Estimates of the Uncertainty of Speed Measurements

The (incompressible) speed measured by a Pitot static tube and a pressure based instrument (such as our FKT series meter) is calculated from the recorded differential (or dynamic) pressure, q, density, ρ, of the fluid, and the probe coefficient, C. The speed is given by

$$V = C\sqrt{\frac{2 \cdot q}{\rho}}$$

If the density is calculated using the ideal gas law then the speed, based on dynamic pressure (q), temperature (T) and ambient pressure (P) sensor readings, becomes

$$V = C\sqrt{\frac{2 \cdot q \cdot R \cdot T}{P}}$$

where R is the gas constant. Temperature is in absolute units (such as Kelvin or Rankine).

Each sensor reading (q, P, and T) has an uncertainty (U) associated with it, so the full speed uncertainty may be expressed below: (see http://www.flowkinetics.com/uncertainty-analysis.htm)

$$U_V = C\sqrt{\left(\frac{\partial V}{\partial q}\right)^2 {U_q}^2 + \left(\frac{\partial V}{\partial T}\right)^2 {U_T}^2 + \left(\frac{\partial V}{\partial P}\right)^2 {U_P}^2}$$

Substituting the differentials, based on the speed equation, the above expression becomes:

$$U_V = C\frac{R}{2P} \cdot \sqrt{\frac{2 \cdot P}{q \cdot R \cdot T}} \sqrt{\left(T \cdot U_q\right)^2 + (q \cdot U_T)^2 + \left(\frac{q \cdot T \cdot U_P}{P}\right)^2}$$

The uncertainty for each reading depends on the characteristics of each sensor and should be determined from the manufacture's specifications.

As an example, assume a test with the following test conditions and parameters:

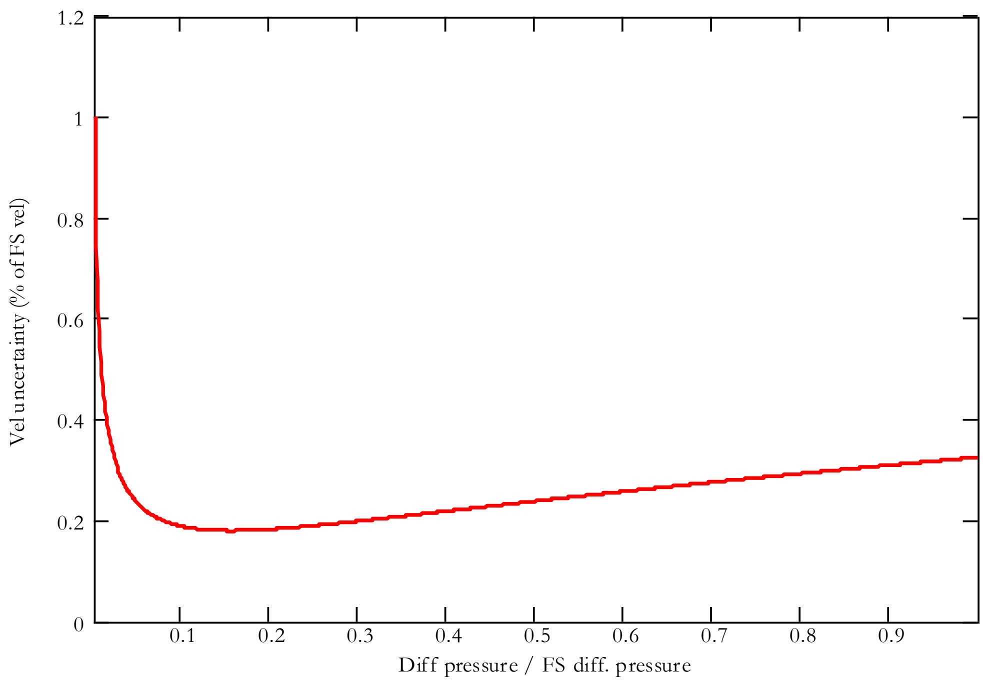
- $P = 101325\ Pa$ (Ambient pressure)
- $T = 293.15\ K$ (20°C) (Ambient temperature)
- $R = 287.026 \frac{Joule}{kg \cdot K}$ (Gas constant for air)
- $q\ full\ scale = 1240\ Pa$ (Full scale dynamic pressure for a 5 inchH2O sensor)

- $V\ full\ scale = 45.5\ m/sec$ (Full scale speed for a 5 inchH_2O sensor)
- $P\ full\ scale = 115000\ Pa$ (Full scale pressure for absolute/ambient sensor)
- Probe coefficient, $C = 1.0$

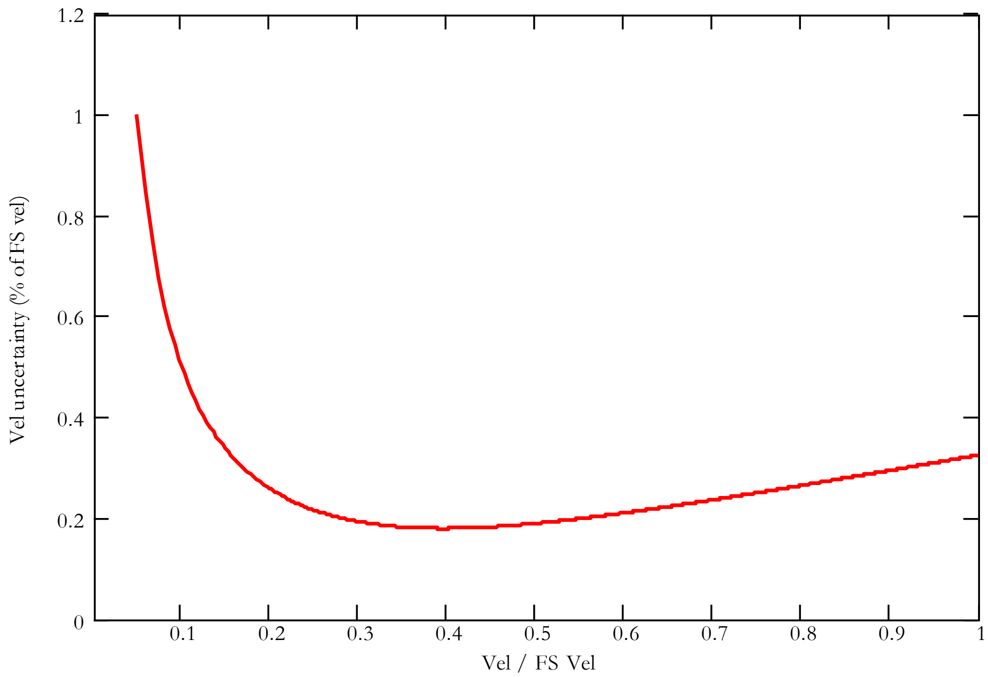
Using the values above the uncertainties are:

- $U_q = \pm 0.1\%\ of\ q\ full\ scale = \pm 1.2\ Pa$
- $U_T = \pm 1℃\ or\ \pm 1K$ (Fixed value)
- $U_P = \pm 0.5\%\ of\ Pfull\ scale = \pm 552\ Pa$

Using the above values in the full uncertainty expression and plotting for different values of dynamic pressure, as a ratio to full scale differential pressure, gives



The uncertainty, as a function of speed, is shown below:



The plots show, as with any Pitot based system, that the uncertainty in the speed is larger than that in the differential pressure. However, as long as measurements are not taken at the low end of the transducer's range, accuracy is still maintained.

To prevent large speed uncertainties the dynamic pressure should not be measured below a certain point. For this example we can assume that the desired maximum allowable uncertainty in speed is 1% of full scale speed. Substituting this value into the equations above and solving for the minimum dynamic pressure results in the following:

$$\frac{q\ minimum}{q\ full\ scale} = 0.25\%$$

Or in terms of speed:

$$\frac{V\ minimum}{V\ full\ scale} = 5\%$$

So for our example the minimum dynamic pressure for a maximum of 1% speed uncertainty is

$$q\ minimum = 3.1\ Pa$$

$$V\ minimum = 2.27\ m/sec$$

So the recommended speed range is 2.27 to 45.46 m/sec. Readings taken below the minimum will have uncertainties above 1% of full scale speed and may not be useful for practical purposes.