Airflow Basics

It is not the intention of this paper to present all the aspects of the study of fluids at the collegiate level. However, it is the intention of this paper to expose the reader to the many configurations of airflow measurement. Much confusion exists about not only how to measure airflow through components, but even more about what to do with the collected data. Many myths are associated with airflow measurement than other practices of similar contexts because the air is not “seen,” so the data collection methods are fundamentally mistrusted.

Many “how-to-build-your-own-flowbench” magazine articles or Internet references exist, but these schemes are often based on incorrect or outright fraudulent information that supplies the user or builder with methods that lack a scientific or factual basis.

Understanding Airflow Measurements

Airflow can be measured through orifices, nozzles, or a venturito provide adequate data on airflow capabilities of components or complete engines. Volume flow rate is often selected for ease of application. Calculations can be made to provide reference for a baseline of measurements. However, flow evaluations are not intuitive, and one needs to learn the rules that apply in order to make a proper assessment.

The most basic equation for airflow measurement is Q = AV, where Q = Airflow in cubic feet per minute (cfm), A = Area of orifice in ft^2, V = Velocity in feet per minute (fpm).

It would be very convenient if things were truly that simple. The application of this equation can provide some useful information for general comparisons. Note, however, that no allocation exists for the coefficient of discharge (C_d) for the orifice under evaluation. Thus, the data provided by the basic equation is lacking in detail.

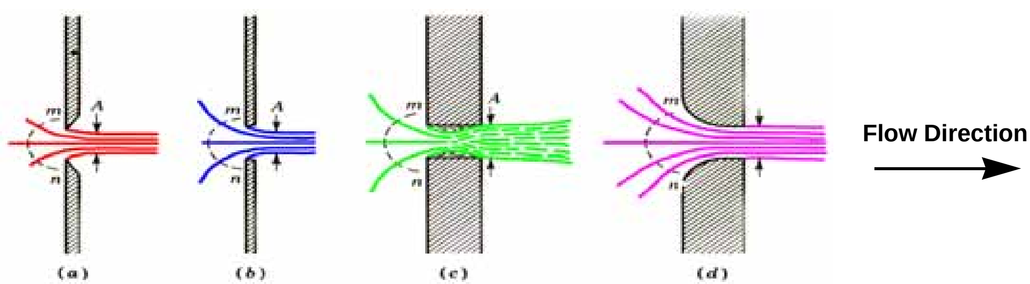

Figure 1. Even though each of the orifices above uses the same diameters, the coefficients of flow are not the same.

In order to get better resolution with the calculation, one must look at various C_d values for different orifice shapes because they are not all the same even if they are the same diameter. The simple equation of Q=AV becomes modified to be $\mathbf{Q = A(C_d K \sqrt{p_1})}$ where C_d = Coefficient of orifice, K = 4005 (this constant is for a sea-level reference where the air density is typically .075lbs / ft^3), and P_1 = pressure differential in inches of H2O. As an example, in Figure 1, the coefficient for orifice **(a)** is .62 while **(b)** is .60 to .62 depending on diameter and thickness, **(c)** is .86, while **(d)** is .98. As stated earlier, the study of fluids and their measurement is not nearly as easy as it might seem.

Orifices have different characteristics that must be addressed in calculations or design of flow measurement equipment or experiments. Issues that must be part of the analysis are such items as the various coefficients of orifices. Coefficient of Velocity (C_v), Coefficient of Contraction (C_c), and the Coefficient of Discharge (C_d) are all related to the overall shapes of orifices. The C_d = (C_v) (C_c).

Coefficients for tubes and entry effect variations are shown in Figure 2.

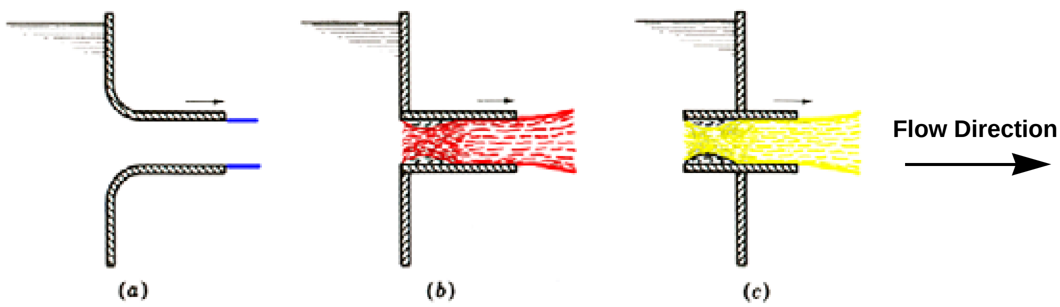

Figure 2. The coefficients of discharge for each of the profiles are not the same (a) .98 (b) .82 (c) .74 even though each example has the same diameter.

The coefficients vary, and one of the reasons for the variations is the phenomenon of the restriction to airflow caused by the Vena Contracta, shown in Figure 3.

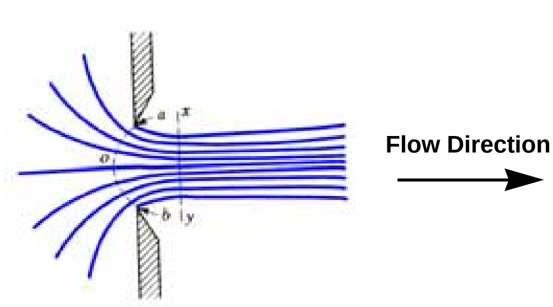

Figure 3. The diameter of the orifice, a-b, is not the same as the dimension of actual flow defined as x-y. The fluid flow phenomenon of the Vena Contracta creates the dimension x-y.

The following equations can also be applied for airflow measurement, which is, simply described, that flow rate (Q) is equal to the coefficient of discharge (C_d) times the cross-sectional area of the orifice times the velocity of flow. This applies readily to a sharp-edged orifice and is using metric units.

$$Q = 1864 C_d d^2 \sqrt{hT_a} / P_a$$ **where Q = Airflow in cubic meters per second**

C_d	=	**Coefficient of Discharge**
d^2	=	**diameter of orifice (mm), squared**
h	=	**head (mm H_2O)**
T_a	=	**Temperature absolute (°C + 273)**
p_a	=	**pressure absolute**

One can apply the following equation to something such as a carburetor venturi.

$$Q = A_2 / \sqrt{1 - (A_2 / A_1)^2} \sqrt{(2g_c / \rho)(p_1 - p_2)}$$ **Where Q = Ft^3/sec**

A_1	=	**Ft^2**
A_2	=	**Ft^2**
g_c	=	**32.17ft/lb-sec^2**
ρ	=	**rho, Greek, air density lb/ft^3**
p_1	=	**lb/ft^2**

Although lacking great precision, you can quickly estimate flow volume of air in cfm using the following equation:

$$q = 411(d^2)\sqrt{(1.02 ¥ 10^{-3})}(T_p)$$ **Where q = flow in cfm**

d	=	**diameter of orifice (inches)**
T_p	=	**test pressure “H_2O**

Many assumptions are made with this simple equation, one being that the fluid is air, another being that the C_d is held constant at .60, so round orifices in thin material are allowed for.

Applying the following equation provides the calculation of local air density that can be used for simple airflow work:

$\rho = 1.325 (P_b / R)$ **Where ρ = rho, Greek, air in lbs/ft^3**

P_b	=	**local barometric pressure in Inches of Mercury (“Hg)**
R	=	**Rankine Temperature (°F + 460)**

Many other equations can be used to initially evaluate a system or components, but it is more common in industry to actually measure the components on an air flowbench that is properly calibrated. It is most common to compare tested parts on a volume flow basis and at the same test pressures. Sometimes the requirement is to correct the volume flow data to mass flow data.

Flowbenches

Air flowbenches and flow measurement systems operate on multiple principles and applications of airflow measurement, with the most common being the use of flat plate, sharp-edged orifices or Pitot tube systems. Some designs also use a laminar flow element for measurements or even positive displacement measuring devices. Also used for flow measurement are sonic nozzles, ASME nozzles, hot-wire and hot-film anemometers, and Laser Doppler Anemometers (LDAs).

While various problems may be inherent with each design, you can generate good results if you apply good test procedures and see a clear path of where the numbers come from. Regardless of the process applied, typically there is a measurement across a known section (flow pressure) which is the flow measurement and a pressure measurement across the device to be tested (test pressure). See Figure 4 for a cross-sectional view of a SuperFlow design typical of models SF-300 / 600 / 1200. These particular designs are ratiometric, volume flow measurement units and provide an easy comparison of data independent of atmospheric conditions so the user does not have to compute correction calculations for changing atmospheric conditions.

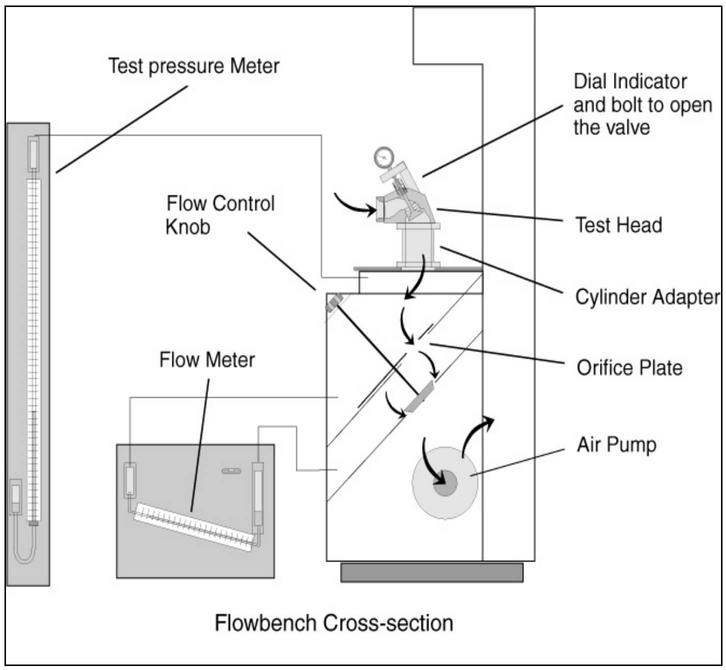

Figure 4. A properly calibrated flowbench is often the easiest way to measure airflow of components in order to compare results with other testers or developers. Good test results are often the result of applying good test procedures. Flowbenches of this general design are typically used for airflow applications from only a few cfm to over 1200 cfm at test pressures from 3"H_2O to more than 60"H_2O.

References

Many textbooks on fluids and fluid flow are available. If you would like to pursue this subject further, the references below are reliable sources.

Fluid Mechanics With Engineering Applications, Robert L. Daugherty and Joseph B. Franzini, 1965, McGraw-Hill, ISBN 0-07-015427-9.

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