

**3-D Flow Measurement System  
SK-3D52  
Operator's Manual**



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*Every reasonable effort has been made to provide reliable information, but Apex Instruments, Inc. cannot assume responsibility for the validity of all materials or for the consequences of their use.*

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## I. INTRODUCTION

In 1971, EPA promulgated Method 2 “Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)”. At the time of its development, Method 2 was principally used with EPA Method 5 “Determination of Particulate Emissions from Stationary Sources” to help ensure appropriate sampling rates throughout a particulate sampling run. Many EPA air quality regulations use Method 2, including part 75 of EPA’s Acid Rain Program regulations, that requires affected electric utility units to install and operate continuous emission monitoring systems that provide EPA with continuous hourly measurements of sulfur dioxide (SO<sub>2</sub>) concentration, NO<sub>x</sub> concentration, carbon dioxide concentration, and volumetric flow rate of flue gas in a stack or duct.

Under the Acid Rain Program, volumetric flow rate and SO<sub>2</sub> concentration are used to calculate sulfur dioxide mass emissions at each affected unit. Volumetric flow rate is also used to calculate a unit’s heat input. In order to ensure the accuracy of compliance determinations, part 75 requires owners and operators of a unit to conduct periodic performance testing of volumetric flow rate monitors by comparing flow rate data from the monitors with data reported using EPA’s Method 2. Similarly, subpart H of part 75 uses Method 2 as the reference method for flow rate measurements used to calculate NO<sub>x</sub> mass emissions. The electric utility industry raised concerns that under some flow conditions EPA’s approved test method for volumetric flow rate (Method 2) could be less than optimal for measuring flow rate and thus for determining sulfur dioxide emissions and heat input.

These concerns focused on situations where flue gas flowed at an angle (i.e., with yaw or pitch), not straight out of a stack or duct. Method 2 does not include procedures for measuring the yaw or pitch angles of flow or wall effects in calculating stack or duct gas velocity or volumetric flow rate. Volumetric flow rate is calculated by multiplying the average flue gas velocity by the stack or duct cross-sectional area. Yaw and pitch characterize the extent to which flue gas is not flowing straight out of a stack or duct. From the standpoint of a tester facing a vertical stack, a yaw angle is represented by flow movement to the left or right of the stack centerline. The pitch angle is represented by flow movement toward or away from the tester. The term “wall effects” refers to the drop-off of flue gas velocity near the inside wall of a stack or duct. This velocity drop-off is caused by friction from the stack wall.

Some amount of yaw and pitch angle and wall effects are almost always present in utility stacks or ducts. Yaw and pitch angles produce flue gas flow that swirls and/or bounces off stack or duct walls (total velocity). Only the straight-up (axial velocity) component of total velocity actually exits the stack. Moreover, determining axial velocity without accounting for the drop-off near the stack or duct wall can result in overstating the actual axial velocity. Thus, when enough yaw, pitch or wall effects are present, Method 2 can overstate the measured flue gas velocities (and thus volumetric flow) because it only allows the total velocity to be measured and does not account for yaw angles, pitch angles, or wall effects.

During the late 1990’s, the US EPA developed three new methods to account for these different variables in flow measurement. US EPA Method 2G allows Type S probes and 3-D probes (DAT and spherical) to be rotated into the flow to measure total velocity pressure and yaw angle. The yaw angle is used to calculate “near-axial” velocity from total velocity. Method 2F allows 3-D probes to be used to measure total velocity, yaw angles, and pitch angle pressure. Pitch angle pressure is used with a calibration curve to determine pitch angle. Yaw and pitch angles are used to calculate axial velocity from total velocity. Method 2H provides a procedure for accounting for wall effects by using either a default wall effects adjustment factor or one derived from near wall measurements. The wall effects adjustment factor is used with the Method 2-, 2G- or 2F-calculated velocity to derive a wall effects adjusted velocity.

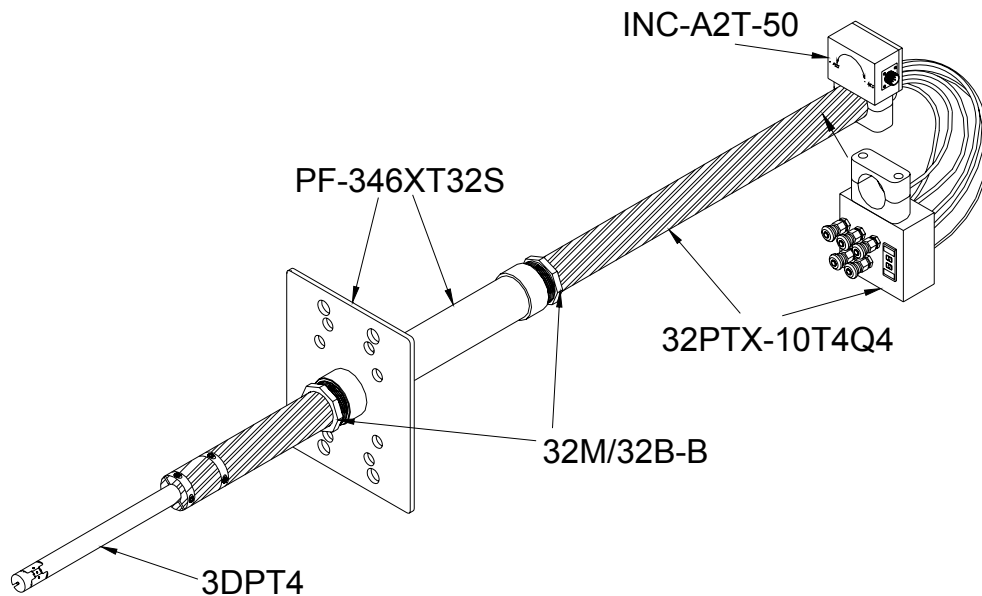
## II. SYSTEM DESCRIPTION

### Unpacking and Equipment Check

The system is carefully packaged to reduce the possibility of damage in transit. Unpack the contents carefully, saving all the packaging material until the parts have been examined for shipping damage. Check each item against the packing list below. If any item is damaged or missing, notify your supplier or Apex Instruments immediately.

**Table 1 List of Parts, SK-3D52**

Quantity	Part Number	Description
1	MC-3D52	3-D Flow Measurement Console
1	3DPT4	3-D Pitot Tube, 5-Hole Prism Shaped, 4ft
1	32PTX-10T4Q4	3-D Pitot Extension, 2in Dia Sheath, 1/4in TFE Lines, 10ft
1	PF-346XT32S	Universal Probe Extension, Flange Fits 3, 4 & 6in Ports
2	32M/32B-B	2in Bored Brass Bushing, 2in MNPT with 2.035in Bore
1	INC-A2T-50	Inclinometer Sensor, 360° ( $\pm 180^\circ$ ) with Housing
1	U-3D-60-QS4	3-D Umbilical Cord, 60ft, Stainless Steel Quick Connects
1	PT-CAL-3D	3-D Wind Tunnel Calibration with Data



**Figure 1 3-D Probe Assembly**

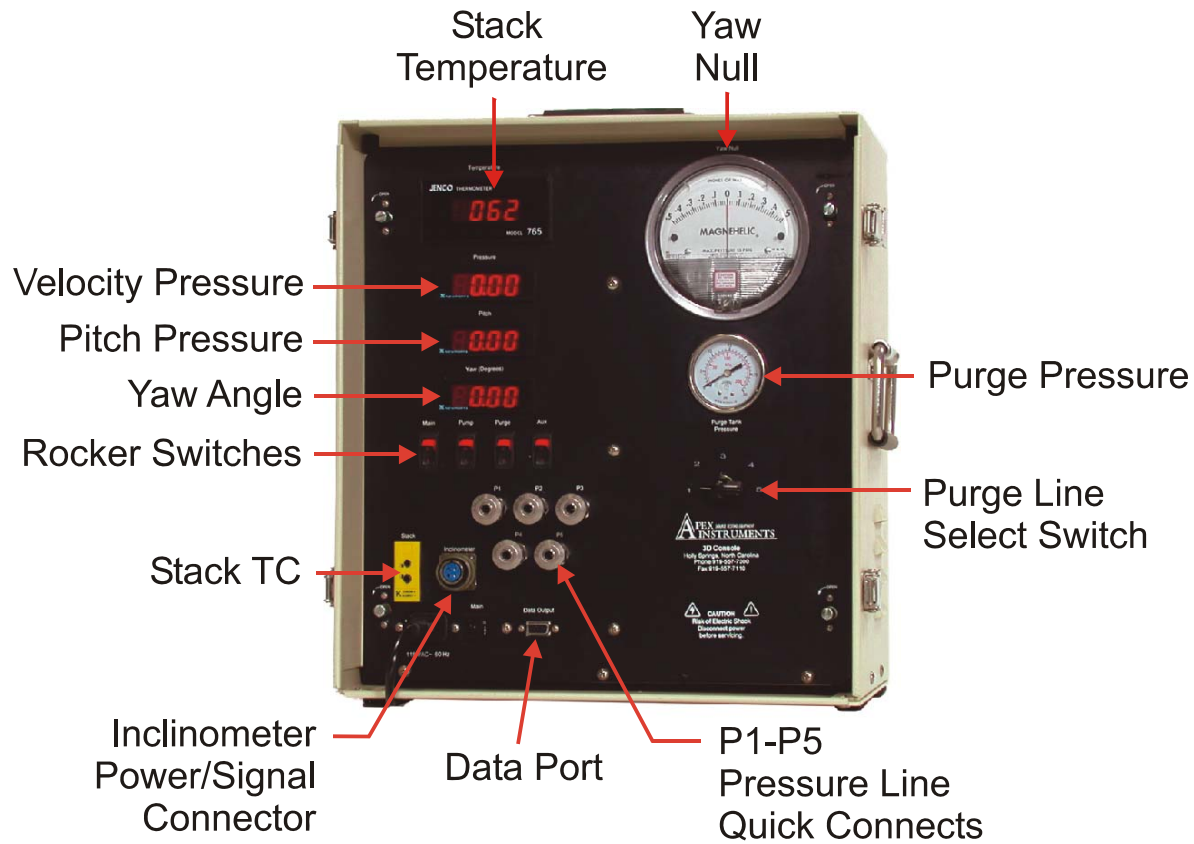


Figure 2 Labeled 3-D Console (MC-3D52)

Table 2 3-D Console (MC-3D52) Specifications

Item	Range/Description	Output
Stack Temperature	-157°F-1999°F (-105°C-1372°C) Type K Thermocouple	1mVDC/degree
Velocity Pressure (P1-P2)	± 6" H <sub>2</sub> O (± 152mm H <sub>2</sub> O)	5 ± 5VDC
Yaw Null Pressure (P2-P3)	± 0.5" H <sub>2</sub> O (± 12.7mm H <sub>2</sub> O)	N/A
Yaw Angle Range	± 180° (1° resolution)	1.8 ± 1.8VDC
Pitch Pressure (P4-P5)	±2" H <sub>2</sub> O (± 50.8mm H <sub>2</sub> O)	5 ± 5VDC
Output Connector	9-Pin Female Sub-D connector	Direct Current Voltage (VDC)
Weight	32 lb (15 kg)	
Dimensions	14.5 x 16 x 10.5 inches	
Power	120VAC/60Hz standard (220VAC/50Hz optional)	

## Electrical System

The 3-D Flow Measurement console is factory-configured for 120VAC/60Hz electrical power. Configuration for 240VAC/50Hz operation is an available option. The Electrical Schematic for the console is presented in Figure 3.

The circuits are protected by a circuit breaker mounted on the front panel for easy access. This circuit breaker detects and interrupts overload and short circuit conditions, providing an important safety factor. If the circuit breaker opens, or “trips,” indicating interruption of the circuit, investigate and repair the electrical fault. Then, reset the breaker by pressing the circuit breaker switch.

A switching power supply energizes when the main power switch is activated. This power supply energizes the pressure and pitch differential pressure transducers and the inclinometer (yaw measurement device). A 4-pin amphenol-style circular connector is used to provide power to and signal from the remote inclinometer sensor.

Rocker switches are panel-mounted to activate the Main Power, Pump and Purge. A dummy Aux switch is added in the case of an additional accessory is needed. The Purge Switch activates the multi-channel rotational selector switch that actuates individual solenoids on a manifold. The function of the Purge System is discussed in the Plumbing Section that follows.

The thermocouple wiring consists of one Type K thermocouple with a standard size, female, panel-mounted receptacle. This thermocouple is used to measure the stack temperature.

Output signals are included for the Stack Thermocouple, Velocity Pressure, Yaw Null Pressure, Yaw Angle and Pitch Pressure. All signals are direct current voltage based. The specific outputs are listed on the electrical schematic and in the specifications listed in Table 2. The connector is front panel mounted and is a 9-pin Sub-D (DB9) female connector.

Process meters are utilized to convert the direct current voltages (VDC) from the various sensors into appropriate engineering units, such as inches or millimeters of water or degrees, etc. The standard units of measurement are English units: in H<sub>2</sub>O, °Fahrenheit. Metric units in mm H<sub>2</sub>O and °Celsius are available. The process meters, transducers and inclinometer have been all been setup and calibrated at Apex Instruments against appropriate standards. Before making any adjustments to the process meters, transducers or inclinometer, please research and read operations manuals, attached, first. Note, the process meters need to be energized, or powered-up, for approximately 15-30 minutes before they will stabilize entirely. Allow this much time before making readings or adjustments. Please call Apex Instruments, Inc. at 800-882-3214 if you have any additional questions.

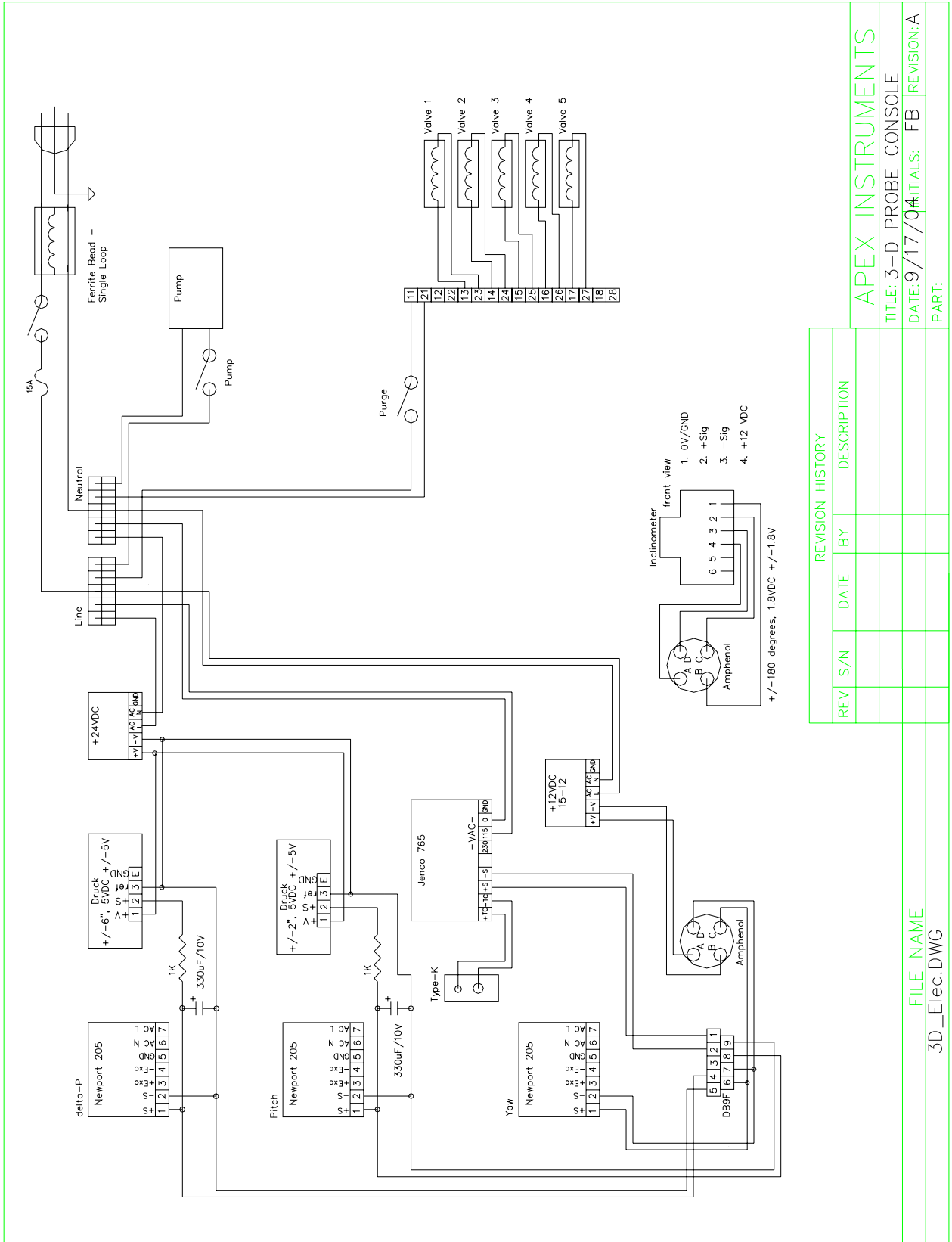


Figure 3 Electrical Schematic 3-D Console (MC-3D52)

REVISION HISTORY	
REV	DESCRIPTION

FILE NAME	3D_Elec.DWG

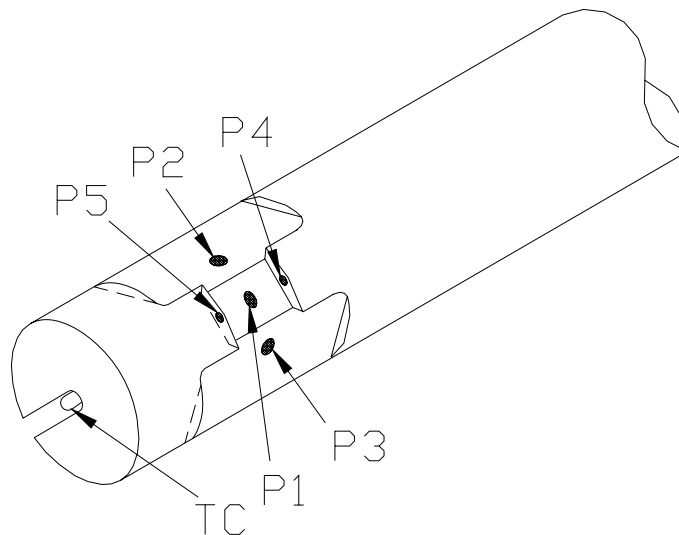
APEX INSTRUMENTS	
TITLE: 3-D PROBE CONSOLE	
DATE: 9/17/04	INITIALS: FB
	REVISION: A
	PART:

## Plumbing

The plumbing subsystem consists of leak-free tubing and fittings that allow accurate pressure measurements. Two pressure transducers measure the velocity head (P1-P2) pressure and the pitch (P4-P5) and are connected to LED process meters scaled and calibrated to the appropriate engineering units. A Magnehelic™ differential pressure gauge is utilized to indicate the Yaw Null (P2-P3).

A purge system includes a pump, pressure gauge and switching solenoid manifold to blow-back, or purge, the individual pressure lines to eliminate blockage from particulate or moisture. To activate the purge system, first activate the “Purge” rocker switch. This switch energizes the purge selector switch and activates the solenoid(s) on the manifold. Then turn on the pump using “Pump” rocker switch on the front panel. If the “Purge Tank Pressure” gauge reads zero then the line(s) are free and clear of any blockage. Make sure to check all five lines in this manner using the selector switch. When sampling, make sure to deactivate the “Purge” and “Pump” rocker switches.

The pitot probe assembly consists of a 5-hole prism-shaped head machined from 316 stainless steel (Figure 4). Four-foot extensions are high-temperature brazed to the pitot head. A 4-foot 1”OD section is then welded to pitot head and a scribe line has been engraved to align this pitot probe to the extension. This pitot head has been calibrated per the US EPA Method 2F specifications and a copy of the calibration is included. The unique serial number of the pitot is machined in the head. If an additional copy of the calibration is needed, please contact Apex Instruments, Inc.



**Figure 4 Prism-Shaped 3-D Pitot Head**

A 10-foot extension is included in the SK-3D52 3-D Flow Measurement System. This includes a bracket clamp to attach to the pitot probe head. Also included are five PTFE lines with union compression fittings to attach to the pitot probe pressure lines. An enclosure with quick-connect fittings attaches to the end of the extension to easily make the fittings to the umbilical. A scribe line has been engraved on this extension to align the pitot probe and the inclinometer sensor that clamps onto the extension.

A universal port flange adapter with bored bushings is used to attach this complete pitot probe assembly to the stack using standard 3, 4 or 6” flanges. This supports the probe and allows the ability to rotate the probe for the measurements.

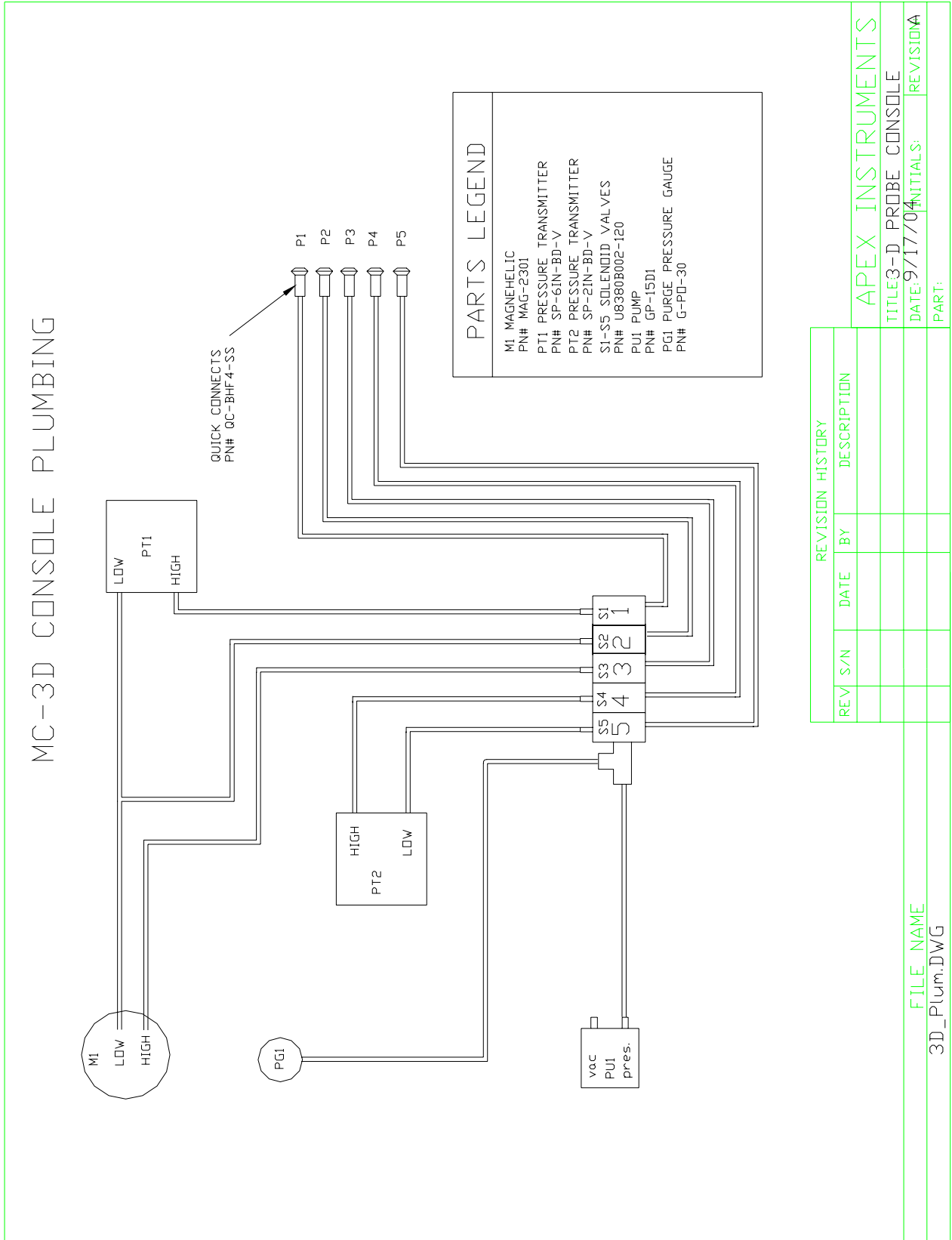


Figure 5 Plumbing Schematic 3-D Console (MC-3D52)

### III. ASSEMBLY & LEAK CHECK PROCEDURES

#### Assembly

1. Connect the pitot tube head (3DPT4) with the 10ft extension (32PTX-10T4Q4). First, screw the 1/4in compression fittings together that connect the stainless tubes of the 3DPT4 to the PTFE lines inside the 32PTX-10T4Q4. Please note to connect P1 to P1, P2 to P2, ...P5 to P5. It will be helpful to lay these two components on a long table or the floor. Next, slide, to your desired length, the pitot tube head into the clamp of the 10ft extension and tighten the four screws on the clamp. Align the scribe lines on the units.
2. Attach the Inclinometer Sensor (INC-A2T-50) to the open end, opposite the pitot clamp, of the 10ft extension (32PTXT32S). Align the scribed bracket with the scribe on the extension.
3. Attach the pitot line connection box (housing with 5 female quick connects, thermocouple jack and clamp) to the 10ft extension using the pipe clamp and thumbscrews.
4. Screw the two Bored Brass Bushings (32M/32B-B) into the ends of the Universal Probe Extension (PF-346XT32S). Mount to the stack flange using the universal 3, 4 or 6 inch pattern mounting holes.
5. Slide the probe into the Universal Probe Extension (PF-346XT32S).
6. Connect the Umbilical (U-3D-60-QS4) to the pitot line connection box. Securely insert the male quick connect in the female to ensure a leak free seal. Please note to connect P1 to P1, P2 to P2, ...P5 to P5. Insert the male thermocouple plug into the female receptacle. Screw the amphenol (circular connector) from the umbilical onto the inclinometer enclosure (INC-A2T-50).
7. Connect the opposite end of the Umbilical (U-3D-60-QS4) to the Meter Console (MC-3D52). Again, please note to connect P1 to P1, P2 to P2, ...P5 to P5. Insert the male thermocouple plug into the female receptacle. Screw the amphenol (circular connector) into the mating connector on the front panel.
8. Insert the IEC end of the power cord into the mating receptacle on the front of the meter console. Plug the male end into the appropriate power supply, 120VAC standard (240VAC optional).
9. Switch the main power on from the front panel of the console.

#### Leak Check

1. Follow the assembly instructions, above. To perform the leak check, pressurize the probe's P1 pressure port until at least 7.6 cm H<sub>2</sub>O (3 in. H<sub>2</sub>O) pressure, or a pressure corresponding to approximately 75 percent of the pressure-measuring device's measurement scale, whichever is less, registers on the device; then, close off the pressure port. The pressure shall remain stable [ $\pm 2.5$  mm H<sub>2</sub>O ( $\pm 0.10$  in. H<sub>2</sub>O)] for at least 15 seconds. Check the P2, P3, P4, and P5 pressure ports in the same fashion.

## IV. OPERATION AND SAMPLING

The general information below includes comments on sampling techniques, compensation for temperature and pressure, number of passes required, and accuracy and speed. To summarize, the 3-D probe is used to determine the velocity pressure and the yaw and pitch angles of the flow velocity vector in a stack or duct. The method determines the yaw angle directly by rotating the probe to null the pressure across a pair of symmetrically placed ports on the probe head. The pitch angle is calculated using probe-specific calibration curves. From these values and a determination of the stack gas density, the average axial velocity of the stack gas is calculated. The average gas volumetric flow rate in the stack or duct is then determined from the average axial velocity. Other US EPA Methods may be mentioned and can be found at [www.epa.gov/ttn/emc/promgate.html](http://www.epa.gov/ttn/emc/promgate.html). A copy of the final rule that details the methodology for Methods 2F, G & H is available from the US EPA website at <http://www.epa.gov/airmarkets/monitoring/flow/rule.pdf>.

It is important to inspect the pitot head for any damage and all equipment for proper operation prior to sampling. Auditing and calibrating the electronics is also required. Please see the Calibration/Recalibration in this section for assistance. It is equally important to document these steps. Forms are included in the appendix of this manual as an aid.

### Method 1

The first step required is to perform US EPA Method 1 to determine the traverse point locations on the probe. Mark the probe.

### Method 2

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

### Method 3

Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially CO<sub>2</sub>, O<sub>2</sub>, CO, and N<sub>2</sub>, 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.

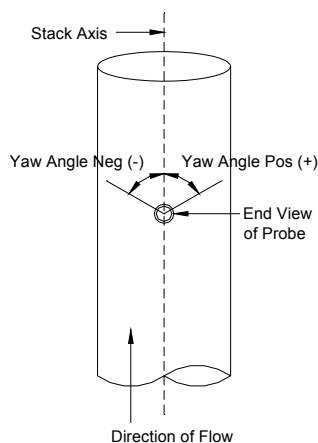
### Method 4

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

### Method 2F Axial Velocity Determination

Yaw angle measurement may be obtained in two alternative ways during the field test, either by using a yaw angle-measuring device (e.g., digital inclinometer INC-A2T-50) affixed to the probe, or using a protractor wheel and pointer assembly (optional). For horizontal traversing, either approach may be used. For vertical traversing, i.e., when measuring from on top or into the bottom of a horizontal duct, only the protractor wheel and pointer assembly may be used.

At each traverse point, first yaw-null the probe. Rotate the probe until a null differential pressure reading (the difference in pressures across the P2 and P3 pressure ports is zero, i.e.,  $P_2 = P_3$ ) is indicated by the yaw angle Magnehelic® pressure gauge. The angle displayed on the angle-measuring device is considered positive when the probe's impact pressure port (as viewed from the "tail" end of the probe) is oriented in a clockwise rotational position relative to the stack or duct axis and is considered negative when the probe's impact pressure port is oriented in a counterclockwise rotational position. See Figure 6 for a visual representation.



**Figure 6 Probe Yaw Orientation Positive/Negative**

Then, with the probe oriented into the direction of flow, measure and record the yaw angle, the differential pressures and the temperature at the traverse point, after stable readings are achieved. At the start of testing in each port (i.e., after a probe has been inserted into the flue gas stream), allow at least the response time to elapse before beginning to take measurements at the first traverse point accessed from that port. Provided that the probe is not removed from the flue gas stream, measurements may be taken at subsequent traverse points accessed from the same test port without waiting again for the response time to elapse.

Maintain the probe rotational position established during the yaw angle determination. Then, begin recording the pressure-measuring device readings for the impact pressure (P1–P2) and pitch angle pressure (P4–P5). These pressure measurements shall be taken over a sampling period of sufficiently long duration to ensure representative readings at each traverse point. If the pressure measurements are determined from visual readings of the pressure device or display, allow sufficient time to observe the pulsation in the readings to obtain a sight-weighted average, which is then recorded manually. If an automated data acquisition system (e.g., data logger, computer-based data recorder, strip chart recorder) is used to record the pressure measurements, obtain an integrated average of all pressure readings at the traverse point. Stack or duct gas temperature measurements shall be recorded, at a minimum, once at each traverse point. Record all necessary data as shown in the example field data form included in the Appendix.

After the required yaw angle and differential pressure and temperature measurements have been made at each traverse point, verify (e.g., by visual inspection) that the yaw angle-measuring device has remained in proper alignment with the reference scribe line. If, for a particular traverse point, the angle-measuring device is found to be in proper alignment, proceed to the next traverse point; otherwise, re-align the device and repeat the angle and differential pressure measurements at the traverse point.

Periodically check for plugging of the pressure ports by observing the responses on pressure differential readouts. Plugging causes erratic results or sluggish responses. Rotate the probe to determine whether the readouts respond in the expected direction. If plugging is detected, use the probe purge system to blow back the plugged lines and repeat the affected measurements.

Measure the static pressure in the stack or duct using the static tap of a standard (Prandtl type) pitot tube or one leg of a Type S pitot tube with the face opening planes positioned parallel to the gas flow may be used for this measurement. Also acceptable is the pressure differential reading of P1–Pbar from Apex Instruments' five-hole prism-shaped probe with the P1 pressure port face opening positioned parallel to the gas flow in the same manner as the Type S probe. However, the spherical probe is unable to provide this measurement and shall not be used to take static pressure measurements. Position the probe at or between any traverse point(s) and rotate the probe until a null differential pressure reading is obtained at P2–P3. Rotate the probe 90°. Disconnect the P2 pressure side of the probe and read the pressure P1–Pbar and record as the static pressure. If a Type S 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

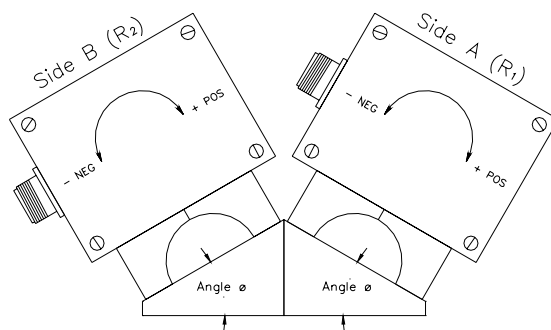
obtained. Disconnect the tubing from one of the pressure ports; read and record the  $\Delta P$ . The pressure sensors are bidirectional thus readings will read either positive (+) or negative (-).

### Calibration/Recalibration

Recalibrate the probe either within 12 months of its first field use after its most recent calibration or after 10 field tests, whichever occurs later. In addition, whenever there is visible damage to the probe head, the probe shall be recalibrated before it is used again.

Calibration of inclinometers pressure measuring devices, transducers and process meters/display, are required before initial use in the field. These are calibrated and audited during manufacture, but it is recommended that the customer calibrate these upon initial receipt to confirm nothing changed during the shipping process.

To calibrate the inclinometer system, secure a calibration 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 shall be within  $\pm 2^\circ$  of the known angle.



**Figure 7 Inclinometer Calibration Diagram**

Calibrate each pressure measuring device (except those used exclusively for yaw nulling) using the three-point calibration procedure described in section 10.3.3 of US EPA Method 2F. 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. 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.

At each pressure setting, the readings made must agree to within  $\pm 2\%$  of full scale of the device being calibrated or  $0.5\text{mm H}_2\text{O}$  ( $0.02\text{in H}_2\text{O}$ ), whichever is less restrictive. Differential pressure devices not meeting this requirement shall not be used.

## V. RESULTS AND CALCULATIONS

### Calculation of Results

Calculate the axial velocity at each traverse point to account for the yaw and pitch angles of flow. Calculate the test run average stack gas velocity by finding the arithmetic average of the point velocity results and calculate the stack gas volumetric flow rate, as applicable. Round off figures only in the final calculation of reported values. Apex Instruments also offers a spreadsheet in MS Excel to aid in the reduction of this data.

First, examine the appropriate pair of F1 and F2 versus pitch angle calibration curves. Examples of these curves are shown in Figures 5 and 6. These curves are included in the calibration of the pitot tube. Please contact Apex Instruments, Inc. with your pitot serial number machined into the pitot head if you need additional copies of your calibration. The F1 curve is referred to as the Pitch Angle Calibration Curve and the F2 curve is referred to as the Velocity Calibration Curve.

First, for each traverse point, calculate F1 using the equation  $F_1 = \frac{P_4 - P_5}{P_1 - P_2}$ . Then, using the Pitch Angle

Calibration Curve interpolate the pitch angle at each traverse point based on the individual yaw angle reading. The Apex Instruments, Inc. 3D Flow spreadsheet interpolates accurately from the data.

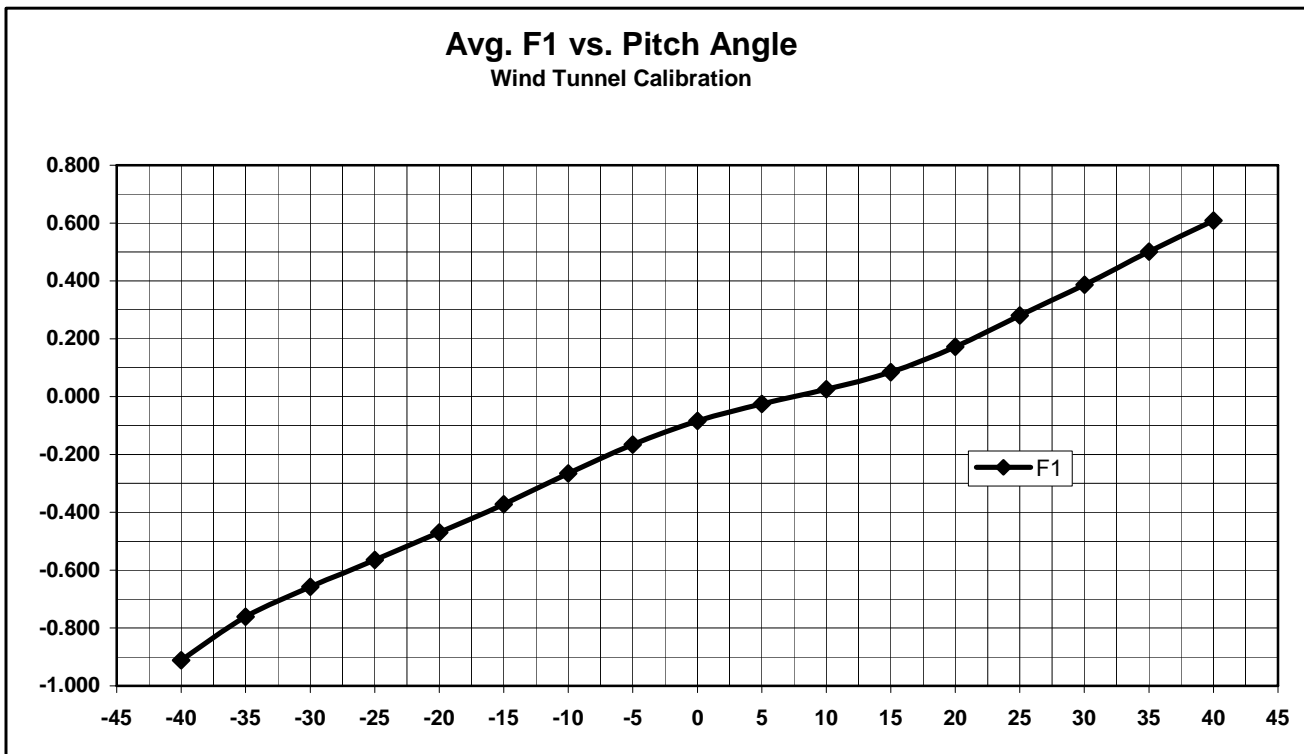
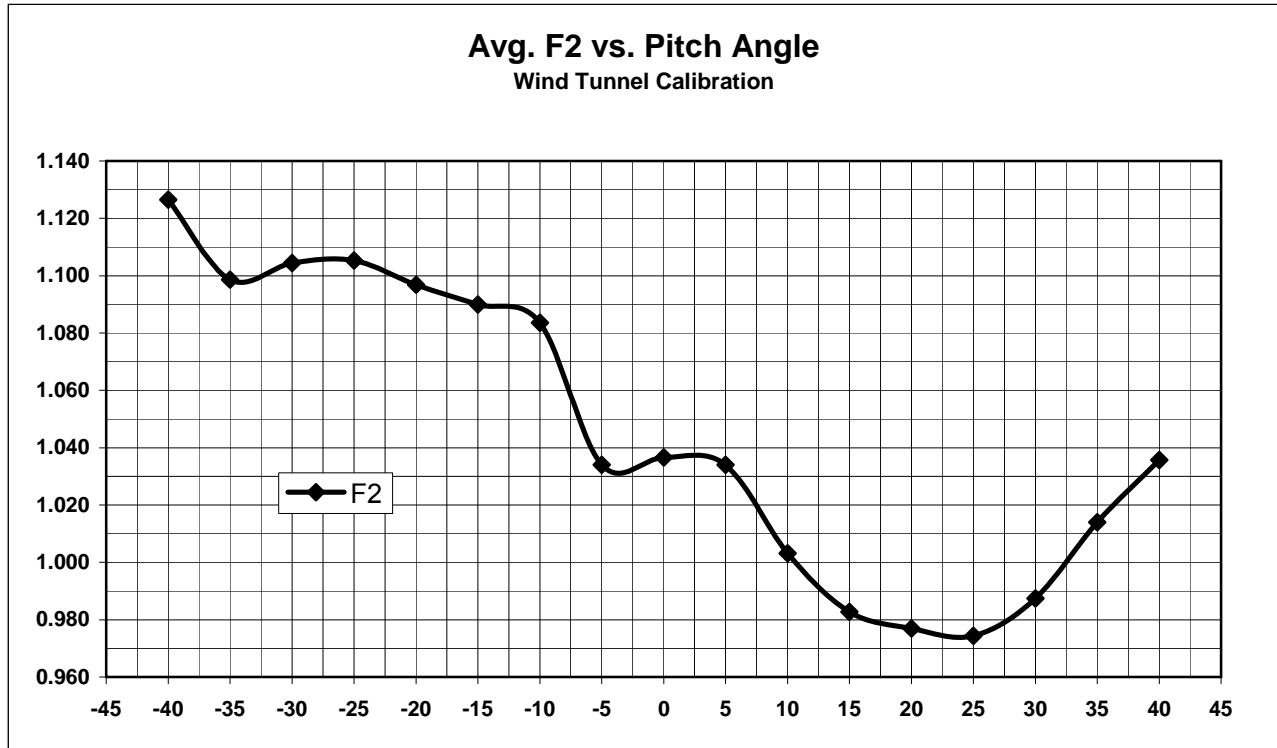


Figure 8 Example F1 vs Pitch Angle Wind Tunnel Calibration Curve

Next, using the Velocity Calibration Curve interpolate the F2 correction factor at each traverse point based on the individual pitch calculated/interpolated in the previous step. Again, the Apex Instruments, Inc. 3D Flow spreadsheet aids in the accuracy and speed in this data reduction.



**Figure 9 Example F2 vs Pitch Angle Wind Tunnel Calibration Curve**

The final steps are simple “plug-and-chug” equations.

Calculate the axial velocity, ft/sec (m/sec), at each traverse point ( $v_{a(i)}$ ) using equation

$$v_{a(i)} = K_p F_{2(i)} \sqrt{\frac{(P_1 - P_2)_i T_{s(i)}}{P_s M_s}} (\cos \theta_{y(i)}) (\cos \theta_{p(i)})$$

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

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

and,

$F_{2(i)}$  = 3-D probe velocity coefficient at traverse point i, unitless

$(P_1 - P_2)_i$  = Velocity head pressure reading at traverse point i, in H<sub>2</sub>O (mm H<sub>2</sub>O)

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

$P_s$  = Absolute stack pressure, in Hg (mm Hg)

$$P_s = P_{\text{bar}} + \frac{P_{\text{static}}}{13.6}$$

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

$$M_s = M_d (1 - B_{ws}) + 18.0 B_{ws}$$

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

$\theta_{p(i)}$  = Pitch angle of the flow velocity vector at traverse point i

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Next, calculate the average axial velocity, ft/sec (m/sec), using equation:

$$V_{a(\text{avg})} = \frac{\sum_{i=1}^n v_{a(i)}}{n}$$

Now, the average standardized (normalized) actual volumetric flow rate, dcfh (dscmh) can be computed using equation:

$$Q_{sw} = 3,600 (v_{a(\text{avg})})(A) \left( \frac{T_{std}}{T_{s(\text{avg})}} \right) \left( \frac{P_s}{P_{std}} \right)$$

and the dry standardized volumetric flow, dscfh (dscmh) is computed using:

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

where,

3,600 = conversion from seconds to hours,

$V_{a(\text{avg})}$  = average axial velocity, ft/sec (m/sec)

A = cross-sectional area of stack, ft<sup>2</sup> (m<sup>2</sup>)

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

$T_{s(\text{avg})}$  = Average absolute stack gas temperature, °R (K)

$P_s$  = Absolute stack pressure, in Hg (mm Hg)

$$P_s = P_{bar} + \frac{P_{static}}{13.6}$$

$P_{std}$  = Standard pressure, typically 29.92in Hg (760mm Hg), in Hg (mm Hg)

## Appendices



## Appendix 2 Pitot Head Inspection Sheet

**Probe Type and ID #** \_\_\_\_\_ **Date of most recent calibration:** \_\_\_\_\_

Fill in the tables below. For any item assigned a value of "1", show its location in the accompanying probe diagrams.

### Inspection of Probe Ports

Port ID	Current Inspection (1=present, 0=absent)			Compared to Previous Calibration (1=changed, 0=unchanged)			Brief Description of Any Item with a Value of "1" in Preceding Columns
	Dents	Scratches	Asymmetries	Dents	Scratches	Asymmetries	
P1							
P2							
P3							
P4							
P5							

### Inspection of Probe Surfaces

Surface ID	Current Inspection (1=present, 0=absent)		Compared to Previous Calibration (1=changed, 0=unchanged)		Brief Description of Any Item with a Value of "1" in Preceding Columns
	Scratches	Indentations	Scratches	Indentations	
S1					
S2					
S3					
S4					
S5					

Surface IDs S1 through S5 refer to the surfaces adjacent to pressure ports with the corresponding numbers, e.g., S3 refers to the surface adjacent to pressure port P3.

#### ***QA/QC Check***

Completeness \_\_\_ Legibility \_\_\_ Accuracy \_\_\_ Specifications \_\_\_ Reasonableness \_\_\_

#### ***Certification***

I certify that the Probe ID \_\_\_\_\_ meets or exceeds all specifications, criteria, and/or applicable design features required under Method 2F.

Certified by: \_\_\_\_\_ Date: \_\_\_\_\_

### Appendix 3 Inclinometer Calibration Sheet

Source: \_\_\_\_\_ Date: \_\_\_\_\_  
 Test Location: \_\_\_\_\_ Tester(s): \_\_\_\_\_  
 Probe Type: \_\_\_\_\_ Affiliation: \_\_\_\_\_  
 Probe ID: \_\_\_\_\_ Fully-Assembled Probe Length (in.): \_\_\_\_\_

<b>Position</b>	<b>Angle Comparisons</b>		
Distance of 2 <sup>nd</sup> measurement device from probe head impact port in mm (in.)  (Col. A)	<u><b>1<sup>st</sup> Device</b></u> Angle measured by device aligned on the reference scribe line, including algebraic sign (degrees)  (Col. B)	<u><b>2<sup>nd</sup> Device</b></u> Angle measured by device mounted at each position to be used during testing, including algebraic sign (degrees)  (Col. C)	<u><b>R<sub>ADO</sub></b></u> Difference between readings by 1 <sup>st</sup> and 2 <sup>nd</sup> angle-measuring devices (degrees) <sup>a</sup>  (Col. C - Col. B)

<sup>a</sup> The algebraic sign must be consistent with section 8.3.2.

Specifications: For the pre-test rotational position check, the value of R<sub>ADO</sub> at each location along the probe shaft must be determined to within ±1°. In the post-test check, R<sub>ADO</sub> at each location must remain within ±2° of the value obtained in the pre-test check.