State of California
Air Resources Board

METHOD 2

Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)

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Amended ________________________

Note: this document consists of the text of the proposed amendment to Method 2. Proposed deletions are noted by graphic screen and proposed additions are noted by underline.

METHOD 2

Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)

1 Principle and Applicability

1.1 Principle

The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

1.2 Applicability

This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable at measurement sites which fail to meet the criteria of Method 1, Section 2.1. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams; Section 2.4 of Method 1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, alternative procedures, subject to the approval of the Executive OfficerControl Agency's Authorized Representative, must be employed to make accurate flow rate determinations; examples of such alternative procedures are: (1) to install straightening vanes; (2) to calculate the total volumetric flow rate stoichiometrically, or (3) to move to another measurement site at which the flow is acceptable.

Any modification of this method beyond those expressly permitted shall be considered a major modification subject to the approval of the Executive Officer. The term Executive Officer as used in this document shall mean the Executive Officer of the Air Resources Board (ARB), or his or her authorized representative.

2 Apparatus

Specifications for the apparatus are given below. Any other apparatus that has been demonstrated (subject to approval of the Executive OfficerControl Agency's Authorized Representative) to be capable of meeting the specifications will be considered acceptable.

2.1 Type S Pitot Tube

The Type S pPitot tube (Figure 2-1) shall be made of metal tubing (e.g., stainless steel) as shown in Figure 2-1. It is recommended that the external tubing diameter (dimension D_t, Figure 2-2b) be between 0.48 and 0.95 centimeters (3/16 and 3/8 inch). There shall be an equal distance from the base of each leg of the pitot tube to its face-opening plane (dimensions P_A and P_B, Figure 2-2b); it is recommended that this distance be between 1.05 and 1.50 times the external tubing diameter. The face openings of the pitot tube shall, preferably, be aligned as shown in Figure 2-2; however, slight misalignments of the openings re permissible (see Figure 2-3).

The Type S pitot tube shall have a known coefficient, determined as outlined in Section 4. An identification number shall be assigned to the pitot tube; this number shall be permanently marked or engraved on the body of the tube.

A standard pitot tube may be used instead of a Type S, provided that it meets the specifications of Sections 2.7 and 4.2; note, however, that the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period; this can be done by taking a velocity head (Δp) reading at the final traverse point, cleaning out the impact and static holes of the standard pitot tube by "back-purging" with pressurized air, and then taking another Δp reading. If the Δp readings made before and after the air purge are the same (±5 percent), the traverse is acceptable. Otherwise, reject the run. Note that if Δp at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, then comparative Δp readings shall be taken, as above, for the last two back purges at which suitably high Δp readings are observed.

2.2 Differential Pressure Gauge

An inclined manometer or equivalent device is used. Most sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer, having 0.01-in. H_2O divisions on the 0- to 1-in. inclined scale, and 0.1-in. H_2O divisions on the 1- to 10-in. vertical scale. This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of Δp values as low as 1.3 mm (0.05 in.) H_2O. However, a differential pressure gauge of greater sensitivity shall be used (subject to the approval of the Executive OfficerControl Agency's Authorized Representative), if any of the following is found to be true: (1) the arithmetic average of all Δp readings at the traverse points in the stack is less than 1.3 mm (0.05 in) H_2O; (2) for traverses of 12 or more points, more than 10 percent of the individual Δp readings are below 1.3 mm (0.05 in.) H_2O; (3) for traverses of fewer than 12 points, more than one Δp reading is below 1.3 mm (0.05 in.) H_2O.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T = \frac{\sum_{i=1}^{n} \sqrt{\Delta P_i + K}}{\sum_{i=1}^{n} \sqrt{\Delta P_i}}$$

equation to be deleted

$$T = \frac{\sum_{i=1}^{n} \sqrt{\Delta p_i + K}}{\sum_{i=1}^{n} \sqrt{\Delta p_i}}$$

equation to be added

Where:

Δp_i = Individual velocity head reading at a traverse point, mm H_2O (in. H_2O) mm(in.) H_2O

n = total number of traverse points

K = 0.13 mm H_2O when metric units are used and 0.005 in. H_2O when English units are used

If T is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

NOTE: If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), their calibration must be checked after each test series. To check the calibration of a differential pressure gauge, compare Δp readings of the gauge with those of a gauge-oil manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp, as read by the differential pressure gauge and gauge-oil manometer agree to within 5 percent, the differential pressure gauge shall be considered to be in proper calibration. Otherwise, the test series shall either be voided, or procedures to adjust the measured Δp values and final results shall be used, subject to the approval of the Executive OfficerControl Agency's Authorized Representative.

2.3 Temperature Gauge

A thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature shall be used. The temperature gauge shall be attached to the pitot tube such that the sensor tip does not touch any metal; the gauge shall be in interference-free arrangement with respect to the pitot tube face openings (see Figure 2-1 and also Figure 2-7 in Section 4). Alternate positions may be used if the pitot tube temperature gauge system is calibrated according to the procedure of Section 4. Provided that a difference of not more than 1 percent in the average velocity measurement is introduced, the temperature gauge need not be attached to the pitot tube; this alternative is subject to the approval of the Executive OfficerControl Agency's Authorized Representative.

2.4 Pressure Probe and Gauge

A piezometer tube and mercury or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap of a standard type pitot tube or one leg of a Type S pitot tube with the face opening planes positioned parallel to the gas flow may also be used as the pressure probe.

2.5 Barometer

A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.01 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm (0.1 in.) Hg per 30-meter (100-foot elevation increase, or vice-versa for elevation decrease.

2.6 Gas Density Determination Equipment

Method 3 equipment, if needed (see Section 3.6), to determine the stack gas dry molecular weight, and Method 4 or Method 5 equipment for moisture content determination; other methods may be used subject to approval of the Executive OfficerControl Agency's Authorized Representative.

2.7 Calibration Pitot Tube

When calibration of the Type S pitot tube is necessary (see Section 4), a standard pitot tube is used as a reference. A standard pitot tube used as a reference when calibration of the Type S pitot tube is necessary (see Section 4). The standard pitot tube shall, preferably, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersburg, MarylandNational Institute of Standards and Technology(NIST), Fluid Mechanics (Bldg 230 room 105), Gaithersburg, MD 20899-0001, or (2) by calibration against another standard pitot tube with an NBSNIST-traceable coefficient. Alternatively, a standard pitot tube designed according to the criterion given in 2.7.1 through 2.7.5 below and illustrated in Figure 2.42-4 (see also Citations 7,8, and 17 in Section 6) may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about 0.99 ±0.01.

2.7.1

Hemispherical (shown in Figure 2-4), ellipsoidal, or conical tip.

2.7.2

A minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes.

2.7.3

A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degree bend.

2.7.4

Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.

2.7.5

Ninety degree bend, with curved or mitered junction.

2.8 Differential Pressure Gauge for Type S Pitot Tube Calibration

An inclined manometer or equivalent is used. If the single-velocity calibration technique is employed (see Section 4.1.2.3), the calibration differential pressure gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in. H_2O)0.13 mm (0.005 in.) H_2O. For multi-velocity calibrations, the gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in. H_2O)0.13 mm (0.005 in.) H_2O for p Δp values between 1.3 and 25 mm $_2O$ (0.05 and 1.0 in.) H_2O), and to the nearest 1.3 mm $_2O$ (0.05 in.) H_2O) for Δp values above 25 mm $_2O$ (1.0 in.) H_2O). A special, more sensitive gauge will be required to read Δp values below 1.3 mm H_2O (0.05 in.) H_2O) (see Citation 18 in Section 6).

3 Procedure

3.1

Set up the apparatus as shown in Figure 2-1. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen p Δp fluctuations. Conduct a pretest leak-checkIt is recommended, but not required, that a pre-test leak check be conducted as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3 in.) H_2O) velocity pressure registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3 in.) H_2O). Other leak-check procedures, subject to the approval of the Executive OfficerControl Agency's Authorized Representative, may be used.

3.2

Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all necessary data as shown in the example or similar data sheet (Figure 2-5).

3.3

Measure the velocity head and temperature at the traverse points specified by Method 1. Ensure that the proper differential pressure gauge is being used for the range of p Δp values encountered (see Section 2.2). If it is necessary to change to a more sensitive gauge, do so, and remeasure the p Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in Section 3.1 above to validate the traverse run.

3.4

Measure the static pressure in the stack. One reading is usually adequate.

3.5

Determine the atmospheric pressure.

3.6

Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. For other processes, other methods, subject to the approval of the Executive OfficerControl Agency's Authorized Representative must be used.

3.7

Obtain the moisture content from Reference Method 4 (or equivalent) or from Method 5.

3.8

Determine the cross-sectional area of the stack or duct at the sampling location. Whenever possible, physically measure the stack dimensions rather than using blueprints.

4 Calibration

4.1 Type S Pitot Tube

Before its initial use, carefully examine the Type S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Figure 2-2 or 2-3. The pitot tube shall not be used if it fails to meet these alignment specifications.

After verifying the face opening alignment, measure and record the following dimensions of the pitot tube: (a) the external tubing diameter (dimension D_t Figure 2-2b); and (b) the base-to-opening plane distances (dimensions P_A and P_B Figure 2-2b). If D_t is between 0.48 and 0.95 cm (3/16 and 3/8 in.), and if P_A and P_B are equal and between 1.05 and 1.50 D_t, there are two possible options: (1) the pitot tube may be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, or (2) a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Note, however, that if the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value (see Section 4.1.1).

If D_t, P_A and P_B are outside the specified limits, the pitot tube must be calibrated as outlined in 4.1.2 through 4.1.5 below.

4.1.1 Type S Pitot Tube Assemblies

During sample and velocity traverses, the isolated Type S pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S pitot tube coefficient (Citation 9 in Section 6); therefore, an assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly).

The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated. Figures 2-6 through 2-8 illustrate interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (3/16 and 3/8 in.). Type S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 shall be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, and prior to calibration, the values of the intercomponent spacings (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) shall be measured and recorded.

NOTE: Do not use any Type S pitot tube assembly which is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Figure 2-6bB).

4.1.2 Calibration Setup

If the Type S pitot tube is to be calibrated, one leg of the tube shall be permanently marked A, and the other, B. Calibration shall be done in a flow system having the following essential design features:

4.1.2.1

The flowing gas stream must be confined to a duct of definite cross sectional area, either circular or rectangular. For circular cross-sections, the minimum duct diameter shall be 30.5 cm (12 in.); for rectangular cross-sections, the width (shorter side) shall be at least 25.4 cm (10 in.).

4.1.2.2

The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D_e = \frac{2\ LW}{(L + W)} \qquad \text{Equation 2-1}$$

Where,

D_e = Equivalent diameter.

L = Length.

W = Width.

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE: The eight- and two-diameter criteria are not absolute; other test section locations may be used (subject to approval of the Executive OfficerControl Agency's Authorized Representative), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

4.1.2.3

The flow system shall have the capacity to generate a test-section velocity around 915 m/min (3,000 ft/min). This velocity must be constant with time to guarantee steady flow during calibration. Note that Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3,000 ft/min) will generally be valid to within ±3 percent for the measurement of velocities above 305 m/min (1,000 ft/min) and to within ±5 to 6 percent for the measurement of velocities between 180 and 305 m/min (600 and 1,000 ft/min). If a more precise correlation between C_P and velocity is desired, the flow system shall have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 180 to 1,525 m/min (600 to 5,000 ft/min), and calibration data shall be taken at regular velocity intervals over this range (see Citations 9 and 14 in Section 6 for details).

4.1.2.4

Two entry ports, one each for the standard and Type S pitot tubes, shall be cut in the test section; the standard pitot entry port shall be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglas or some other transparent material.

4.1.3 Calibration Procedure

Note that this procedure is a general one and must not be used without first referring to the special considerations presented in Section 4.1.5. Note also that this procedure applies only to single-velocity calibration. To obtain calibration data for the A and B sides of the Type S pitot tube, proceed as follows:

4.1.3.1

Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.

4.1.3.2

Level and zero the manometer. Turn on the fan and allow the flow to stabilize. Seal the type S entry port.

4.1.3.3

Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as outlined in Section 4.1.5.1), and align the tube so that its tip is pointed directly into the flow. Particular care should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.4

Read Δp_{std} and record its value in a data table similar to the one shown in Figure 2-9. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.

4.1.3.5

Connect the Type S pitot tube to the manometer. Open the Type S entry port. Check the manometer level and zero. I insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.6

Read Δp_s and enter its value in the data table. Remove the Type S pitot tube from the duct and disconnect it from the manometer.

4.1.3.7

Repeat steps 4.1.3.3 through 4.1.3.6 above until three pairs of p Δp readings have been obtained.

4.1.3.8

Repeat steps 4.1.3.2 through 4.1.3.7 above for the B side of the Type S pitot tube.

4.1.3.9

Perform calculations, as described in Section 4.1.4 below.

4.1.4 Calculations

4.1.4.1

For each of the six pairs of p Δp readings (i.e., three from side A and three from side B) obtained in Section 4.1.3 above, calculate the value of the Type S pitot tube coefficient as follows:

equation to be deleted:

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta P_{std}}{\Delta p_s}}$$ Equation 2-2

equation to be added:

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$ Equation 2-2

wWhere:

$C_{p(s)}$ = Type S pitot tube coefficient

$C_{p(std)}$ = Standard pitot tube coefficient; use 0.99 if the coefficient is unknown and the tube is designed according to the criteria of Sections 2.7.1 to 2.7.5 of this method

Δp_{std} = Velocity head measured by the standard pitot tube, cm $_s$O (in.) H_2O)

Δp_s = Velocity head measured by the Type S pitot tube, cm $_2$O (in.) H_2O)

4.1.4.2

Calculate $\bar{C}_p$ (side A), the mean A side coefficient, and $\bar{C}_p$ (side B), the mean B-side coefficient; calculate the difference between these two average values.

4.1.4.3

Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from $\bar{C}_p$ (side A), and the deviation of each B-side value of $C_{p(s)}$ from $\bar{C}_p$ (side B). Use the following equation:

$$\text{Deviation} = C_{p(s)} - \bar{C}_p \text{ (A or B)}$$ Equation 2-3

4.1.4.4

Calculate aσ, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation:

Equation to be deleted:

$$a(\text{side A or B}) = \frac{\sum_{1}^{3} \left|C_{p(s)} - \bar{C}_p\ (\text{A or B})\right|}{3} \qquad \text{Equation 2-4}$$

Equation to be added:

$$\sigma\ (\text{side A or B}) = \frac{\sum_{1}^{3} \left|C_{p(s)} - \bar{C}_p\ (\text{A or B})\right|}{3} \qquad \text{Equation 2-4}$$

4.1.4.5

Use the Type S pitot tube only if the values of (side A) and (side B) are less than or equal to 0.01 and if the absolute value of the difference between $\bar{C}_p$ (A) and $\bar{C}_p$ (B) is 0.01 or less.

4.1.5 Special Considerations

4.1.5.1 Selection of Calibration Point

4.1.5.1.1

When an isolated Type S pitot tube is calibrated, select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The Type S pitot coefficients so obtained, i.e., $\bar{C}_p$ (side A) and $\bar{C}_p$ (side B), will be valid, so long as either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Figures 2-6 through 2-8).

4.1.5.1.2

For Type S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, and follow the procedures outlined in Section 4.1.3 and 4.1.4 above. The coefficients so obtained will be valid so long as the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Figures 2-6 and 2-8).

4.1.5.1.3

For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of the probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values (Citation 9). Therefore, to minimize the blockage effect, the calibration point may be a few inches off center if necessary. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected area model of the probe sheath, is two2 percent or less of the duct cross-sectional area for assemblies without external sheaths (Figure 2-10a), and three3 percent or less for assemblies with external sheaths (Figure 2-10b).

4.1.5.2

For those probe assemblies in which pitot tube nozzle interference is a factor (i.e., those in which the pitot-nozzle separation distance fails to meet the specification illustrated in Figure 2-6A), the value of $C_{p(s)}$ depends upon the amount of free-space between the tube and nozzle, and therefore, is a function of nozzle size. In these instances, separate calibrations shall be performed with each of the commonly used nozzle sizes in place. Note that the single-velocity calibration technique is acceptable for this purpose, even though the larger nozzle sizes (>0.635 cm or 1/4 in.) are not ordinarily used for isokinetic sampling at velocities around 915 m/min. (3,000 ft/min.), which is the calibration velocity; note also that it is not necessary to draw an isokinetic sample during calibration (Citation 9 in Section 6).

4.1.5.3

For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube need be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Figure 2-2 or 2-3, however, and must have an average deviation (aσ) value of 0.01 or less (see Section 4.1.4.4).

4.1.6 Field Use and Recalibration

4.1.6.1 Field Use

4.1.6.1.1

When a Type S pitot tube (isolated tube or in an assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) shall be used to perform velocity calculations. For calibrated Type S pitot tubes, the A side coefficient shall be used when the A side of the tube faces the flow, and the B side coefficient shall be used when the B side faces the flow; alternatively, the arithmetic average of the A and B side coefficient values may be used, irrespective of which side faces the flow.

4.1.6.1.2

When a probe assembly is used to sample a small duct 30.5 to 91.4 cm (12 to 36 in.) in diameter), the probe sheath sometimes blocks a significant part of the duct cross-section, causing a reduction in the effective value of $C_{p(s)}$. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 30.5 cm (12 in.)inches (Citation 16 in Section 6).

4.1.6.2 Recalibration

4.1.6.2.1 Isolated Pitot Tubes

After each field use, the pitot tube shall be carefully reexamined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Figure 2-2 or 2-3, it can be assumed that the baseline coefficient of the pitot tube has not changed. If, however, the tube has been damaged to the extent that it no longer meets the specifications of Figure 2-2 or 2-3, the damage shall either be repaired to restore proper alignment of the face openings or the tube shall be discarded.

4.1.6.2.2 Pitot Tube Assemblies

After each field use, check the face opening alignment of the pitot tube, as in Section 4.1.6.2.1; also, remeasure the intercomponent spacings of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, it can be assumed that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Figures 2-2 or 2-3, either repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

4.2 Standard Pitot Tube (if applicable)

If a standard pitot tube is used for the velocity traverse, the tube shall be constructed according to the criteria of Section 2.7 and shall be assigned a baseline coefficient value of 0.99. If the standard pitot tube is used as part of the assembly, the tube shall be in an interference-free arrangement (subject to the approval of the Executive OfficerControl Agency's Authorized Representative).

4.3 Temperature Gauges

After each field use, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gauges at a temperature within 10 percent of the average absolute stack temperature. For temperatures up to 405°C (761°F), use an ASTM Mercury in glass thermometer as a reference; alternatively, either a reference thermocouple and potentiometer (calibrated by NIST) or thermometric fixed points, e.g., ice bath and boiling water (corrected for barometric pressure) may be used. For temperatures above 405°C (761°F) use an NBSNIST-calibrated reference thermocouple-potentiometer system or an alternate reference, subject to the approval of the Executive OfficerControl Agency's Authorized Representative.

If, during calibration, the absolute temperatures measured with the gauge being calibrated and the reference gauge agree within 1.5 percent, the temperature data taken in the field shall be considered valid. Otherwise, the pollutant emission test shall either be considered invalid or adjustments (if appropriate) of the test results shall be made, subject to the approval of the Executive OfficerControl Agency's Authorized Representative.

4.4 Barometer

Calibrate the barometer used against a mercury barometer.

5 Calculations

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

5.1 Nomenclature

A = Cross-sectional area of stack, m^2 (ft^2).

B_{ws} = Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume.

C_p = Pitot tube coefficient, dimensionless.

K_p = Pitot tube constant.,

Equation to be deleted:

$$34.97 \frac{m}{sec} \frac{[(g/g-mole)\ (mm\ Hg)]^{1/2}}{(^oK)\ (mm\ H_2O)}$$

Equation to be added:

$$34.97 \frac{m}{sec} [\ \frac{(g/g-mole)\ (mm\ Hg)}{(^oK)\ (mm\ H_2O)}\ ]^{1/2}$$

for the metric system and

Equation to be deleted:

$$85.49 \frac{ft}{sec} \frac{[(lb/lb-mole)\ (in.\ Hg)]^{1/2}}{(^oR)\ (in.\ H_2O)}$$

Equation to be added:

$$85.49 \frac{ft}{sec} [\ \frac{(lb/lb-mole)\ (in.\ Hg)}{(^oR)\ (in.\ H_2O)}\ ]^{1/2}$$

for the English system.

M_d = Molecular weight of stack gas, dry basis (see Section 3.6) g/g-mole (lb/lb-mole).

M_s = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).

$$= M_d\ (1 - Bws)\ +\ 18.0\ Bws \qquad \text{Equation 2-5}$$

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg).

P_g = Stack static pressure, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg).

$$= P_{bar}\ +\ P_g \qquad \text{Equation 2-6}$$

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

Q_{sd} = Dry volumetric stack gas flow rate corrected to standard conditions, dscmdsm^3/hr (dscf/hr).

t_s = Stack temperature ^oC (^oF).

T_s = Absolute stack temperature,^oK (^oR).

$$= 273\ +\ t_s\ \text{for metric} \qquad \text{Equation 2-7}$$

$$= 460\ +\ t_s\ \text{for English} \qquad \text{Equation 2-8}$$

T_{std} = Standard absolute temperature, 293^{o}K (528^{o}R).

V_s v_s = Average stack gas velocity, m/sec (ft/sec).

pΔp = Velocity head of stack gas, mm H_2) (in. H_2O).

3,600 = Conversion factor, sec/hr.

18.0 = Molecular weight of water, g/g-mole (lb-lb/mole).

5.2 Average Stack Gas Velocity

Equation to be deleted**:**

$$V_s\ =\ K_p\ C_p\ (\sqrt{\Delta p})avg\ \sqrt{\frac{T_{s(avg)}}{P_s\ M_s}} \qquad \text{Equation 2-9}$$

Equation to be added**:**

$$V_s = K_p \ C_p \ (\sqrt{\Delta p})_{avg} \sqrt{\frac{T_{s(avg)}}{P_s \ M_s}} \qquad \text{Equation 2-9}$$

5.3 Average Stack Gas Dry Volumetric Flow Rate

Equation to be deleted:

$$Q_{std} = 3{,}600 \ (1 - B_{ws}) \ V_s A \ \left(\frac{T_{std}}{T_{s(avg)}}\right) \left(\frac{P_s}{P_{std}}\right)$$

Equation to be added:

$$Q_{sd} = 3{,}600\ (1 - B_{ws})\ v_s\ A\ \frac{T_{std}}{T_{s(avg)}}\ \frac{P_s}{P_{std}}$$

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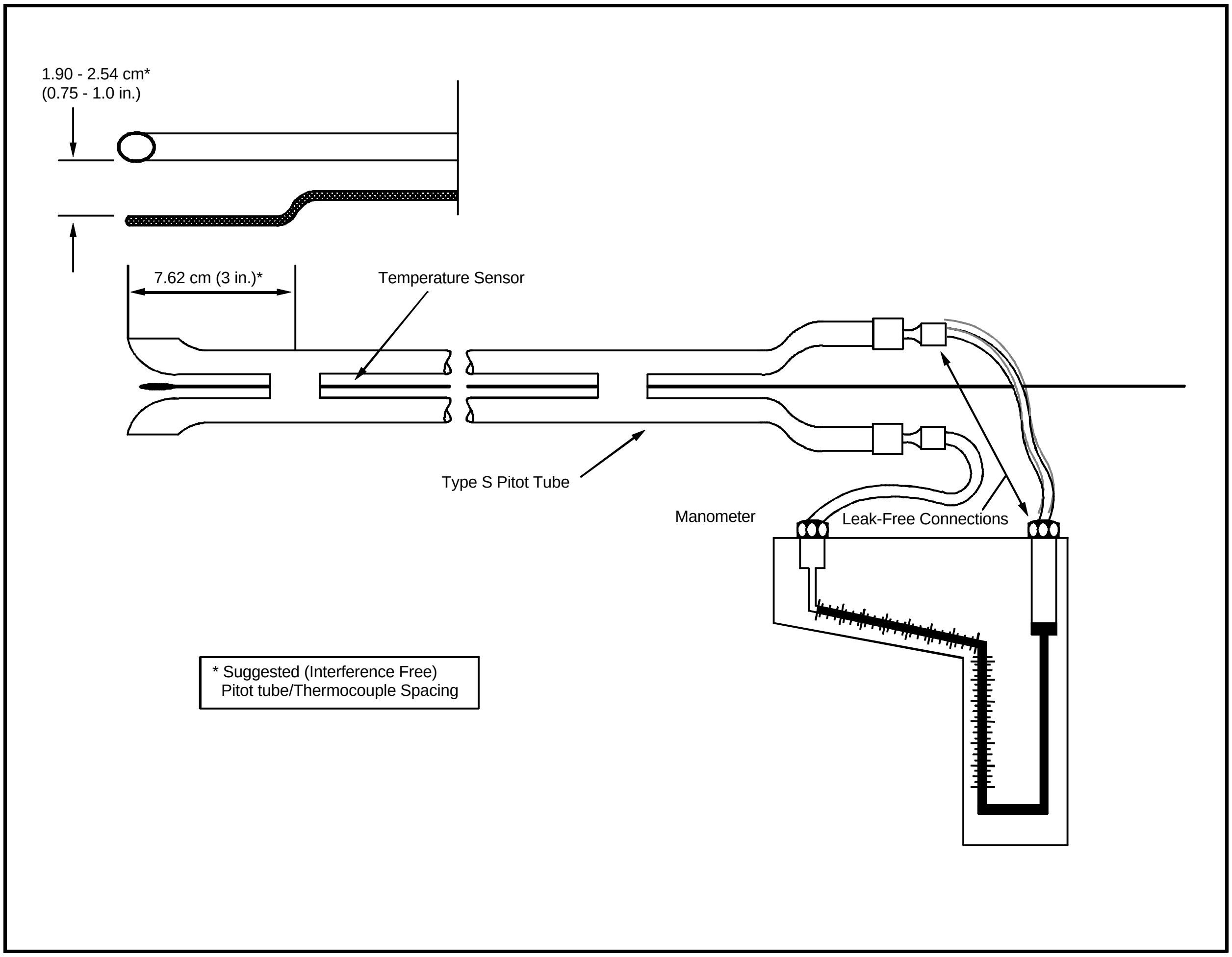
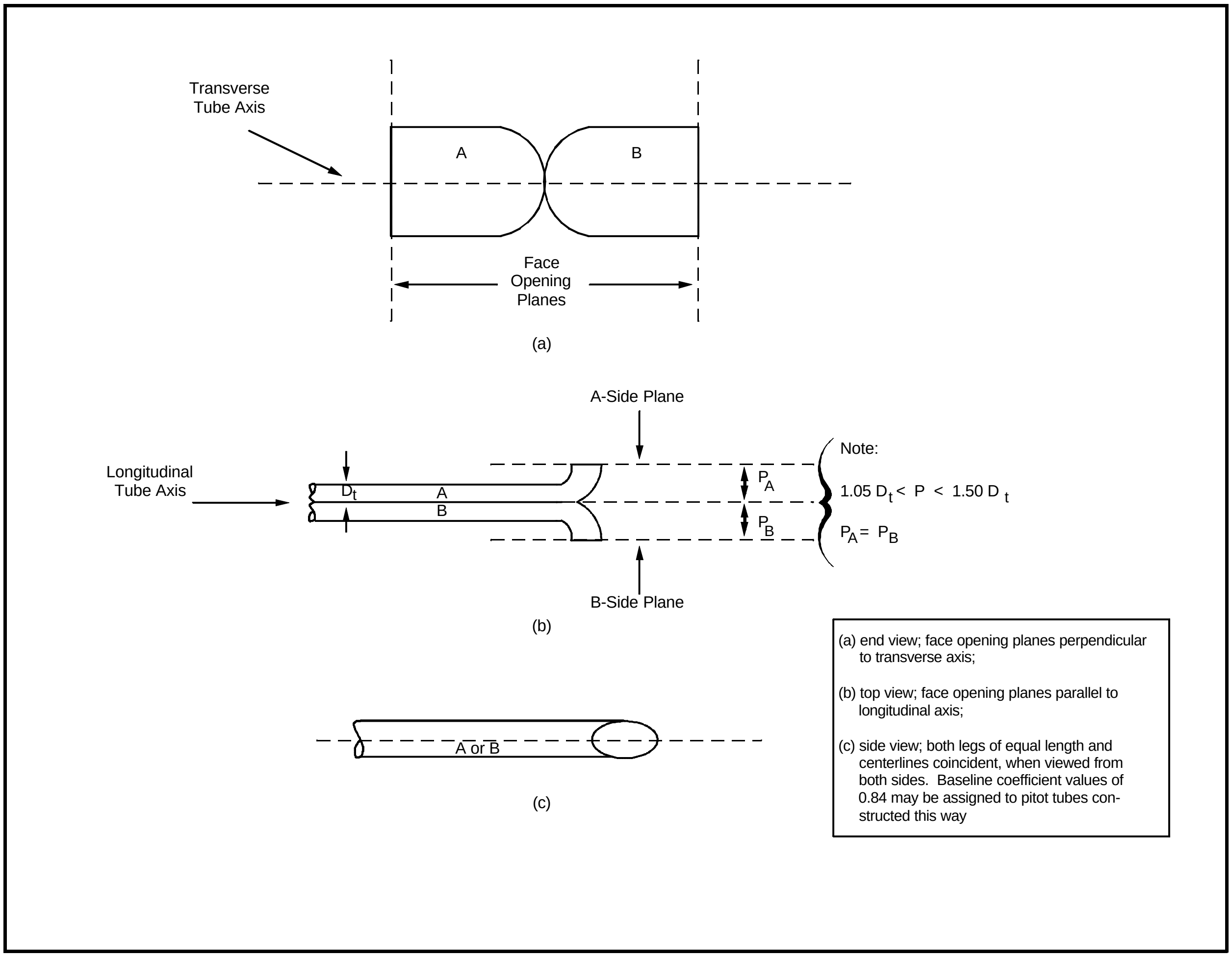


Figure 2-1. Type S pitot tube manometer assembly.



Note:

$1.05\ D_t < P < 1.50\ D_t$

$P_A = P_B$

(a) end view; face opening planes perpendicular to transverse axis;

(b) top view; face opening planes parallel to longitudinal axis;

(c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way

Figure 2-2. Properly constructed Type S pitot tube.

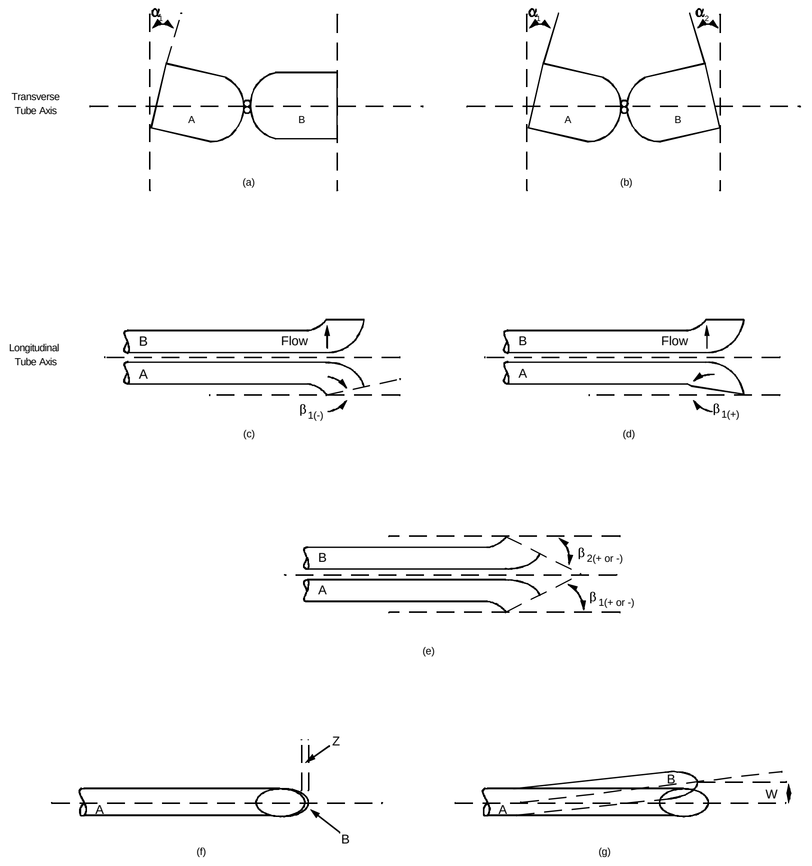


Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of Cp(s) so long as α^1 and $\alpha^2 \leq 10^\circ$, β^1 and $\beta^2 \leq 5^\circ$, $z \leq 0.32$ cm (1/8 in.) and $w \leq 0.08$ cm (1/32 in.).

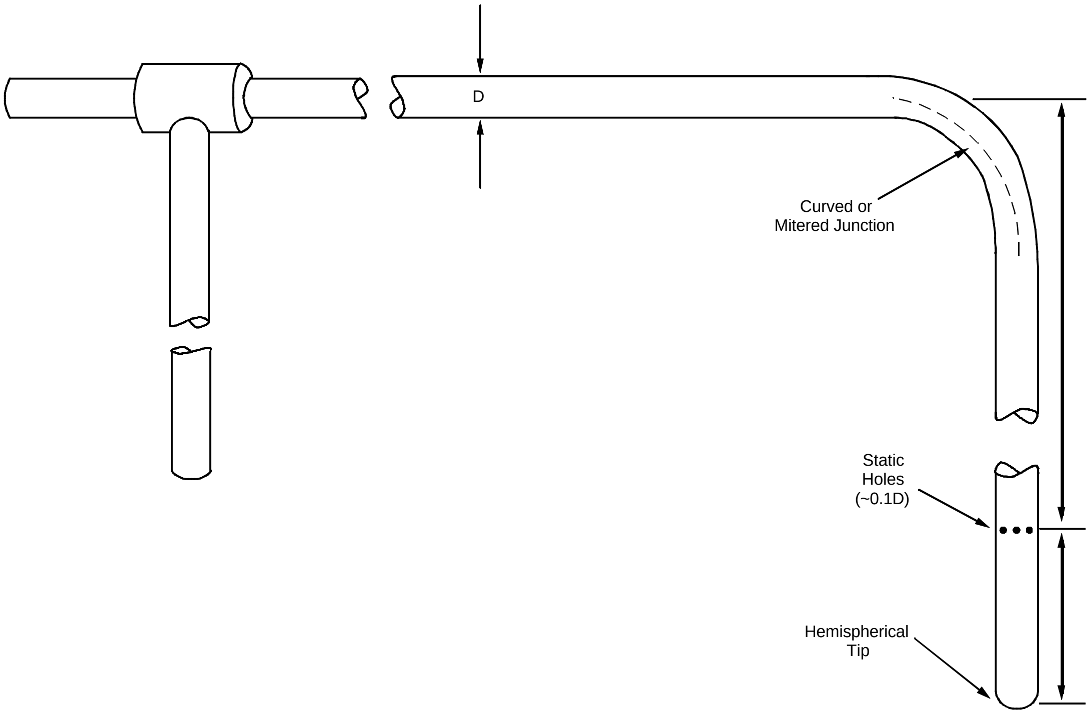


Figure 2-4. Standard pitot tube design specifications.

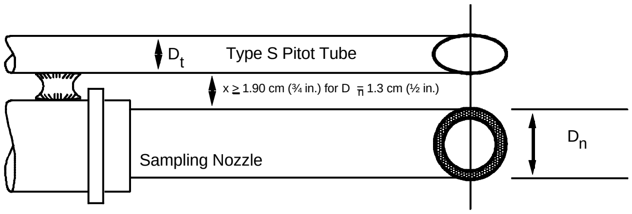
PLANT ________________
DATE ____ RUN NO. ________STACK DIA. OR DIMENSIONS, m (in.)
__ BAROMETRIC PRESS., mm Hg (in. Hg) __CROSS SECTIONAL
AREA, m^2 (ft^2)____
OPERATORS ______________
PITOT TUBE I.D. NO. _________
AVG. COEFFICIENT, Cp = _______
LAST DATE CALIBRATED ________

SCHEMATIC OF STACK
CROSS SECTION

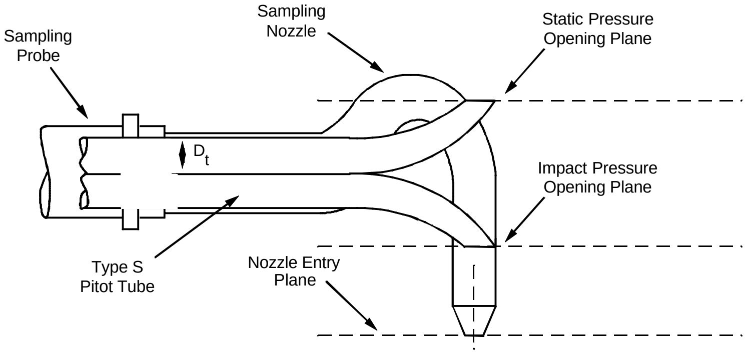
Traverse Pt. No.	Vel. Hd., Δp mm (in.) H_2O	Stack Temperature		P_g mm Hg (in.Hg)	$(\Delta p)^{1/2}$
		T_s, °C (°F)	T_s, °K (°R)		
		Average			

Figure 2-5. Velocity traverse data.

.



A. Bottom View; showing minimum pitot tube-nozzle separation.



B. Side View; to prevent pitot tube from interfering with gas flow streamlines approaching the nozzle, the impact pressure opening plane of the pitot tube shall be even with or above the nozzle entry plane.

Figure 2-6. Proper pitot tube-sampling nozzle configuration to prevent aerodynamic interference; button-hook type nozzle; centers of nozzle and pitot opening aligned; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

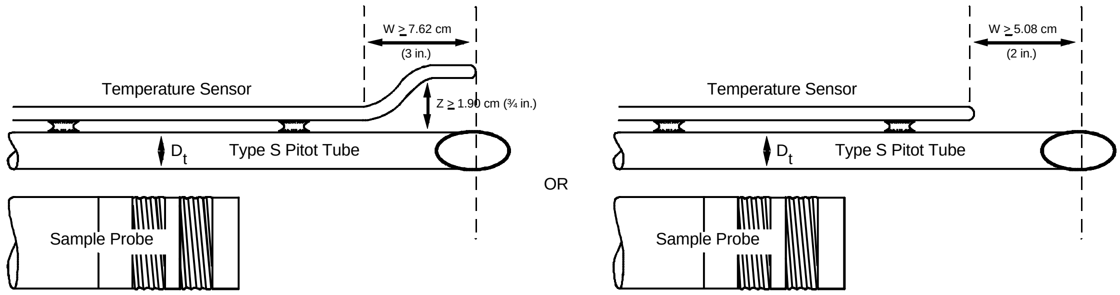


Figure 2-7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

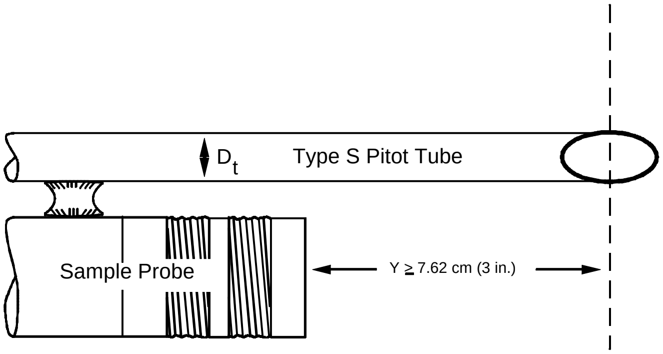


Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

FIGURE 2-9

PITOT TUBE CALIBRATION DATA

Pitot tube identification number ____________________________________ Date _______________________________

Calibrated by ____

	"A" SIDE CALIBRATION			
RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - C_p(A)$
1				
2				
3				
		C_p (SIDE A)		

	"B" SIDE CALIBRATION			
RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - C_p(B)$
1				
2				
3				
		C_p (SIDE B)		

$$\text{AVERAGE DEVIATION} = a(\text{side A or B}) = \frac{\sum_{1}^{3} |C_{p(s)} - \overline{C_p}\ (\text{A or B})|}{3} \leftarrow \text{MUST BE} <$$

$$|\ \overline{C_p}\ (\text{SIDE A}) - \overline{C_p}\ (\text{SIDE B})\ | \leftarrow \text{MUST BE} < 0.01$$

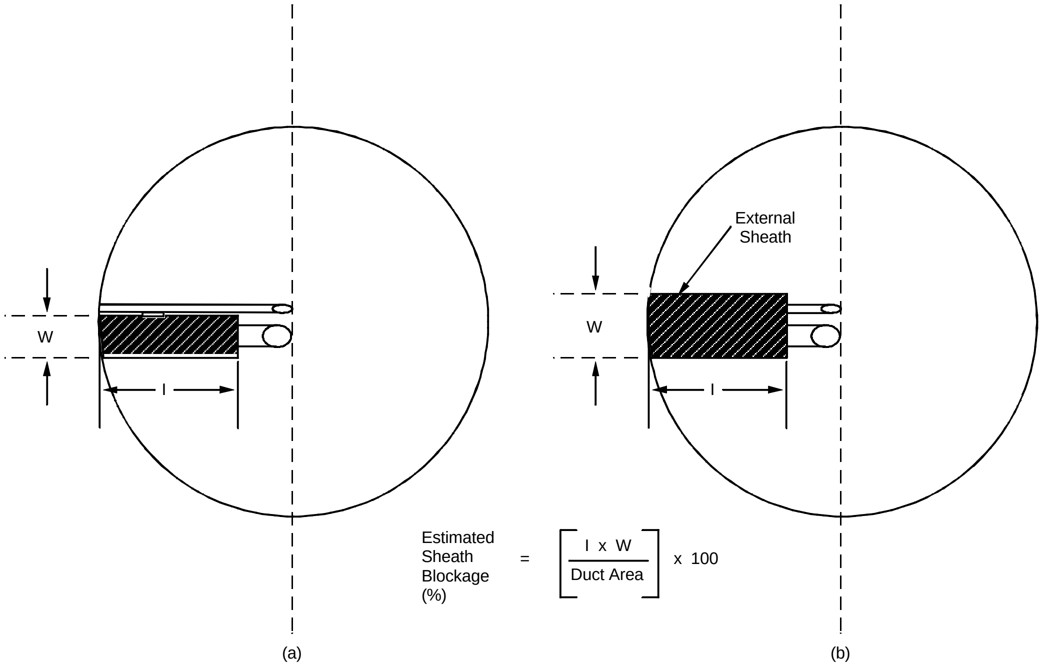


Figure 2-10. Projected-area models for typical pitot tube assemblies.