All Sensors ***Pressure Points*** are application tips to simplify designing with microelectromechanical systems (MEMS) pressure sensors and avoiding common pitfalls.

Pressure Point 11: Calculating Flow Rate from Pressure Measurements

Fluid flow occurs with the motion of liquid and gaseous materials and pressure sensors play a critical role in determining many aspects of fluid flow. Fluid dynamics provides the means of understanding the parameters that impact fluid flow. The active links in the following sections provide more details.

Basic Fluid Dynamics Concepts
Reynolds number (Re) is a dimensionless velocity value used to predict flow patterns. It is a function of the inertia force (ρ u L), and the viscous or friction force (μ).

Viscous vs. Nonviscous Flow
Viscous flow results in energy loss (and subsequently a temperature rise) but ideal fluids have nonviscous flow with no energy loss.

Laminar (Steady) vs. Turbulent Flow
In laminar flow, the particle motion is very uniform/orderly and results in straight lines parallel to the enclosure's walls and is very predictable. With turbulent flow, random motion can result in eddies and other less predictable behavior. A mixture of laminar and turbulent flow, called transitional flow, occurs in pipes and other enclosures with turbulence in the center of the enclosure, and laminar flow near the edges. More viscous fluids tend to have laminar flow and a lower Reynolds number.

Compressible or Incompressible Flow
Unlike compressible flow where the density changes with the applied pressure, with incompressible flow, the density is constant in space and time.

Bernoulli's Equation is used to determine fluid velocities through pressure measurements. It starts with qualifications of nonviscous, steady, incompressible flow at a constant temperature.

$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$

P = pressure
v = velocity
ρ = density of the fluid
g = gravity
y = height

The Venturi effect is increase in velocity that occurs when fluid flow is restricted. The Venturi meter is an application of Bernoulli's equation. Common types of restrictions include orifice plates, Venturi tubes, nozzles and any structure that has an easily measured pressure differential.

Flow in a Pipe/Tube. Several factors determine the pressure drop that occurs in fluid flow applications including laminar versus turbulent flow, the flow velocity, kinematic viscosity and Reynolds number of the fluid, internal roughness of the inside of the pipe as well as its diameter, length and form factor. Orifice plates, Venturi tubes and nozzles simplify the situation. In these cases (refer to Figure 1), the flow is related to ΔP (P_1-P_2) by the equation:

$q = c_d \pi/4 D_2^2 [2(P_1 - P_2) / \rho(1 - d^4)]^{1/2}$
Where:
q is the flow in m^3/s
c_D is the discharge coefficient, the area ratio = A_2 / A_1
P_1 and P_2 are in N/m^2
ρ is the fluid density in kg/m^3
D_2 is the orifice, venturi or nozzle inside diameter (in m)
p1"> D_1 is the upstream and downstream pipe diameter (in m)
and $d = D_2 / D_1$ diameter ratio

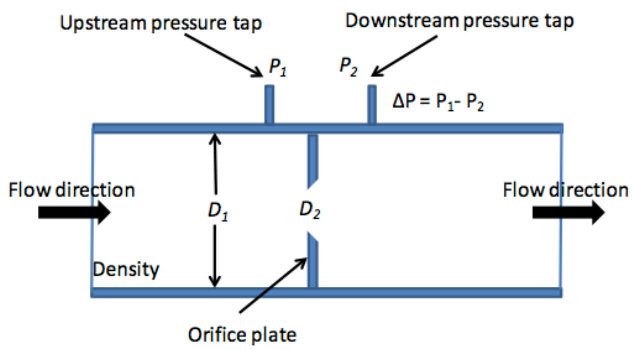

Figure 1. Elements of a ΔP flow measurement.

Pitot tubes use the difference between total pressure and static pressure to calculate the velocity of the aircraft or fluid flowing in the pipe or enclosure. A Pitot-static tube for measuring aircraft velocity is shown in Figure 2.

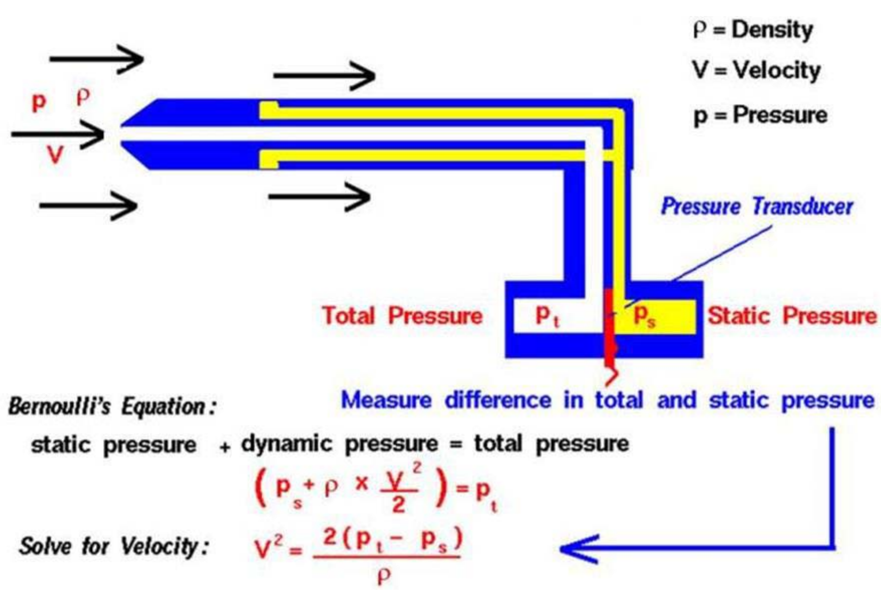

Figure 2. A Pitot-static or Prandtl tube used to measure aircraft velocity.

Water hammer is the shock caused by the sudden decrease in velocity of a flowing fluid and the time it takes for the pressure wave for round trip travel in the pipe. The Joukowski impulse equation is used to calculate the resulting pressure when the liquid velocity that drops to zero upon contacting a closed valve.

$\Delta P = \rho \cdot c \cdot \Delta V$
In psf

For rigid pipes, the celerity of the pressure wave or wave speed, c, is found by:

$c = \sqrt{E_B/\rho}$

where E_B is the bulk modulus of fluid in psf and ρ is the density of the fluid.

Measurements in Specific Applications
In the medical area, respiratory issues require airflow measurements for ventilator flow/control, and analysis, such as spirometers, as well as gas and liquid flow measurements for treatment. For example, the differential pressure in a spirometer or respirator is nominally 4 kPa and in a ventilator, it is nominally 25 cm H_2O. In either case, the values are quite low and the pressure measurement requires special consideration in the pressure sensor to achieve the desired accuracy and precision.

HVAC
Clean and low power consumption in heating, ventilation and air conditioning (HVAC) systems require the proper air filters and frequently monitoring to identify a filter that requires changing. Normal operating pressures are typically in the range of 0.1 to 1" H_2O. The American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE's) minimum efficiency reporting value, or MERV rating, measures the effectiveness of air filters. Sensing the pressure drop across an air filter minimizes unnecessary power consumption by motors.

Tools for Fluid Calculations and Simulation
Online calculations tools from efunda, KAHN, LMNO Engineering, valvias, Pressure Drop Online-Calculator and others can provide some quick tools to implement the calculations shown previously. In addition, several companies offer advanced simulation tools for computational fluid dynamics and consulting services to delve much deeper into the more sophisticated and complex issues involved with fluid flow, including: ANSYS, Applied Flow Technology, Autodesk, MathWorks, SOLIDWORKS, and others.