direction is noted with the negative side disconnected, then the static pressure is positive. Likewise, if a deflection in the positive direction is noted with the positive side disconnected, then the static pressure is negative.

8.11.2 If a 3–D probe is used for this measurement, position the probe at or between any traverse point(s) and rotate the probe until a null differential pressure reading is obtained at P_2–P_3. Rotate the probe 90°. Disconnect the P_2 pressure side of the probe and read the pressure P_1–P_{bar} and record as the static pressure. (NOTE: The spherical probe, specified in section 6.1.2 of Method 2F, is unable to provide this measurement and shall not be used to take static pressure measurements.)

8.12 Atmospheric Pressure. Determine the atmospheric pressure at the sampling elevation during each test run following the procedure described in section 2.5 of Method 2.

8.13 Molecular Weight. Determine the stack or duct gas dry molecular weight. For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3 or 3A. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. Other methods may be used, if approved by the Administrator.

8.14 Moisture. Determine the moisture content of the stack gas using Method 4 or equivalent.

8.15 Data Recording and Calculations. Record all required data on a form similar to Table 2G–3.

8.15.1 2–D probe calibration coefficient. When a Type S pitot tube is used in the field, the appropriate calibration coefficient as determined in section 10.6 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.

8.15.2 3–D calibration coefficient. When a 3–D probe is used to collect data with this method, follow the provisions for the calibration of 3–D probes in section 10.6 of Method 2F to obtain the appropriate velocity calibration coefficient (F_2 as derived using Equation 2F–2 in Method 2F) corresponding to a pitch angle position of 0°.

8.15.3 Calculations. Calculate the yaw-adjusted velocity at each traverse point using the equations presented in section 12.2. Calculate the test run average stack gas velocity by finding the arithmetic average of the point velocity results in accordance with sections 12.3 and 12.4, and calculate the stack gas volumetric flow rate in accordance with section 12.5 or 12.6, as applicable.

9.0 Quality Control

9.1 Quality Control Activities. In conjunction with the yaw angle determination and the pressure and temperature measurements specified in section 8.9, the following quality control checks should be performed.

9.1.1 Range of the differential pressure gauge. In accordance with the specifications in section 6.4, ensure that the proper differential pressure gauge is being used for the range of ΔP values encountered. If it is necessary to change to a more sensitive gauge, replace the gauge with a gauge calibrated according to section 10.3.3, perform the leak check described in section 8.4 and the zero check described in section 8.5, and repeat the differential pressure and temperature readings at each traverse point.

9.1.2 Horizontal stability check. For horizontal traverses of a stack or duct, visually check that the probe shaft is maintained in a horizontal position prior to taking a pressure reading. Periodically, during a test run, the probe's horizontal stability should be verified by placing a carpenter's level, a digital inclinometer, or other angle-measuring device on the portion of the probe sheath that extends outside of the test port. A comparable check should be performed by automated systems.

10.0 Calibration

10.1 Wind Tunnel Qualification Checks. To qualify for use in calibrating probes, a wind tunnel shall have the design features specified in section 6.11 and satisfy the following qualification criteria. The velocity pressure cross-check in section 10.1.1 and axial flow verification in section 10.1.2 shall be performed before the initial use of the wind tunnel and repeated immediately after any alteration occurs in the wind tunnel's configuration, fans, interior surfaces, straightening vanes, controls, or other properties that could reasonably be expected to alter the flow pattern or velocity stability in the tunnel. The owner or operator of a wind tunnel used to calibrate probes according to this method shall maintain records documenting that the wind tunnel meets the requirements of sections 10.1.1 and 10.1.2 and shall provide these records to the Administrator upon request.

10.1.1 Velocity pressure cross-check. To verify that the wind tunnel produces the same velocity at the tested probe head as at the calibration pitot tube impact port, perform the following cross-check. Take three differential pressure measurements at the fixed calibration pitot tube location, using the calibration pitot tube specified in section 6.10, and take three measurements with the calibration pitot tube at the wind tunnel calibration location, as defined in section 3.21. Alternate the measurements between the two positions. Perform this procedure at the lowest and highest velocity settings at which the probes will be calibrated. Record the values on a form similar to Table 2G–4.

At each velocity setting, the average velocity pressure obtained at the wind tunnel calibration location shall be within ±2 percent or 2.5 mm H_2O (0.01 in. H_2O), whichever is less restrictive, of the average velocity pressure obtained at the fixed calibration pitot tube location. This comparative check shall be performed at 2.5-cm (1-in.), or smaller, intervals across the full length, width, and depth (if applicable) of the wind tunnel calibration location. If the criteria are not met at every tested point, the wind tunnel calibration location must be redefined, so that acceptable results are obtained at every point. Include the results of the velocity pressure cross-check in the calibration data section of the field test report. (See section 16.1.4.)

10.1.2 Axial flow verification. The following procedures shall be performed to demonstrate that there is fully developed axial flow within the wind tunnel calibration location and at the calibration pitot tube location. Two options are available to conduct this check.

10.1.2.1 Using a calibrated 3–D probe. A probe that has been previously calibrated in a wind tunnel with documented axial flow (as defined in section 3.22) may be used to conduct this check. Insert the calibrated 3–D probe into the wind tunnel test section using the tested probe port. Following the procedures in sections 8.9 and 12.2 of Method 2F, determine the yaw and pitch angles at all the point(s) in the test section where the velocity pressure cross-check, as specified in section 10.1.1, is performed. This includes all the points in the calibration location and the point where the calibration pitot tube will be located. Determine the yaw and pitch angles at each point. Repeat these measurements at the highest and lowest velocities at which the probes will be calibrated. Record the values on a form similar to Table 2G–5. Each measured yaw and pitch angle shall be within ±3° of 0°. Exceeding the limits indicates unacceptable flow in the test section. Until the problem is corrected and acceptable flow is verified by repetition of this procedure, the wind tunnel shall not be used for calibration of probes. Include the results of the axial flow verification in the calibration data section of the field test report. (See section 16.1.4.)

10.1.2.2 Using alternative probes. Axial flow verification may be performed using an uncalibrated prism-shaped 3–D probe (e.g., DA or DAT probe) or an uncalibrated wedge probe. (Figure 2G–8 illustrates a typical wedge probe.) This approach requires use of two ports: the tested probe port and a second port located 90° from the tested probe port. Each port shall provide access to all the points within the wind tunnel test section where the velocity pressure cross-check, as specified in section 10.1.1, is conducted. The probe setup shall include establishing a reference yaw-null position on the probe sheath to serve as the location for installing the angle-measuring device. Physical design features of the DA, DAT, and wedge probes are relied on to determine the reference position. For the DA or DAT probe, this reference position can be determined by setting a digital inclinometer on the flat facet where the P_1 pressure port is located and then identifying the rotational position on the probe sheath where a second angle-measuring device would give the same angle reading. The reference position on a wedge probe shaft can be determined either geometrically or by placing a digital inclinometer on each side of the wedge and rotating the probe until equivalent readings are obtained. With the latter approach, the reference position is the rotational position on the probe sheath where an angle-measuring device would give a reading of 0°. After installation of the angle-measuring device in the reference yaw-null position on the probe sheath, determine the yaw angle from the tested port. Repeat this measurement using the 90° offset port, which provides the pitch angle of flow. Determine the yaw and pitch angles at all the point(s) in the test section where the velocity pressure cross-check, as specified in section 10.1.1, is performed. This includes all the points in the wind tunnel calibration location and the point where the calibration pitot tube will be located. Perform this check at the highest and lowest velocities at which the probes will be calibrated. Record the values on a form similar to Table 2G–5. Each measured yaw and pitch angle shall be within ±3° of 0°. Exceeding the limits indicates unacceptable flow in the test section. Until the problem is corrected and acceptable flow is verified by repetition of this procedure, the wind tunnel shall not be used for calibration of probes. Include the results in the probe calibration report.

10.1.3 Wind tunnel audits.

10.1.3.1 Procedure. Upon the request of the Administrator, the owner or operator of a wind tunnel shall calibrate a 2-D audit probe in accordance with the procedures described in sections 10.3 through 10.6. The calibration shall be performed at two velocities that encompass the velocities typically used for this method at the facility. The resulting calibration data shall be submitted to the Agency in an audit test report. These results shall be compared by the Agency to reference calibrations of the audit probe at the same velocity settings obtained at two different wind tunnels.

10.1.3.2 Acceptance criterion. The audited tunnel's calibration coefficient is acceptable if it is within ±3 percent of the reference calibrations obtained at each velocity setting by one (or both) of the wind tunnels. If the acceptance criterion is not met at each calibration velocity setting, the audited wind tunnel shall not be used to calibrate probes for use under this method until the problems are resolved and acceptable results are obtained upon completion of a subsequent audit.

10.2 Probe Inspection.

10.2.1 Type S probe. Before each calibration of a Type S probe, verify that one leg of the tube is permanently marked A, and the other, B. Carefully examine the pitot tube from the top, side, and ends. Measure the angles (α_1, α_2, β_1, and β_2) and the dimensions (w and z) illustrated in Figures 2–2 and 2–3 in Method 2. Also measure the dimension A, as shown in the diagram in Table 2G–1, and the external tubing diameter (dimension D_t, Figure 2–2b in Method 2). For the purposes of this method, D_t shall be no less than 9.5 mm (3⁄8 in.). The base-to-opening plane distances P_A and P_B in Figure 2–3 of Method 2 shall be equal, and the dimension A in Table 2G–1 should be between $2.10D_t$ and $3.00D_t$. Record the inspection findings and probe measurements on a form similar to Table CD2–1 of the "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III, Stationary Source-Specific Methods' (EPA/600/R–94/038c, September 1994). For reference, this form is reproduced herein as Table 2G–1. The pitot tube shall not be used under this method if it fails to meet the specifications in this section and the alignment specifications in section 6.1.1. All Type S probes used to collect data with this method shall be calibrated according to the procedures outlined in sections 10.3 through 10.6 below. During calibration, each Type S pitot tube shall be configured in the same manner as used, or planned to be used, during the field test, including all components in the probe assembly (e.g., thermocouple, probe sheath, sampling nozzle). Probe shaft extensions that do not affect flow around the probe head need not be attached during calibration.

10.2.2 3-D probe. If a 3-D probe is used to collect data with this method, perform the pre-calibration inspection according to procedures in Method 2F, section 10.2.

10.3 Pre-Calibration Procedures. Prior to calibration, a scribe line shall have been placed on the probe in accordance with section 10.4. The yaw angle and velocity calibration procedures shall not begin until the pretest requirements in sections 10.3.1 through 10.3.4 have been met.

10.3.1 Perform the horizontal straightness check described in section 8.2 on the probe assembly that will be calibrated in the wind tunnel.

10.3.2 Perform a leak check in accordance with section 8.4.

10.3.3 Except as noted in section 10.3.3.3, calibrate all differential pressure-measuring devices to be used in the probe calibrations, using the following procedures. At a minimum, calibrate these devices on each day that probe calibrations are performed.

10.3.3.1 Procedure. Before each wind tunnel use, all differential pressure-measuring devices shall be calibrated against the reference device specified in section 6.4.3 using a common pressure source. Perform the calibration at three reference pressures representing 30, 60, and 90 percent of the full-scale range of the pressure-measuring device being calibrated. For an inclined-vertical manometer, perform separate calibrations on the inclined and vertical portions of the measurement scale, considering each portion of the scale to be a separate full-scale range. [For example, for a manometer with a 0-to 2.5-cm H_2O (0-to 1-in. H_2O) inclined scale and a 2.5-to 12.7-cm H_2O (1-to 5-in. H_2O) vertical scale, calibrate the inclined portion at 7.6, 15.2, and 22.9 mm H_2O (0.3, 0.6, and 0.9 in. H_2O), and calibrate the vertical portion at 3.8, 7.6, and 11.4 cm H_2O (1.5, 3.0, and 4.5 in. H_2O).] Alternatively, for the vertical portion of the scale, use three evenly spaced reference pressures, one of which is equal to or higher than the highest differential pressure expected in field applications.

10.3.3.2 Acceptance criteria. At each pressure setting, the two pressure readings made using the reference device and the pressure-measuring device being calibrated shall agree to within ±2 percent of full scale of the device being calibrated or 0.5 mm H_2O (0.02 in. H_2O), whichever is less restrictive. For an inclined-vertical manometer, these requirements shall be met separately using the respective full-scale upper limits of the inclined and vertical portions of the scale. Differential pressure-measuring devices not meeting the ±2 percent of full scale or 0.5 mm H_2O (0.02 in. H_2O) calibration requirement shall not be used.

10.3.3.3 Exceptions. Any precision manometer that meets the specifications for a reference device in section 6.4.3 and that is not used for field testing does not require calibration, but must be leveled and zeroed before each wind tunnel use. Any pressure device used exclusively for yaw nulling does not require calibration, but shall be checked for responsiveness to rotation of the probe prior to each wind tunnel use.

10.3.4 Calibrate digital inclinometers on each day of wind tunnel or field testing (prior to beginning testing) using the following procedures. Calibrate the inclinometer according to the manufacturer's calibration procedures. In addition, use a triangular block (illustrated in Figure 2G–9) with a known angle θ, independently determined using a protractor or equivalent device, between two adjacent sides to verify the inclinometer readings. (NOTE: If other angle-measuring devices meeting the provisions of section 6.2.3 are used in place of a digital inclinometer, comparable calibration procedures shall be performed on such devices.) Secure the triangular block in a fixed position. Place the inclinometer on one side of the block (side A) to measure the angle of inclination (R_1). Repeat this measurement on the adjacent side of the block (side B) using the inclinometer to obtain a second angle reading (R_2). The difference of the sum of the two readings from 180° (i.e., 180°-R_1-R_2) shall be within ±2° of the known angle, θ.

10.4 Placement of Reference Scribe Line. Prior to the first calibration of a probe, a line shall be permanently inscribed on the main probe sheath to serve as a reference mark for determining yaw angles. Annex C in section 18 of this method gives a guideline for placement of the reference scribe line.

10.4.1 This reference scribe line shall meet the specifications in sections 6.1.5.1 and 6.1.5.3 of this method. To verify that the alignment specification in section 6.1.5.3 is met, secure the probe in a horizontal position and measure the rotational angle of each scribe line and scribe line segment using an angle-measuring device that meets the specifications in section 6.2.1 or 6.2.3. For any scribe line that is longer than 30.5 cm (12 in.), check the line's rotational position at 30.5-cm (12-in.) intervals. For each line segment that is 12 in. or less in length, check the rotational position at the two endpoints of the segment. To meet the alignment specification in section 6.1.5.3, the minimum and maximum of all of the rotational angles that are measured along the full length of main probe must not differ by more than 2°. (NOTE: A short reference scribe line segment [e.g., 15.2 cm (6 in.) or less in length] meeting the alignment specifications in section 6.1.5.3 is fully acceptable under this method. See section 18.1.1.1 of Annex A for an example of a probe marking procedure, suitable for use with a short reference scribe line.)

10.4.2 The scribe line should be placed on the probe first and then its offset from the yaw-null position established (as specified in section 10.5). The rotational position of the reference scribe line relative to the yaw-null position of the probe, as determined by the yaw angle calibration procedure in section 10.5, is the reference scribe line rotational offset, R_{SLO}. The reference scribe line rotational offset shall be recorded and retained as part of the probe's calibration record.

10.4.3 Scribe line for automated probes. A scribe line may not be necessary for an automated probe system if a reference rotational position of the probe is built into the probe system design. For such systems, a ''flat'' (or comparable, clearly identifiable physical characteristic) should be provided on the probe casing or flange plate to ensure that the reference position of the probe assembly remains in a vertical or horizontal position. The rotational offset of the flat (or comparable, clearly identifiable physical characteristic) needed to orient the reference position of the probe assembly shall be recorded and maintained as part of the automated probe system's specifications.

10.5 Yaw Angle Calibration Procedure. For each probe used to measure yaw angles with this method, a calibration procedure shall be performed in a wind tunnel meeting the specifications in section 10.1 to determine the rotational position of the reference scribe line relative to the probe's yaw-null position. This procedure shall be performed on the main probe with all devices that will be attached to the main probe in the field [such as thermocouples, resistance temperature detectors (RTDs), or sampling nozzles] that may affect the flow around the probe head. Probe shaft extensions that do not affect flow around the probe head need not be attached during calibration. At a minimum, this procedure shall include the following steps.

10.5.1 Align and lock the angle-measuring device on the reference scribe line. If a marking procedure (such as described in section 18.1.1.1) is used, align the angle-measuring device on a mark within ±1° of the rotational position of the reference scribe line. Lock the angle-measuring device onto the probe sheath at this position.

10.5.2 Zero the pressure-measuring device used for yaw nulling.

10.5.3 Insert the probe assembly into the wind tunnel through the entry port, positioning the probe's impact port at the calibration location. Check the responsiveness of the pressure-measurement device to probe rotation, taking corrective action if the response is unacceptable.

10.5.4 Ensure that the probe is in a horizontal position, using a carpenter's level.

10.5.5 Rotate the probe either clockwise or counterclockwise until a yaw null [zero ΔP for a Type S probe or zero (P_2-P_3) for a 3–D probe] is obtained. If using a Type S probe with an attached thermocouple, the direction of the probe rotation shall be such that the thermocouple is located downstream of the probe pressure ports at the yaw-null position.

10.5.6 Use the reading displayed by the angle-measuring device at the yaw-null position to determine the magnitude of the reference scribe line rotational offset, R_{SLO}, as defined in section 3.15. Annex D in section 18 of this method gives a recommended procedure for determining the magnitude of R_{SLO} with a digital inclinometer and a second procedure for determining the magnitude of R_{SLO} with a protractor wheel and pointer device. Table 2G–6 gives an example data form and Table 2G–7 is a look-up table with the recommended procedure. Procedures other than those recommended in Annex D in section 18 may be used, if they can determine R_{SLO} to within 1° and are explained in detail in the field test report. The algebraic sign of R_{SLO} will either be positive if the rotational position of the reference scribe line (as viewed from the ''tail'' end of the probe) is clockwise, or negative, if counterclockwise with respect to the probe's yaw-null position. (This is illustrated in Figure 2G–10.)

10.5.7 The steps in sections 10.5.3 through 10.5.6 shall be performed twice at each of the velocities at which the probe will be calibrated (in accordance with section 10.6). Record the values of R_{SLO}.

10.5.8 The average of all of the R_{SLO} values shall be documented as the reference scribe line rotational offset for the probe.

10.5.9 Use of reference scribe line offset. The reference scribe line rotational offset shall be used to determine the yaw angle of flow in accordance with section 8.9.4.

10.6 Velocity Calibration Procedure. When a 3–D probe is used under this method, follow the provisions for the calibration of 3–D probes in section 10.6 of Method 2F to obtain the necessary velocity calibration coefficients (F_2 as derived using Equation 2F–2 in Method 2F) corresponding to a pitch angle position of 0°. The following procedure applies to Type S probes. This procedure shall be performed on the main probe and all devices that will be attached to the main probe in the field (e.g., thermocouples, RTDs, sampling nozzles) that may affect the flow around the probe head. Probe shaft extensions that do not affect flow around the probe head need not be attached during calibration. (Note: If a sampling nozzle is part of the assembly, two additional requirements must be satisfied before proceeding. The distance between the nozzle and the pitot tube shall meet the minimum spacing requirement prescribed in Method 2, and a wind tunnel demonstration shall be performed that shows the probe's ability to yaw null is not impaired when the nozzle is drawing sample.) To obtain velocity calibration coefficient(s) for the tested probe, proceed as follows.

10.6.1 Calibration velocities. The tester may calibrate the probe at two nominal wind tunnel velocity settings of 18.3 m/sec and 27.4 m/sec (60 ft/sec and 90 ft/sec) and average the results of these calibrations, as described in sections 10.6.12 through 10.6.14, in order to generate the calibration coefficient, C_p. If this option is selected, this calibration coefficient may be used for all field applications where the velocities are 9.1 m/sec (30 ft/sec) or greater. Alternatively, the tester may customize the probe calibration for a particular field test application (or for a series of applications), based on the expected average velocity(ies) at the test site(s). If this option is selected, generate the calibration coefficients by calibrating the probe at two nominal wind tunnel velocity settings, one of which is less than or equal to and the other greater than or equal to the expected average velocity(ies) for the field application(s), and average the results as described in sections 10.6.12 through 10.6.14. Whichever calibration option is selected, the probe calibration coefficient(s) obtained at the two nominal calibration velocities shall meet the conditions specified in sections 10.6.12 through 10.6.14.

10.6.2 Connect the tested probe and calibration pitot tube to their respective pressure-measuring devices. Zero the pressure-measuring devices. Inspect and leak-check all pitot lines; repair or replace them, if necessary. Turn on the fan, and allow the wind tunnel air flow to stabilize at the first of the selected nominal velocity settings.

10.6.3 Position the calibration pitot tube at its measurement location (determined as outlined in section 6.11.4.3), and align the tube so that its tip is pointed directly into the flow. Ensure that the entry port surrounding the tube is properly sealed. The calibration pitot tube may either remain in the wind tunnel throughout the calibration, or be removed from the wind tunnel while measurements are taken with the probe being calibrated.

10.6.4 Check the zero setting of each pressure-measuring device.

10.6.5 Insert the tested probe into the wind tunnel and align it so that the designated pressure port (e.g., either the A-side or B-side of a Type S probe) is pointed directly into the flow and is positioned within the wind tunnel calibration location (as defined in section 3.21). Secure the probe at the 0° pitch angle position. Ensure that the entry port surrounding the probe is properly sealed.

10.6.6 Read the differential pressure from the calibration pitot tube (ΔP_{std}), and record its value. Read the barometric pressure to within ±2.5 mm Hg (±0.1 in. Hg) and the temperature in the wind tunnel to within 0.6°C (1°F). Record these values on a data form similar to Table 2G–8.

10.6.7 After the tested probe's differential pressure gauges have had sufficient time to stabilize, yaw null the probe (and then rotate it back 90° for Type S probes), then obtain the differential pressure reading (ΔP). Record the yaw angle and differential pressure readings.

10.6.8 Take paired differential pressure measurements with the calibration pitot tube and tested probe (according to sections 10.6.6 and 10.6.7). The paired measurements in each replicate can be made either simultaneously (i.e., with both probes in the wind tunnel) or by alternating the measurements of the two probes (i.e., with only one probe at a time in the wind tunnel).

10.6.9 Repeat the steps in sections 10.6.6 through 10.6.8 at the same nominal velocity setting until three pairs of ΔP readings have been obtained from the calibration pitot tube and the tested probe.

10.6.10 Repeat the steps in sections 10.6.6 through 10.6.9 above for the A-side and B-side of the Type S pitot tube. 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 that will face the flow). However, the pitot tube must still meet the alignment and dimension specifications in section 6.1.1 and must have an average deviation (σ) value of 0.01 or less as provided in section 10.6.12.4.

10.6.11 Repeat the calibration procedures in sections 10.6.6 through 10.6.10 at the second selected nominal wind tunnel velocity setting.

10.6.12 Perform the following calculations separately on the A-side and B-side values.

10.6.12.1 Calculate a C_p value for each of the three replicates performed at the lower velocity setting where the calibrations were performed using Equation 2–2 in section 4.1.4 of Method 2.

10.6.12.2 Calculate the arithmetic average, $C_{p(avg\text{-}low)}$, of the three C_p values.

10.6.12.3 Calculate the deviation of each of the three individual values of C_p from the A-side average $C_{p(avg\text{-}low)}$ value using Equation 2–3 in Method 2.

10.6.12.4 Calculate the average deviation (σ) of the three individual C_p values from $C_{p(avg\text{-}low)}$ using Equation 2–4 in Method 2. Use the Type S pitot tube only if the values of σ (side A) and σ (side B) are less than or equal to 0.01. If both A-side and B-side calibration coefficients are calculated, the absolute value of the difference between $C_{p(avg\text{-}low)}$ (side A) and $C_{p(avg\text{-}low)}$ (side B) must not exceed 0.01.

10.6.13 Repeat the calculations in section 10.6.12 using the data obtained at the higher velocity setting to derive the arithmetic C_p values at the higher velocity setting, $C_{p(avg\text{-}high)}$, and to determine whether the conditions in 10.6.12.4 are met by both the A-side and B-side calibrations at this velocity setting.

10.6.14 Use equation 2G–1 to calculate the percent difference of the averaged C_p values at the two calibration velocities.

$$\%\text{Difference} = \frac{C_{p(\text{avg-low})} - C_{p(\text{avg-high})}}{C_{p(\text{avg-low})}} \times 100\% \qquad \text{Eq. 2G-1}$$

The percent difference between the averaged C_p values shall not exceed ±3 percent. If the specification is met, average the A-side values of $C_{p(avg\text{-}low)}$ and $C_{p(avg\text{-}high)}$ to produce a single A-side calibration coefficient, C_p. Repeat for the B-side values if calibrations were performed on that side of the pitot. If the specification is not met, make necessary adjustments in the selected velocity settings and repeat the calibration procedure until acceptable results are obtained.

10.6.15 If the two nominal velocities used in the calibration were 18.3 and 27.4 m/sec (60 and 90 ft/sec), the average C_p from section 10.6.14 is applicable to all velocities 9.1 m/sec (30 ft/sec) or greater. If two other nominal velocities were used in the calibration, the resulting average C_p value shall be applicable only in situations where the velocity calculated using the calibration coefficient is neither less than the lower nominal velocity nor greater than the higher nominal velocity.

10.7 Recalibration. Recalibrate the probe using the procedures in section 10 either within 12 months of its first field use after its most recent calibration or after 10 field tests (as defined in section 3.3), whichever occurs later. In addition, whenever there is visible damage to the probe head, the probe shall be recalibrated before it is used again.

10.8 Calibration of pressure-measuring devices used in the field. Before its initial use in a field test, calibrate each pressure-measuring device (except those used exclusively for yaw nulling) using the three-point calibration procedure described in section 10.3.3. The device shall be recalibrated according to the procedure in section 10.3.3 no later than 90 days after its first field use following its most recent calibration. At the discretion of the tester, more frequent calibrations (e.g., after a field test) may be performed. No adjustments, other than adjustments to the zero setting, shall be made to the device between calibrations.

10.8.1 Post-test calibration check. A single-point calibration check shall be performed on each pressure-measuring device after completion of each field test. At the discretion of the tester, more frequent single-point calibration checks (e.g., after one or more field test runs) may be performed. It is recommended that the post-test check be performed before leaving the field test site. The check shall be performed at a pressure between 50 and 90 percent of full scale by taking a common pressure reading with the tested probe and a reference pressure-measuring device (as described in section 6.4.4) or by challenging the tested device with a reference pressure source (as described in section 6.4.4) or by performing an equivalent check using a reference device approved by the Administrator.

10.8.2 Acceptance criterion. At the selected pressure setting, the pressure readings made using the reference device and the tested device shall agree to within ±3 percent of full scale of the tested device or 0.8 mm H_2O

(0.03 in. H_2O), whichever is less restrictive. If this specification is met, the test data collected during the field test are valid. If the specification is not met, all test data collected since the last successful calibration or calibration check are invalid and shall be repeated using a pressure-measuring device with a current, valid calibration. Any device that fails the calibration check shall not be used in a field test until a successful recalibration is performed according to the procedures in section 10.3.3.

10.9 Temperature Gauges. Same as Method 2, section 4.3. The alternative thermocouple calibration procedures outlined in Emission Measurement Center (EMC) Approved Alternative Method (ALT–011) ''Alternative Method 2 Thermocouple Calibration Procedure'' may be performed. Temperature gauges shall be calibrated no more than 30 days prior to the start of a field test or series of field tests and recalibrated no more than 30 days after completion of a field test or series of field tests.

10.10 Barometer. Same as Method 2, section 4.4. The barometer shall be calibrated no more than 30 days prior to the start of a field test or series of field tests.

11.0 Analytical Procedure

Sample collection and analysis are concurrent for this method (see section 8.0).

12.0 Data Analysis and Calculations

These calculations use the measured yaw angle and the differential pressure and temperature measurements at individual traverse points to derive the near-axial flue gas velocity ($v_{a(i)}$) at each of those points. The near-axial velocity values at all traverse points that comprise a full stack or duct traverse are then averaged to obtain the average near-axial stack or duct gas velocity ($v_{a(avg)}$).

12.1 Nomenclature

A = Cross-sectional area of stack or duct at the test port location, m^2 (ft^2).

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

C_p = Pitot tube calibration coefficient, dimensionless.

$F_{2(i)}$ = 3-D probe velocity coefficient at 0 pitch, applicable at traverse point i.

K_p = Pitot tube constant,

$$34.97 \frac{\text{m}}{\text{sec}} \left[\frac{(\text{g/g-mole})(\text{mm Hg})}{(^\circ\text{K})(\text{mm H}_2\text{O})} \right]^{1/2}$$

for the metric system, and

$$85.49 \frac{\text{ft}}{\text{sec}} \left[\frac{(\text{lb/lb-mole})(\text{in. Hg})}{(^\circ\text{R})(\text{in. H}_2\text{O})} \right]^{1/2}$$

for the English system.

M_d = Molecular weight of stack or duct gas, dry basis (see section 8.13), g/g-mole (lb/lb-mole).

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

$$M_s = M_d(1 - B_{ws}) + 18.0 B_{ws} \quad \text{Eq. 2G-2}$$

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

P_g = Stack or duct static pressure, mm H_2O (in. H_2O).

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

$$P_s = P_{bar} + \frac{P_g}{13.6} \quad \text{Eq. 2G-3}$$

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

13.6 = Conversion from mm H_2O (in. H_2O) to mm Hg (in. Hg).

Q_{sd} = Average dry-basis volumetric stack or duct gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).

Q_{sw} = Average wet-basis volumetric stack or duct gas flow rate corrected to standard conditions, wscm/hr (wscf/hr).

$t_{s(i)}$ = Stack or duct temperature, °C (°F), at traverse point i.

$T_{s(i)}$ = Absolute stack or duct temperature, °K (°R), at traverse point i.

$$T_{s(i)} = 273 + t_{s(i)} \quad \text{Eq. 2G-4}$$

for the metric system, and

$$T_{s(i)} = 460 + t_{s(i)} \quad \text{Eq. 2G-5}$$

for the English system.

$T_{s(avg)}$=Average absolute stack or duct gas temperature across all traverse points.

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

$v_{a(i)}$=Measured stack or duct gas impact velocity, m/sec (ft/sec), at traverse point i.

$v_{a(avg)}$=Average near-axial stack or duct gas velocity, m/sec (ft/sec) across all traverse points.

ΔP_i=Velocity head (differential pressure) of stack or duct gas, mm H_2O (in. H_2O), applicable at traverse point i.

$(P_1\text{-}P_2)$=Velocity head (differential pressure) of stack or duct gas measured by a 3-D probe, mm H_2O (in. H_2O), applicable at traverse point i.

3,600=Conversion factor, sec/hr.

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

$\theta_{y(i)}$=Yaw angle of the flow velocity vector, at traverse point i.

n=Number of traverse points.

12.2 Traverse Point Velocity Calculations. Perform the following calculations from the measurements obtained at each traverse point.

12.2.1 Selection of calibration coefficient. Select the calibration coefficient as described in section 10.6.1.

12.2.2 Near-axial traverse point velocity. When using a Type S probe, use the following equation to calculate the traverse point near-axial velocity ($v_{a(i)}$) from the differential pressure (ΔP_i), yaw angle ($\theta_{y(i)}$), absolute stack or duct standard temperature ($T_{s(i)}$) measured at traverse point i, the absolute stack or duct pressure (P_s), and molecular weight (M_s).

$$v_{a(i)} = K_p C_p \sqrt{\frac{(\Delta P)_i T_{s(i)}}{P_s M_s}} \left(\cos\theta_{y(i)}\right) \qquad \text{Eq. 2G-6}$$

Use the following equation when using a 3–D probe.

$$v_{a(i)} = K_p F_2 \sqrt{\frac{(P_1 - P_2)_i T_{s(i)}}{P_s M_s}} \left(\cos\theta_{y(i)}\right) \qquad \text{Eq. 2G-7}$$

12.2.3 Handling multiple measurements at a traverse point. For pressure or temperature devices that take multiple measurements at a traverse point, the multiple measurements (or where applicable, their square roots) may first be averaged and the resulting average values used in the equations above. Alternatively, the individual measurements may be used in the equations above and the resulting calculated values may then be averaged to obtain a single traverse point value. With either approach, all of the individual measurements recorded at a traverse point must be used in calculating the applicable traverse point value.

12.3 Average Near-Axial Velocity in Stack or Duct. Use the reported traverse point near-axial velocity in the following equation.

$$v_{a(avg)} = \frac{\sum_{i=1}^{n} v_{a(i)}}{n} \qquad \text{Eq. 2G-8}$$

12.4 Acceptability of Results. The acceptability provisions in section 12.4 of Method 2F apply to 3-D probes used under Method 2G. The following provisions apply to Type S probes. For Type S probes, the test results are acceptable and the calculated value of $v_{a(avg)}$ may be reported as the average near-axial velocity for the test run if the conditions in either section 12.4.1 or 12.4.2 are met.

12.4.1 The average calibration coefficient C_p used in Equation 2G–6 was generated at nominal velocities of 18.3 and 27.4 m/sec (60 and 90 ft/sec) and the value of $v_{a(avg)}$ calculated using Equation 2G–8 is greater than or equal to 9.1 m/sec (30 ft/sec).

12.4.2 The average calibration coefficient C_p used in Equation 2G–6 was generated at nominal velocities other than 18.3 or 27.4 m/sec (60 or 90 ft/sec) and the value of $v_{a(avg)}$ calculated using Equation 2G–8 is greater than or equal to the lower nominal velocity and less than or equal to the higher nominal velocity used to derive the average C_p.

12.4.3 If the conditions in neither section 12.4.1 nor section 12.4.2 are met, the test results obtained from Equation 2G–8 are not acceptable, and the steps in sections 12.2 and 12.3 must be repeated using an average calibration coefficient C_p that satisfies the conditions in section 12.4.1 or 12.4.2.

12.5 Average Gas Volumetric Flow Rate in Stack or Duct (Wet Basis). Use the following equation to compute the average volumetric flow rate on a wet basis.