# FAN ENGINEERING

Fans & Blowers
Twin City

Information and Recommendations for the Engineer FE-900

# Field Testing of Fans

## Introduction

There are many reasons why a fan test may be performed. AMCA publications cover three categories of tests.

1. **General Fan System Evaluation** — A measurement of the fan-systems' performance to use as the basis of modification or adjustment of the system.
2. **Acceptance Test** — A test specified in the sales agreement to verify that the fan is achieving the specified performance.
3. **Proof of Performance Test** — A test in response to a complaint to demonstrate that the fan is meeting the specified performance requirement.

The first type of test usually must be performed in the field. The fan is connected to a system, and the combination fan-system performance is measured. The other two types of tests can be performed in either the field or in a laboratory. If a high degree of accuracy is required, a laboratory test is recommended. A typical laboratory test has an uncertainty of air performance usually less than 2% while a typical field test will have an uncertainty around 7% to 11%.

If it is determined that a field test of a fan is desired or necessary, the parties involved need to understand the basics of field testing — site conditions, personnel and equipment required, measurements necessary, and how to interpret the results. The purpose of this newsletter is to provide the reader with a basic understanding of all aspects of a field test of a fan for air performance.

## Testing Standards

One of the most common standards for field testing fans in the United States is AMCA Publication 203, "Field Performance Measurements of Fan Systems." This publication details a fairly quick and simple-to-use standard for measuring fan system performance and the uncertainty in results is usually less than 11%. Another test standard is AMCA Publication 803, "Industrial Process/Power Generation Fans: Site Performance Test Standard." This standard was written specifically for fans in industrial processes or power generation. It is a bit more complicated and time consuming than the method in AMCA Publication 203, but it also yields results with lower uncertainties. ASME PTC-11 "Fans" is another document concerning fan performance testing. This method uses complicated equipment and procedures. Setup time alone could exceed 100 hours. PTC-11 does publish the lowest uncertainty range however. This newsletter will focus on the equipment and requirements of AMCA Publication 203 (hereafter referred to as Pub. 203) as it is the most commonly used field testing standard.

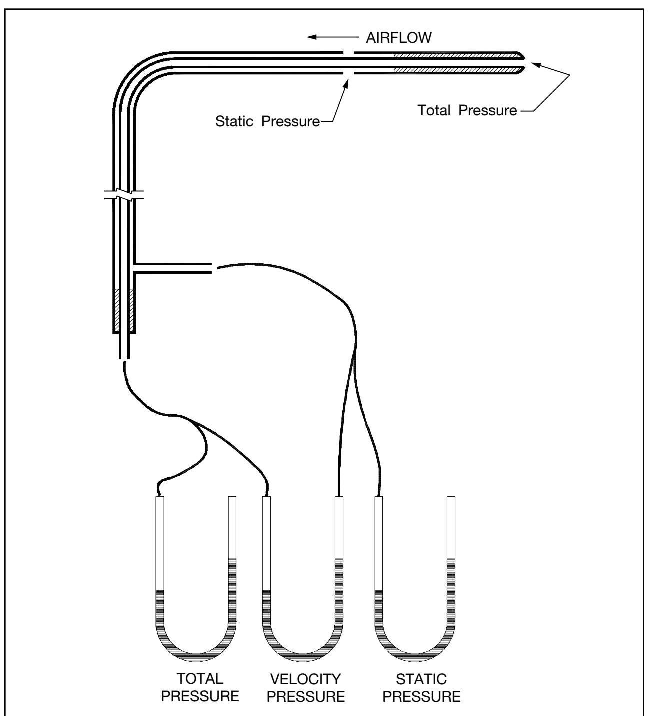
## Prior to Testing

Before testing begins, the parties involved (equipment owner and tester) should discuss and agree on a variety of issues. First, both parties should discuss the purpose of the test. Next, both parties must agree on the testing standard that will be followed. The tester should visit the site or obtain drawings of the site and review the site's suitability for testing, look for potential system effects, and discuss where measurements are to be made. Usually the best places to make measurements are long straight runs of ductwork just prior to the fan's inlet or just after the fan's outlet. Also consider that most test instruments will require a few holes to be drilled in the ductwork to obtain measurements. Insulated ductwork may require that fairly large holes be cut in the outer skin in order for instruments to be inserted into the flow. Last, both parties should discuss and agree on the number of points of operation that will be tested and the site conditions present during testing.

## Testing Equipment

The most common piece of air testing equipment is the pitot tube. The pitot tube (see Figure 1) has no moving parts and does not require calibration. It can directly measure total, static, or velocity pressure. The pitot tube is oriented so that its nose points parallel to the axis of the duct and into the flow. The tip of the tube runs to a port so that total pressure can be measured. Holes along the circumference of the tube run to a port for static pressure measurements. The differential pressure from these ports can be used to measure the velocity pressure of the flow. The holes for the static pressure

*Figure 1. Pitot Tube*



are usually very small, so they can easily become blocked in dirty or wet flows. In those situations, periodically check the tube to make sure the holes are not blocked, or use an alternate instrument for traverse measurements.

Total or velocity pressure can also be measured with a double reverse tube (S-tube). This instrument has two large ports. One faces upstream and the other downstream. The double reverse tube must be calibrated before each use and the direction of airflow for the calibration must be marked on the instrument. The large ports on the tube allow it to be used in dirty flows with little chance that the ports will be blocked.

PTC-11 requires that flow measurements be made with a 5-hole probe (Yaw probe). This unusual instrument measures airflow three dimensionally. One port measures a pseudo total pressure, two ports measure a pseudo static pressure and yaw angle, and the other two ports are used for measuring the pitch angle of the flow. The probe required for PTC-11 also has a thermocouple on the tip for measuring flow temperature. Like the pitot tube, the holes in the yaw probe are small and are not well suited for dirty flows.

The most commonly used pressure indicator is the manometer. This is simply a clear piece of liquid-filled tubing. When a differential pressure is applied across the ends of the tubing, the amount the liquid rises indicates the pressure. The magnitude of the pressure depends only on the vertical rise of the liquid. The tube on the manometer is often sloped so that a more precise reading can be obtained. The height of the rise of the liquid (head) is independent of the diameter of the tubing. The pressure applied to the manometer = $\rho gh$, where "$\rho$" is the liquid's density (mass/volume), "g" is the gravitational constant (acceleration), and "h" is the head (length). Thus, if the head on the manometer is 10.00 inches and the fluid in the manometer is gauge oil with a specific gravity of 0.826, the pressure measured by the manometer is:

$$0.000925 \text{ (slugs/in}^3\text{ density) x } 32.2 \text{ (ft/s}^2\text{ gravity)}$$
$$\text{x } 10.00 \text{ (inches head)} = 0.298 \text{ (lb/in}^2\text{) or } 8.26 \text{ in } H_2O$$

Make sure to keep units consistent. For fans, most pressure readings are given in inches of water. This refers to a head of water in a manometer at standard conditions. Most manometers are filled with a gauge oil and have scales calibrated to inches of water. Gauge oil density is more constant under a variety of temperatures than water is. Make sure that the gauge oil with which you fill your manometer has the correct specific gravity. Manometers should indicate the specific gravity of gauge oil that they are calibrated for use with.

For temperature measurements, make sure you have a thermometer calibrated for use in the expected flow temperature. Thermocouples may also be used for making temperature measurements.

You will need to know the barometric pressure at the site. You can find this using a portable barometer or by calling an airport close to the site. The airport can tell you the local barometric pressure corrected to sea level. Correct this reading to the altitude of the job site by multiplying the reading by the appropriate factor from the following chart.

*Table 1. Altitude Correction Factors*

| ALTITUDE (FEET) | CORRECTION FACTOR |
|---|---|
| 0 | 1.000 |
| 1000 | 0.965 |
| 2000 | 0.930 |
| 3000 | 0.896 |
| 4000 | 0.864 |
| 5000 | 0.832 |
| 6000 | 0.801 |
| 7000 | 0.772 |
| 8000 | 0.743 |

You must also be able to measure the rotational speed of the fan wheel. The best instrument for doing this is a hand held tachometer.

Finally, for a field test you will need a tape measure for making various measurements.

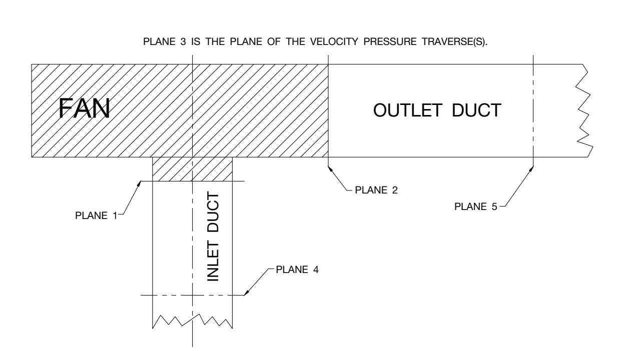
## Conducting a Test

The first thing to do for a field test is to inspect the fan and ductwork. Have someone at the site turn off and lock out the fan. Open any access doors and visually inspect as much of the fan as is possible. Verify that there is no material buildup on the fan blades or the ductwork that can affect fan performance. Make sure that the fan is constructed properly and that the wheel is correctly positioned inside the housing. If the fan has an inlet cone, make sure that the wheel/cone overlap is correct and that the radial clearance between the wheel and cone is normal. Rotate the wheel a few times by hand to make sure no parts are rubbing. If there are screens or filters installed, make sure these are not plugged with debris. Next, following proper safety precautions, have the power to the fan "bumped" on briefly and check to make sure that the wheel is rotating in the correct direction. All fans should have a sticker on them indicating the direction the wheel should spin. It is common for field performance deficiencies to be corrected during this inspection procedure.

After making any necessary corrections, start the fan up and allow some time for the system to reach a steady state. The tester should then inspect the system to make sure the test can be conducted correctly. Check to make sure any flex connectors on the fan are not collapsed. A collapsed flex connector will act as an orifice, restricting the flow of air through the fan and causing turbulence in the flow. All dampers and inlet vanes must be 100% open and remain so throughout the duration of the test. The temperature of the flow must also be fairly stable throughout the duration of the test (e.g., there should not be a burner turning off and on in the system being tested).

Identify the measurement planes. Pub. 203 describes five reference planes (see Figure 2). Plane 1 is the plane immediately at the fan's inlet. Plane 2 is the plane immediately at the fan's outlet. Plane 3 is the plane where flow measurements are conducted. Plane 4 is the plane of static pressure measurement upstream of the fan. Plane 5 is the plane of static pressure measurement downstream of the fan. The plane where the flow traverse readings are made need not be the same as where static pressure readings are taken.

*Figure 2. Measurement Reference Planes*




If the fan and system check out, begin testing the fan. There are five critical measurement groups that must be made to get the most accurate air performance test:

1. At least one traverse of velocity and static pressure measurements needs to be made at either the inlet or outlet side of the fan.
2. Take static pressure readings on the opposite side of the fan that you performed the velocity and static pressure traverse on (i.e., if you performed the velocity and static traverse on the inlet side, take additional static pressure readings on the outlet side).
3. Take pressure and temperature readings to determine the density at the flow traverse and at the fan's inlet.
4. Determine the RPM of the fan wheel.
5. Determine the cross-sectional area of all the measurement planes.
6. An estimate of the motor horsepower can be made by taking motor amp and volt measurements.

Generally, field testing is a two person job. One person will position the traverse instruments while the other person takes and records the readings.

The following paragraphs will detail how these measurements are performed using Pub. 203 and with some of the most commonly used pieces of equipment.

**The Velocity Pressure and Static Pressure Traverse(s)**

Section 9.3 in Pub. 203 offers guidelines for finding the best location possible for the location of measurement planes. Generally, it is not recommended to take measurements too close downstream to a bend, appurtenance, or accessory in the flow. The cross-sectional shape of the measurement plane should be a regular shape.

Appendix H in Pub. 203 details the number and location of measurement points to take. Use the pitot tube and a tape measure to find the length of the traverse. Insert the pitot tube into the duct and pull it up against the near side of the duct and make a mark on the pitot tube just outside of the duct. Push the tube to the far end of the duct and make another mark just outside of the duct. The distance between marks plus the diameter of the tube equals the length of the traverse. Pull the tube out of the duct and make marks at the locations where traverse points are to be measured.

Run one piece of tubing from the total pressure tap to one side of the manometer used for measuring the velocity pressure. Run another piece of tubing from the static tap to a “T” junction. Connect one port of the “T” junction to the other port of the velocity pressure manometer. Connect the other port of the “T” junction to a manometer for measuring static pressure. Be careful on how you attach the tubing to inclined manometers. It is likely that the total and static pressures on the inlet side of the fan are negative (suction). If the tubing is attached to the wrong end of the inclined manometer, fluid could be sucked out of the manometer requiring you to refill and re-zero the manometer.

*Table 2. Symbols*

| Symbol | Description | Unit |
|---|---|---|
| A | Area of a plane/cross section | $ft^2$ |
| Ps | Static pressure | $inH_2O$ |
| $Ps_n$ | Static pressure at plane n | $inH_2O$ |
| Pt | Total pressure | $inH_2O$ |
| $Pt_n$ | Total pressure at plan n | $inH_2O$ |
| Pv | Velocity pressure | $inH_2O$ |
| Q | Fan flow rate | $ft^3/min$ |
| $\rho$ | Density | $lbm/ft^3$ |
| $\rho_n$ | Density at plane n | $lbm/ft^3$ |
| V | Velocity | ft/min |

Reinsert the pitot tube and begin taking measurements. Temporarily block the tubes during insertion to prevent fluid being sucked/blown out of manometers. At each measurement location, orient the pitot tube such that its nose points parallel to the axis of the duct. When reading the manometers, it is likely that the readings will fluctuate around a point. Mentally average the fluctuations to obtain the pressure readings. If you are testing per Pub. 203, any velocity pressure that seems to be negative should be recorded as zero.

**Note:** Common sense would seem to indicate that a duct that discharges into an outlet duct would have a positive static pressure. This is not always the case however. If the duct contains hot air and has a vertical rise to it (e.g., a stack), the natural buoyancy of the hot air can cause a small negative static pressure on the outlet side of the fan.

Make sure to take a dry bulb temperature reading at each measurement plane.

Repeat the process above for each traverse of pressure measurements. You will need to make velocity pressure measurements on only one side of the fan (inlet or outlet), but the test code requires a static pressure traverse on both the inlet and outlet side. If the static pressure is fairly constant across the duct, one static pressure reading in the plane will be enough for accurate results.

If the inlet and outlet ducts are unsuitable for taking velocity pressure readings, you may need to make multiple traverses through branches from the ductwork to determine the fan's flow rate. One traverse of the static or total pressures near plane 1 (immediately at the fan’s inlet) should always be made. It is best if the static pressure on the fan’s outlet is measured some distance downstream of the fan’s outlet to allow the flow to develop more evenly across the duct.

If you are testing per Pub. 203, at least 75% of the velocity pressure readings must be greater than 1/10th the highest velocity pressure reading to ensure a satisfactory flow profile. Consult figure 9-1 in Pub. 203 for reference on satisfactory flow profiles.

**Determining Air/Fluid Density**

The measurements for air density are performed at the same plane as the velocity pressure traverse. Insert a thermometer into the duct and measure the dry bulb temperature. Then, tape a cloth sock around the bulb of the thermometer. Wet the sock with distilled water. Reinsert the thermometer into the duct and measure the wet bulb temperature after the temperature stabilizes. Use a barometer to measure the ambient pressure. There are many psychrometric charts, tables, and equations in many different sources that can be used to determine the density of air using wet/dry bulb temperatures and barometric pressure. Appendix N in Pub. 203 has a density chart and some density tables for standard air.

If the gas in the duct is not air, the fluid density must be determined. Appendix M in Pub. 203 contains examples on calculating the density of gasses other than standard air. It may be necessary to consult a chemist to determine the density of the fluid.

To find the density at a measurement plane knowing the density at any other plane, use the following formula:

$$\text{Density}_X = \text{Density}_Y \times \left(\frac{\text{Absolute Pressure}_X}{\text{Absolute Pressure}_Y}\right) \times \left(\frac{\text{Absolute Temperature}_Y}{\text{Absolute Temperature}_X}\right)$$

**Determining the RPM of the Fan**

One simple way to measure the RPM of the fan is to obtain a hand held dial tachometer with a readout in RPM. Fan shafts typically have a small hole drilled in their center. Put the rubber tip of the tachometer into this hole, holding the tachometer in line with the shaft and firmly pressed into the hole. Push the start button on the tachometer. After a short time, the tachometer dial will stop and you can read the fan's RPM.

If the fan's shaft is not accessible on a belt driven fan, you can use the tachometer on the motor shaft. Tach the motor shaft as you would the fan shaft. Correct your tachometer reading using the sheave ratio from the motor to the fan. This will give you an approximate fan RPM provided there is negligible belt slip.

There are many other instruments available for measuring the fan's RPM, and a discussion of all these instruments is beyond the scope of this document.

**Measurements**

Make sure you record the dimensions of every measurement plane. Record the dimensions of every appurtenance or accessory between the measurement planes and the inlet or outlet of the fan. If possible, obtain prints for the ductwork, appurtenances, and accessories.

These measurements might be necessary for calculating the correct performance of the fan. For example, if there is an evasé or outlet cone between the outlet of the fan and the plane of the outlet static pressure measurements, you must adjust the fan's static pressure to account for the difference in the velocity pressures between planes 2 and 5.

## Calculating the Fan's Air Performance

To find the fan's flow rate, you need to calculate the root mean square (RMS) of the velocity pressure traverse(s). This is calculated by:

1. Take the square root of all the velocity traverse readings.
2. Sum all of the square roots and divide the sum by the number of readings.
3. Square the result.

$$Pv_{RMS} = \left[\frac{\sum \left(Pv_{Readings}\right)^{1/2}}{\text{Number Of Readings}}\right]^2$$

The root mean square of the velocity pressure is calculated instead of the linear average because you actually need the average of the velocities at each point and velocity is a function of the square root of the velocity pressure. Once you calculate the RMS of the velocity pressure, you can calculate the average velocity of the flow using the following formula:

The flow in the duct is then the velocity times the cross sectional area of the duct, or $Q = V \times A$. If the velocity pressure traverse(s) were not made at the fan's inlet, correct the flow calculation to the density of the fan's inlet using the fan laws. If multiple traverses were taken, sum the corrected flows calculated to obtain the fan's flow rate.

$$V = 1096 \times \sqrt{\frac{Pv_{RMS}}{\rho_3}}$$

Fan static pressure is defined as the static pressure at the outlet minus the total pressure at the inlet. Static pressure at a plane is the linear average of the static pressure readings in the plane (the sum of the readings divided by the number of readings). You may also need to adjust the pressures to account for systems effects or appurte-nances/accessories in the flow (e.g., an evasé or cone). The final equation for calculating the fan's static pressure is then:

$$Ps = Ps_2 - Ps_1 - Pv_1 + \text{System Effect 1} + \text{System Effect 2} + \ldots + \text{System Effect n}$$

Good references for system effects and the effects of appurtenances in the flow can be found in both AMCA Publication 201 "Fans and Systems," and in "Industrial Ventilation: A Manual of Recommended Practice."

Consult the testing standard you are using on how to calculate uncertainty in your results. This will be important for analyzing the results of the test.

## Estimating Motor Horsepower

Using appropriate instrumentation, measure the motor's amperage and voltage. For three phase motors, measure the amperage and voltage on each lead and average them. Contact the motor manufacturer and obtain a motor performance chart of amps versus power factor (PF) and motor efficiency (ME) at the voltage applied to the motor. The motor horsepower for single phase motors is then:

$$P_1 = P_2 \times \left(\frac{Q_1}{Q_2}\right)^2$$

or for three phase motors:

$$P_1 = 2 \times \left(\frac{30000}{20000}\right)^2 = 4.5 \text{ in. w.g.}$$

Ammeters and voltmeters may not work properly if the motor is run from an inverter.

## Analyzing the Results

Obtain a fan performance curve plotted at the RPM and density measured during the test. Also, plot a curve indicating the allowed fan performance tolerance. Plot the fan performance point calculated from the test on this curve. Draw a box around the point enclosing the area of the calculated uncertainty. If the performance curve or tolerance line pass though the box, the test indicates that the fan is performing as it should. The box may also be above the performance curve along a system line if the fan is performing correctly.

If the fan is not performing as it should, draw a system line that passes through the point measured by the test. Divide the flow rate calculated by the test by the flow rate at the point where the system curve intersects the fan curve to find the percentage of flow rate the fan is producing compared to what it should produce. One minus this ratio is the percentage down that the fan is performing at. It's easy to prove with the fan laws that the percentage down along a system line is the same percentage speed up of the wheel required to move the point of operation to the fan curve.

## Common Problems

**Measuring flow velocity, not velocity pressure:**
Sometimes tests are conducted using instruments to measure the flow velocity instead of the velocity pressure (e.g., a hot wire anemometer). These instruments normally do not automatically adjust for different flow densities. A high velocity low density flow can give the same readings as a low velocity high density flow. If you use a velocity measuring instrument, make sure you correct the readings to account for the density that the instrument is calibrated for.

**Wind effects**
If you are taking velocity pressure measurements on a stack, a wind across the top of the stack can greatly affect your readings. Velocity pressure tends to be much higher on the windward side of the stack. If the wind is not steady, it will also cause your readings to fluctuate with wind speed.

**Unstable systems**
A fan may be operating in its unstable regime. Fans with large cyclic fluctuations in flow and pressure are unstable. Unstable fans are not suitable for conducting field performance testing.

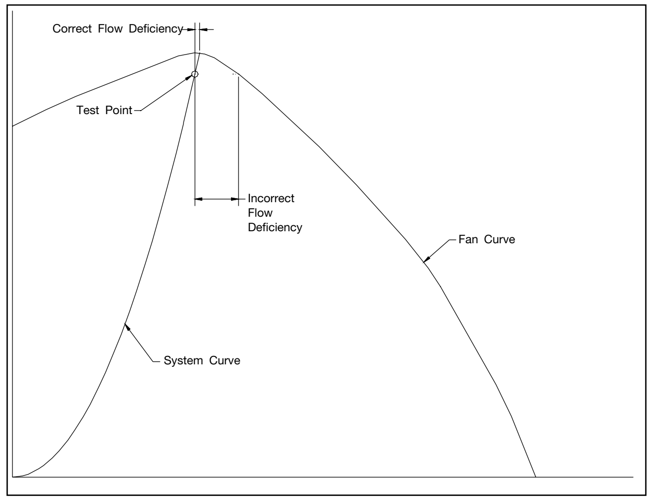
**Pre-swirl**
Bends in ducts, appurtenances, accessories, or uneven flow in a duct can lead to a pre-swirl of the air going into a fan's inlet. Swirl before the inlet can have two effects depending on the direction of rotation. A swirl in the same direction as the wheel is rotating reduces the fan's static pressure development. A swirl in the opposite direction will increase it. Pre-swirl can be detected by rotating the pitot tube on the inlet side of the duct and observing the direction of the highest velocity pressure reading.

**Eccentric Flows**
If the flow velocities leading to the fan are non-uniform, the fan's inlet is unevenly loaded. Fans are generally rated with uniform inlet velocities. Non-uniform velocities will unevenly load the fan impeller and the fan will not produce as high a flow rate as it is capable of.

**No Inlet Bell**
Some fans are rated for performance with an inlet duct. If these fans are installed in a system without an inlet duct, a bell/cone should be installed on the inlet of the fan. Without a bell or cone, a vena contracta will be present in the inlet, effectively reducing the inlet area and flow rate.

**Misinterpretation of Results**
Sometimes during a fan test, a specific static pressure is set and the flow rate is recorded. At this point, the tester may simply take a horizontal line on the performance plot from the test point to the fan curve and report this as flow deficiency. Comparisons from test results to fan curves should always be made along system lines. Figure 3 shows how not using system lines can result in drastically misinterpreted results.

*Figure 3. Misinterpreted Results*




**EXAMPLE TEST CALCULATIONS**

**Velocity and inlet traverse data (planes 3 and 4)**
Velocity pressure traverse measurements made before fan's inlet:
Traverse #1 =0.46, 0.53, 0.54, 0.52, 0.52, 0.56, 0.53, 0.42 $inH_2O$
Traverse #2 =0.44, 0.56, 0.54, 0.53, 0.60, 0.62, 0.64, 0.46 $inH_2O$
Static pressure = –13.8 $inH_2O$
Duct diameter for both traverses = 60 inches
Dry bulb temperature = 120°F
Wet bulb temperature = 70°F
Barometric pressure = 28.74 inHg

**Plane 3 and 4 calculations:**
$Pv_3$ RMS = 0.53 $inH_2O$
$\rho_3$ from a psychrometric chart = 0.068 lb/ft$^3$ at sea level (Pb at sea level is 29.92 for standard air)
To correct to duct conditions:

$$P_1 = P_0 + (P_2 - P_0) \times \left(\frac{Q_1}{Q_2}\right)^2$$

$\rho_3$ = 0.064 lbm/ft$^3$

$$V_3 = 1096 \times \sqrt{\frac{Pv_3}{\rho_3}}$$

$V_3$ = 3154 ft/min. $A_3$ = 19.64 ft$^2$ $Q_3$ = 61,945 ft$^3$/min

Assuming that the readings are taken close to the inlet of the fan and there are no obstructions in the duct between plane 4 and plane 1, it is accurate to state that the properties measured at planes 3 and 4 will be the same at plane 1.

**Outlet static pressure (plane 5):**
Static pressure = 5.34 $inH_2O$

**Fan static pressure**
Assuming a straight unimpeded run of duct from the fan's outlet to plane 5, we can assume that the conditions at plane 2 are the same as plane 5.

$$Pt_1 = Ps_1 + Pv_1 = -13.27 \ inH_2O$$

Fan static pressure = $Ps_2 - Pt_1$ = 18.61 $inH_2O$

The test point measured for this fan is 61,945 ft$^3$/min at 18.61 $inH_2O$ static pressure at 0.064 lbm/ft$^3$ density.