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AIRFLOW SCIENCES CORPORATION

The Airflow Update

Wind Tunnel Calibration of Velocity and Particulate Sampling Probes

By: Robert Mudry, P.E. and Karolina Rak, Airflow Sciences Corporation

There are a variety of probes used for flow measurement in gas streams, including hot wire, vane anemometer, and pressure differential, or pitot probes. For industrial applications, the S-type pitot probe (Figure 1) is widely used because its large pressure ports make it resistant to pluggage from moist or particulate-laden flow streams. This probe is thus often used when measuring gas flow rates in the exhaust stream of industrial plants. These results are reported to the US Environmental Protection Agency (EPA) to accurately monitor pollution emissions from these plants

Figure 1. S-type pitot probe for velocity measurement

The EPA provides the test protocol "Method 2", which describes the proper use of the S-type pitot probe, in the US Code of Federal Regulations 40CFR60, Appendix A. Though there is a standard design for the S-type pitot probe, minor deviations in manufacturing tolerances and wear over time can cause the probe measurements to vary. EPA Method 2 thus provides guidelines on how to perform regular calibration of a probe in the controlled environment of a wind tunnel. With a proper calibration, the most accurate flow measurements are obtain in the gas streams for ducts and smokestacks at industrial sites.

To protect the public from excess pollution emissions, the EPA requires that industrial sites measure more than just the gas flow rate in their exhaust stacks. Measurements of the pollutant emissions are also required, such as gaseous chemicals including nitrous oxides (NOx), sulfur oxides (SOx), or mercury (Hg). If the facility has a particulate

Staff News

ASC was thrilled to welcome six new hires over the course of the last year.

Lauren Stromberg, Marketing Manager, came to us from Chicago with extensive experience in marketing & events.
Jacob Morrida, Engineer, came to ASC from Ohio where he was working in the auto industry in wind tunnel testing and data acquisition system.
Smrithi Keerthivarman, Engineer, graduated from the University of Michigan with her Master's in Aerospace Engineering. Her prior work experience includes modeling a satellite launch adapter in Singapore and conducting CFD analysis of a hybrid UAV in Ann Arbor.
Lara Buckingham, Engineer, recently graduated with a Bachelor's in Mechanical Engineering from Kettering University in Flint. She is a Michigan native and has had internships at an aerospace company in Lansing.
Quentin Minaker, Engineer, recently graduated with a Masters in Mechanical Engineering from University of Windsor. He is currently training on CAD and Azore CFD simulation.
Johnny Henson, Engineering Technician, joined ASC in our Atlanta office to work on flow heat transfer experiments at the R&D Water Research & Conservation Center.

emission, then the concentration of particulate matter (PM) in the exhaust stream is also measured. Very fine PM is measured using the EPA test protocol of Method 201A, which focuses on PM in the size range below 10 microns (called PM10) and below 2.5 microns (PM2.5). These measurement methods use a probe head that is a combination of an S-type pitot probe for velocity and a vacuum-assisted sampling nozzle with a cyclone separator for the PM (Figure 2).

Figure 2. PM10 Probe Head

Pitot Probe Calibration – Airflow Sciences Wind Tunnel

Airflow Sciences Corporation performs S-type pitot calibrations in their Livonia, Michigan wind tunnel (Figure 3). The tunnel test section has an area of 4 sq.ft, and its design with bell-mouth inlet and 125 HP fan exceeds all EPA specifications for calibrating probes. The wind tunnel has a velocity range up to 150 ft/s. Airflow Sciences provides complete velocity probe calibration services for Vane Anemometers and Hot Wire Anemometers as well as all types of differential pressure style probes, including S-Type Pitot Probes, 3D Velocity Probes, Dirty Air Pitot Tubes and, PM Emission Probes. Figure 4 shows close up views during a probe calibration.

Figure 3. Airflow Sciences Wind Tunnel

Figure 4. Probe Calibration in the Airflow Sciences Wind Tunnel

Particulate Sampling Probe Calibration – University of Michigan Wind Tunnel

The EPA test protocol requires that the wind tunnel be large enough such that the blockage of the probe is no more than 2% of the tunnel cross section. The Airflow Sciences' wind tunnel is large, and can thus accommodate all velocity and particulate sampling probes except one – the PM10 probe. This probe has the largest cyclone separator and filter assembly, as shown in Figure 2. Unfortunately, the PM10 probe blocks 2.2% of the Airflow Sciences wind tunnel when positioned per the EPA protocol.

Airflow personnel teamed up with the Aerospace Engineering department at the University of Michigan, Ann Arbor for the use of their subsonic low turbulence 5' x 7' wind tunnel. This large tunnel, shown in Figure 5, is capable of velocities up to 250 ft/s with its 1,200 HP motor generator set. Figure 6 shows the set up of a PM10 probe within the wind tunnel test section.

Figure 5. University of Michigan 5'x7' Wind Tunnel

Calibration Procedure

For the calibration of a differential pressure velocity probe like the S-type pitot, certain steps need to be followed. First, the probe geometry is verified against EPA standards and a leak checked completed. The leak check is accomplished by sealing off the sensor tip of the probe and applying pressure to the entire system, including the probe, tubing connecting the probe to the pressure meter, and the meter itself. If the system holds this pressure with no leakage, the set up passes the leak check. The EPA protocol prescribes the pressurization (3.0 inches of water), and the leakage requirement (less than 0.1 inches of water drop over 15 seconds duration).

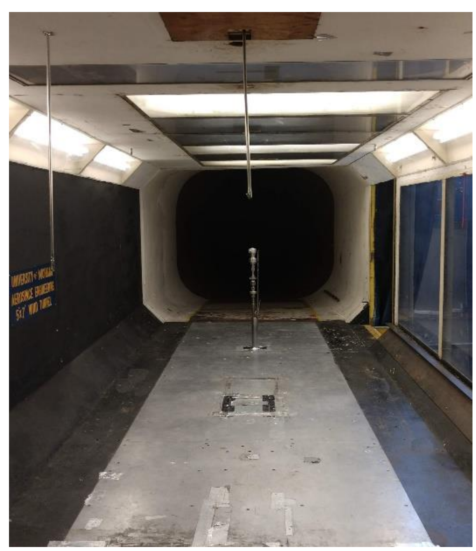

Figure 6. PM10 Probe in UofM Test Section

Once the test set up is confirmed to have correct geometry and be leak free, the pressure measurement instrumentation is zeroed, and then the wind tunnel turned on. The calibration is generally performed at multiple velocities, with each velocity setting needing 3 runs performed to verify repeatability. The key measurement is the probe differential pressure

(DP) and the wind tunnel velocity for each run. After each test, calculations are performed to determine the S-Type pitot calibration coefficient, deviation from the mean, and other required values per EPA Method 2. Finally, a calibration report documenting the raw data and calculated values is completed.

Figure 7. 3DDAS Measurement System

Although the EPA guidelines do not specify any requirements regarding pressure transducer accuracy or range, the selection of instrumentation for the calibration is important. In working with the United States National Institute of Standards & Technology (NIST), Airflow Sciences has selected appropriate wind tunnel transducer range and accuracy to obtain the most accurate wind tunnel calibrations.

Airflow Sciences uses a data acquisition system called the 3DDAS™ to perform the calibrations. This measurement system includes fast response, accurate pressure transducers for probe DP and also measures important ambient conditions such as barometric pressure, temperature, and static pressure. The 3DDAS is capable of reading up to 5 pressures simultaneously, so it is used for standard pitot probes (S-type, pitot static, DAP) with a single pressure signal, or with 3-dimensional pitot probes (prism, spherical, DAT) with multiple pressure signals. The 3DDAS is shown in Figure 7, and was used to measure both the probe under testing and the reference pitot probe permanently mounted in the U of M wind tunnel.

Calibration Results

A recent client submitted a variety of S-type probes for calibration, including those with both PM2.5 and PM10 cyclone assemblies. The pitot probes were calibrated in both the Airflow Sciences and University of Michigan wind tunnels. The probes were calibrated at 8 velocity setpoints, ranging from 15 to 130 ft/s. These velocities were monitored and measured from permanently mounted hot wire and/or pitot static probes in the wind tunnels. At each of the 8 velocities, 3 data points were taken for repeatability.

Example data from the calibration for a select probe is shown in Table 1 below. As indicated, the calibration coefficient for the S-type pitot probe alone, with no sampling array, is 0.83. The coefficient of the same probe with the PM10 sampling array attached is 0.92. This 10% difference is due to the aerodynamic influences of the sampling array on the flow patterns near the tip of the S-type pitot. This result clearly shows why the EPA test protocol requires that a pitot probe be calibrated in both scenarios, allowing the appropriate calibration coefficient to be used when testing is conducted either with or without the full PM10 sampling array in place.

Probe Serial Number	Calibration Coefficient (Cp) No sampling array	Calibration Coefficient (Cp) PM10 sampling array
57	0.83	0.92

Table 1. Comparison of probe calibration coefficient with and without PM10 sampling array

Wind Tunnel Blockage Comparison

As noted above, the PM10 probe requires a wind tunnel of large size in order to meet the EPA criteria of blocking less than 2% of the tunnel cross section. As an experiment to assess the sensitivity of this criteria, the PM10 probe was calibrated in both the Airflow Sciences tunnel (2.2% probe blockage) and the University of Michigan tunnel (0.25% probe blockage). Table 2 provides results of the comparison. As the data indicate, there is a slight but measureable difference (3.3%) of the pitot probe calibration coefficient for the two different size wind tunnels.

Probe Serial Number	Calibration Coefficient (Cp) ASC Wind Tunnel	Calibration Coefficient (Cp) UofM Wind Tunnel
57	0.89	0.92

Table 2. Calibration comparison for S-type pitot with PM10 sampling array in 2 wind tunnels

Summary

The calibration protocol for S-type pitot probes requires specific procedures be followed in order to obtain accurate results. This includes proper selection of instrumentation (3DDAS), wind tunnel (correct size and design), set up, leakage check, and data analysis. Test results show that it is essential to calibrate the S-type pitot with the PM10 array in place; otherwise the calibration coefficient could vary by up to 10%. Standard S-type pitot probes for flow testing of industrial ductwork, stacks, or HVAC systems can be calibrated in a 4 sq.ft. cross section wind tunnel. Larger probes such as the PM10 sampling array require larger a wind tunnel or results could vary by 3-4%.

Appendix – More Test Photos

Figure 8. Airflow Engineer Andrew and summer interns Emily and Karolina assisting in probe calibration

Figure 9. Airflow Sciences at the University of Michigan Wind Tunnel

HVAC Fan Flow Testing for Grow Rooms

By: Jeff Everett and Karolina Rak, Airflow Sciences Corporation

Indoor grow rooms are a huge industry these days, with a wide range of agricultural products being grown inside the climate-controlled environment of greenhouses and warehouses all over the world. Keeping the temperature, humidity, lighting, and air circulation consistent within these grow rooms is a critical factor in maximizing plant growth and health. Most grow rooms have several air entry and exhaust locations,along with stationary or oscillating fans placed within the room to provide constant circulation and improve uniformity within the space. Figure 10 shows some typical grow room environments.

Figure 10. Climate-controlled grow rooms

In addition to CFD modeling for grow room HVAC design, Airflow Sciences performs lab testing of grow room equipment, including fans, filters, air conditioning, and humidity control systems. Recently, one of Airflow's customers in the indoor gardening business requested a flow and velocity characterization of a number of fans that they use and sell for grow rooms large and small. The fan flow testing effort involved wall mounted fans, ceiling mounted models, large floor fans, and oscillating stand fans.

Two primary tests were performed, one to determine the velocity profile exiting the fans and the other to characterize the fan flow rate versus motor setting. Both these parameters play a role in optimizing the flow patterns within the room, and also in providing inlet conditions used for Computational Fluid Dynamics (CFD) modeling. The flow patterns exiting a fan are quite complex, and thus require some sophisticated test instrumentation that can measure three-dimensional flow properties.

Innovations at ASC !

ASC personnel were awarded 2 patents over the past year and received a grant from the US Small Business Innovative Research (SBIR) program.

- US Patent 9,644,511 "Combustion Gas Cooling Apparatus, Denitration Apparatus, including the Combustion Gas Cooling Apparatus, and Combustion Gas Cooling Method", ASC inventors Paul Harris, Ph.D. and Kevin Linfield, Ph.D., P.E.
- US Patent 10,539,494 "Portable Apparatus for Testing or Calibration of a Particulate Emission Monitor", ASC inventors Bruce Devlin, Jeff Everett, and Rob Mudry.
- Department of Commerce NIST SBIR award "Advanced Instrumentation for Non-Nulling Stack Velocity Testing," principal investigator Matt Gentry.

HVAC Fan Flow Testing

(Continued)

Fan Testing Procedure

For the velocity profile measurements, a 3D velocity probe with a prism-style sensing tip (aka, DAT probe) was used. This probe is shown in Figure 11, with both a close up view of the probe and the 3DDAS™ flow measurement system which provides the accurate data collection. The probe is small, ¼" diameter, so its presence does not adversely influence the velocity patterns.

Figure 11. 3D Probe and 3DDAS Measurement System

The test set up for measurement of the fan discharge velocity profile is shown in Figure 12 for a large floor fan and Figure 13 for a ceiling mounted fan. The 3D probe is traversed over the cross section as shown in Figure 14. As indicated, a 15-point traverse across 2 paths at 90-degree orientation is used to provide full coverage of the fan discharge. The point spacing is based on equal areas, such that each data point covers 1/30 of the total cross section.

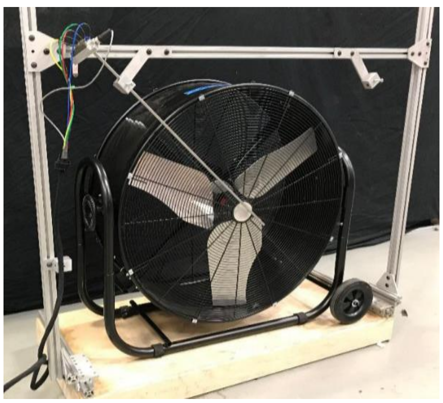

Figure 12. Floor fan velocity traverse set up

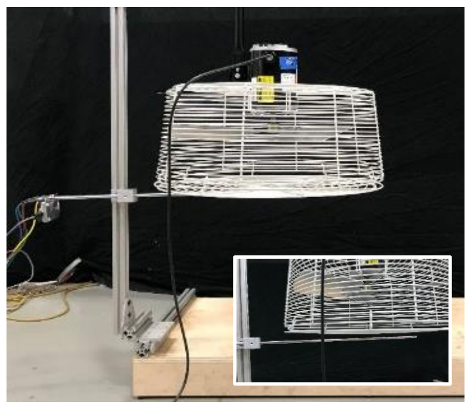

Figure 13. Ceiling fan velocity traverse set up

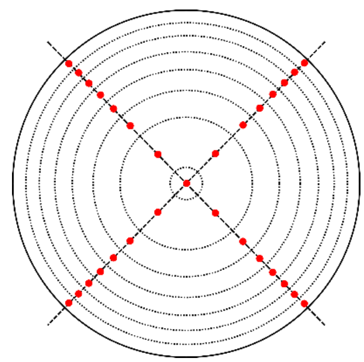

Figure 14. Traverse point layout

Mobile Sewer Odor Testing

ASC has been conducting sewer odor tests for several years (read the 2013 Fall newsletter article: "'Fan Test' Helps Design Odor Control Facility" for more details). Sewer odors can be quite offensive, but the odor-causing emissions can be reduced. An increasingly popular odor control technique is to depressurize the sewer system by withdrawing air with a suitably sized and located fan. With location and size optimized, the proper fan will:

- increase negative pressure of sewer system
- reduce odor-causing hydrogen sulfide (H_2S) concentrations emitted.

Airflow Sciences' Mobile Extractive Sewer Sampler (MESS) is equipped with the ductwork and fan necessary for mobile sewer odor control testing. The test rig allows for rapid data collection of pressure at varying fan speeds. These data are used for design validation or optimization prior to committing to the expense of installing a permanent system.

ASC's Moblie Extractive Sewer Sampler houses all the equipment necessary for efficient mobile sewer testing

Having sewer odor problems? ASC will send out our MESS to clean up yours.

HVAC Fan Flow Testing

(Continued)

The fan flow rate testing procedure involves measuring a number of parameters at each fan motor setting. This includes the pressure rise across the fan, blade RPM, fan amps, and volumetric flow rate. The flow rate is measured using an industry standard test protocol based on the Air Movement and Control Association (AMCA) Standard 210-16. This is also known as the American Society of Heating, Refrigerating, and Air Conditioning (ASHRAE) Standard 51-16. The test protocol requires that the flow measurement system does not adversely effect the fan performance, i.e. the instrumentation cannot cause any undo back pressure that alters the fan flow rate during the test. Airflow Sciences has several calibrated flow instruments that follow the AMCA/ASHRAE protocol. One system, for flow rate measurements (up to 1200 CFM), is the portable Air Flow Measurement Tunnel shown in Figure 15. Larger tunnels are used by ASC for higher flow rate systems, with capacity up to 30,000 CFM.

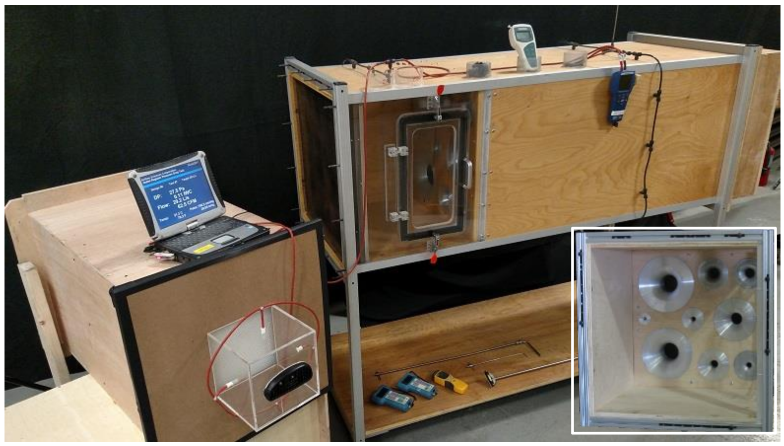

Figure 15. ASC Air Flow Measurement Tunnel

The procedure for using an AMCA flow tunnel to measure the volume flow involves installing the the test fan to a large open plenum that is connected to the front of the tunnel. A schematic of this test set up, taken from AMCA 210-16, is shown in Figure 16. The test fan is turned on to a specific motor setting so that air flows through the fan, plenum, and measurement tunnel. Then a variable speed exhauster fan, mounted at the outlet of the flow tunnel, is turned on and throttled until the static pressure in the plenum at the test fan outlet is zero. This effectively negates the flow resistance of the plenum and flow measurement instrument, as if the fan is free-flowing into an open room. The flow rate from the instrumentation is recorded, along with the fan RPM and amperage.

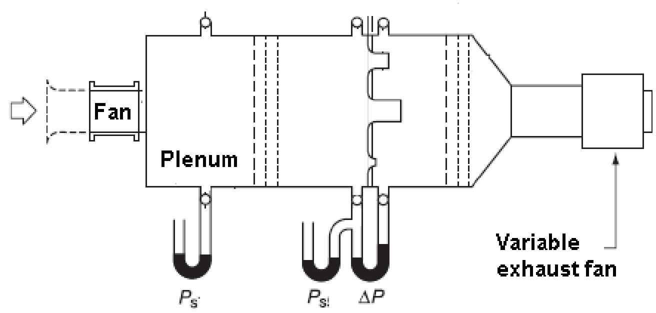

Figure 16. Fan test set up per AMCA 210-16

This test is repeated for each fan setting in order to obtain curves of flow rate versus fan setting. In addition, testing can be adapted per the methods of AMCA 201, which provides methodology to obtain the fan curve (i.e., fan flow rate versus pressure rise).

Results

In all ASC tested 27 different fans ranging in size from 8” to 48” diameter and flow rate between 400 CFM and 15,000 CFM. Example results are shown in Figures 17 and 18 for one example fan, a 36” diameter floor mounted drum fan. As Figure 17 indicates, the velocity profile is highly non-uniform, parabolic in shape, which is typical of propeller-style fan blades. There is a velocity deficiency at the center of the fan due to the presence of the motor and hub. The peak velocity occurs roughly 2/3 the distance from the centerline to the blade tip. Figure 18 is the measured fan performance curve. The plot distinguishes between the Upper half of the fan and the Lower half, and It is noted that the profile is not symmetric. This is because the Lower half of the fan is influenced by the floor, while the Upper half expands differently into the open room. Table 3 shows the fan flow rate versus motor setting for several example fans.

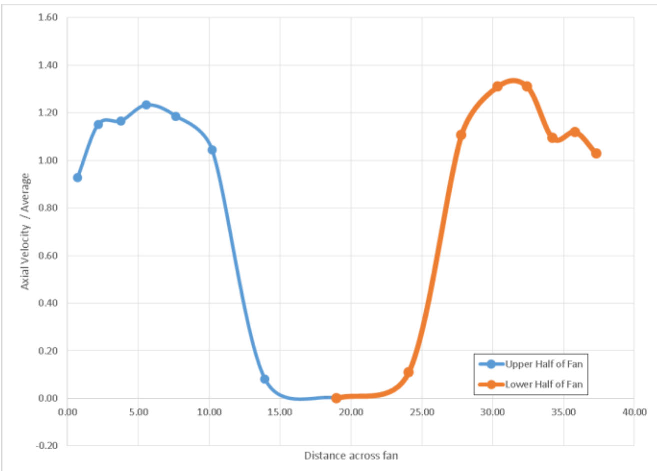

Figure 17. Example fan discharge velocity profile

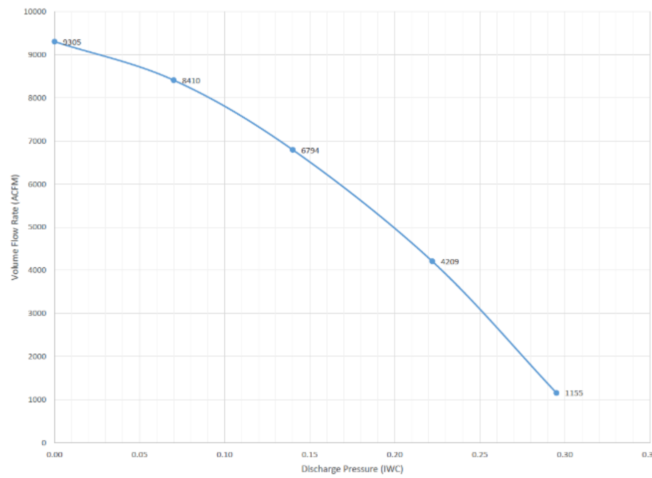

Figure 18. Example fan performance curve

Fan	Low Speed Setting		High Speed Setting	
	Flow (ACFM)	RPM	Flow (ACFM)	RPM
36” Drum fan	7740	690	9305	830
18” Oscillating wall fan	723	800	1021	1170
16: Orbital floor fan	822	1230	903	1410

Table 3. Example fan flow rate and RPM results at different motor settings

Summary

The performance of grow room fans is measured in a controlled laboratory environment with calibrated instrumentation in order to characterize the fan performance. Two different types of tests were required in order to measure both the fan flow rate and the discharge velocity profile. With these key performance data, grow room HVAC system designers can optimize flow uniformity and thus plant growth and health. The fan performance data will be used to specify the correct fans for different size grow rooms and also to import into Computational Fluid Dynamics models of the rooms. These CFD models are used to locate fans , climate control equipment, and sensors in their ideal locations within the indoor gardens.

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