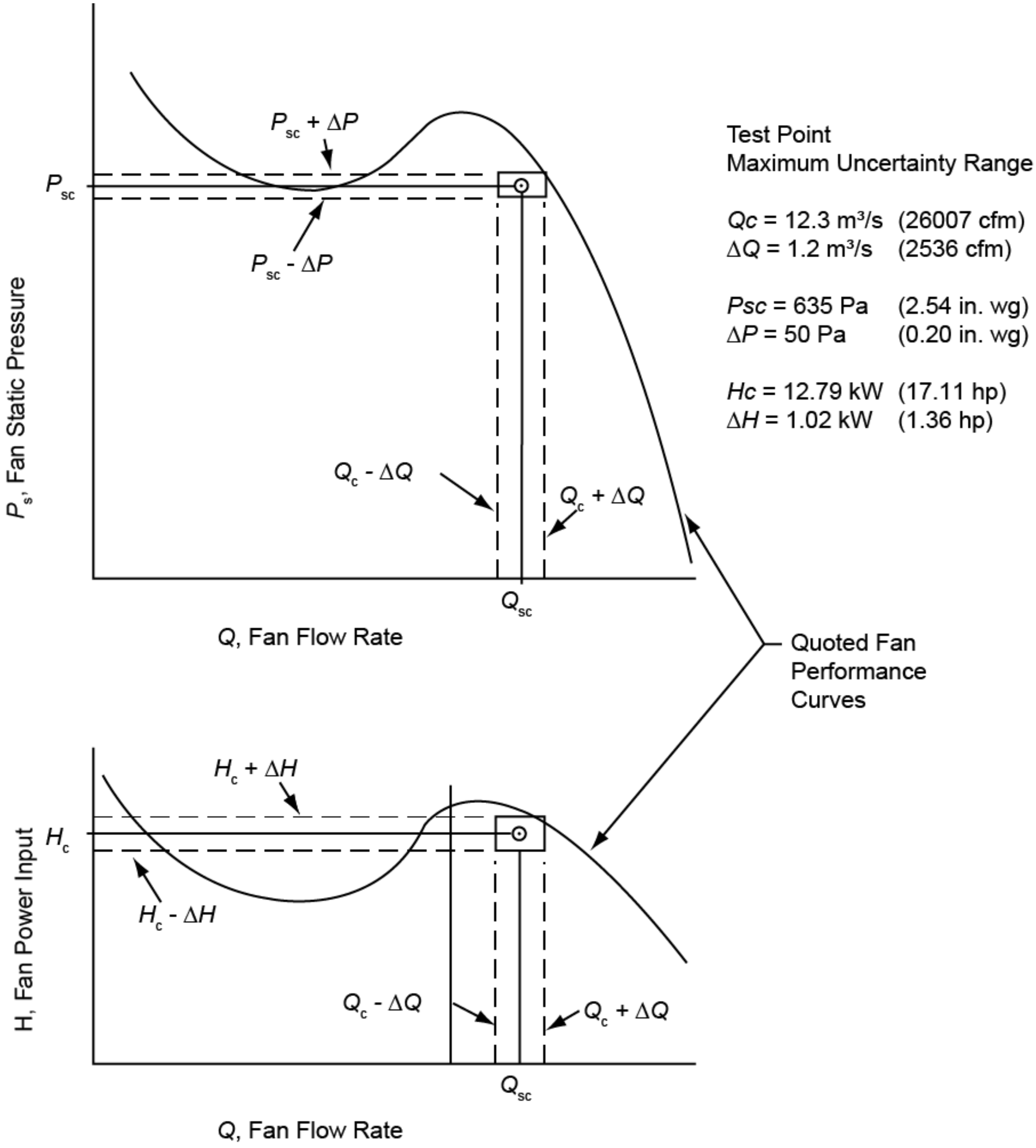
$$\begin{aligned}
Q_c + \Delta Q &= 25{,}964 + 2{,}570 \\
&= 28{,}534\ \text{cfm}
\end{aligned}$$

$$\begin{aligned}
Q_c - \Delta Q &= 25{,}964 - 2{,}570 \\
&= 23{,}394\ \text{cfm}
\end{aligned}$$

$$\begin{aligned}
\Delta H &= e_H H_c \\
&= 0.088 \times 17.21 \\
&= 1.51\ \text{hp}
\end{aligned}$$

$$\begin{aligned}
H_c + \Delta H &= 17.21 + 1.51 \\
&= 18.72\ \text{hp}
\end{aligned}$$

$$\begin{aligned}
H_c - \Delta H &= 17.21 - 1.51 \\
&= 15.70\ \text{hp}
\end{aligned}$$



Test Point
Maximum Uncertainty Range

$Qc = 12.3\ \mathrm{m^3/s}$ (26007 cfm)
$\Delta Q = 1.2\ \mathrm{m^3/s}$ (2536 cfm)

$Psc = 635$ Pa (2.54 in. wg)
$\Delta P = 50$ Pa (0.20 in. wg)

$Hc = 12.79$ kW (17.11 hp)
$\Delta H = 1.02$ kW (1.36 hp)

**Figure C.8 — Graphical Presentation - Example 2**

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# Air Movement and Control Association International

**AMCA Corporate Headquarters**
30 W. University Drive, Arlington Heights, IL 60004-1893, USA
communications@amca.org ▪ Ph: +1-847-394-0150 ▪ www.amca.org

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