Sonic Thermometry

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Sonic anemometers have had extensive use in the scientific community. These instruments are used to measure atmospheric parameters that most rotating instruments cannot. Wind speed and wind direction or individual axes of wind velocity are most commonly measured. Along with these measurements, another parameter can be extracted from the sonic anemometer (i.e.), sonic temperature.

Since the transit time measurement method is used by sonic anemometers for wind, it is independent of temperature, relative humidity, and pressure. The common method of computing wind velocities is:

$$V = d/2\ (1/t_1 - 1/t_2) \tag{1}$$

Where t_1 ant t_2 are transit times in the opposing directions, d is the distance between the transducers.

In order to determine the distance between transducers, it is necessary to calibrate the sonic anemometer, using a zero-air chamber placed over the instrument axis to be calibrated and inserting a temperature probe into the zero-air chamber. Since there is theoretically no wind movement, the transit times will be effectively equal. One can then compute the speed of sound by:

$$C = (\gamma RT/M_d)^{1/2} \tag{2}$$

Where γ is the ratio of C_d and C_v of dry air, (1.4 is commonly used), R is the universal gas constant, latest value 8314.51 (N·m/kmol·K), T is the temperature of calibration in Kelvin, and M_d is the mol value of dry air (28.954812).

From the transit times of the sonic anemometer, the speed of sound can be computed as follows:

$$C^2 = d^2/4\ (1/t_1 + 1/t_2)^2 + V_n^2, \tag{3}$$

V_n^2 is the crosswind contamination component

Substituting the calibration speed of sound into the above equation, it can be solved for d the distance between transducers. This d value remains stored in the anemometer memory until the unit is recalibrated.

In most three axis sonic anemometers, of u, v, w, the w axis is the axis normally chosen to represent the sonic temperature. It is also worth noting that in many tri-axis sonic anemometers, the w component is not directly measured, but is algebraically derived from tilted axes. A recent paper published in the June 6, 2012 issue of Journal of Boundary-Layer Meteorology, titled "*How Well Can We Measure the Vertical Wind Speed? Implications for Fluxes of Energy and Mass"*, discussed that research-grade three-dimensional sonic anemometers, currently in use, should be redesigned to minimize sine errors by measuring the vertical wind speed using one pair of vertically aligned transducers. The conclusion of this study was that estimates of w from one pair of vertically aligned transducers experienced negligible angle-of-attack errors at typical flux angles.

The sonic temperature parameter along with velocity values of the vertical axis (w) are used to compute momentum flux, sensible heat flux and friction velocity. For these flux measurements, the absolute value of the sonic temperature is not necessary. The fluctuations at 10 Hz or more is the primary factor. Other atmospheric parameters can be determined by using the sonic anemometer with conjoined instruments.

For a two-axis sonic anemometer, the measurement of the wind velocities in the horizontal plane is the primary usage. One or both of these axes can be used to determine the sonic temperature as derived in the above equations. The axis used to determine the speed-of-sound cannot be the axis used to supply crosswind contamination values.

For a requirement to measure absolute or ambient temperature, it should be noted that the calibration was accomplished using dry air as the denominator in equation (2). Kaimal, 1990, (*Another Look at Sonic Thermometry*), has shown the sonic temperature measurement is subject to errors due to the humidity in the air.

$$C^2 = 403T\ (1+0.32e/P) \tag{4}$$

Where 403 is the product of $\gamma R/M_d$, this value has been since upgraded by ATI to reflect the latest R and M_d, (401.8778). The value of CO_2 has since risen to 394.5 ppm, increasing the molecular weight of dry air. The factor e is the vapor pressure of water and P is the atmospheric pressure in Pa.

Dr. Kaimal, has shown that, discounting the effects of humidity, for a calculation of atmospheric temperature from sonic temperature can be erroneous by as much as 2.4° C. This effect is computed from his paper,

$$T_s = T\ (1 + 0.32\ e/P) \tag{5}$$

The value 0.32 has been upgraded to 0.3279 because of change in molecular weight of dry air. The altitude that the sonic anemometer is operating (i.e.) pressure cannot be predicted, so 920 kPa was chosen as a median pressure between Boulder, CO and sea level. Plotting equation (5) at 20° C for T shows a negative slope of -0.024, indicating the possible error of 2.4° C at 100 percent humidity. The sonic anemometer temperature (T_s) will always be high due to the amount of humidity in the air.

By applying an algorithm to the sonic temperature computed, a value of the atmospheric air can be obtained with some degree of accuracy.

ATI Temperature Calculation

ATI has for some time understood the effect of humidity on the calculation of atmospheric temperature from sonic temperature. One of the choices of our instrument is the capability of inserting a known humidity factor when calibrating. When calibrating the instrument the software asks for "Temp C" the temperature inside the zero-air chamber. When a value is inserted, a second query asks for "RH". At this point an operator may insert the humidity that is closest to that inside the zero-air chamber.

The calibration, when complete, has computed a "d" commensurate with a known value of humidity. If this same humidity were encountered in the outside atmosphere, the value returned for sonic temperature will be the same as that temperature inserted in calibration.

Another feature of the ATI sonic anemometer is that a menu selection allows the operator to choose the relative humidity, in which the instrument will be operating, from 0 to 100 percent. If 50 percent were chosen, this adjusts the sonic temperature due to relative humidity to a mid-range of 0 to -2.4º C. The error of calculation is now halved to 1.2º C or ±0.6º C. If the outside relative humidity does not deviate much from the 50%, the error is probably much less. By this means, the ATI sonic anemometer can provide nearly-accurate temperature of the outside environment, lessening any post-operation data correction.

For comparing sonic anemometers, the ATI sonic anemometer could be used as a standard to which others are compared. Again, referring to the Journal of Boundary-Layer Meteorology paper discussed earlier, some of the sonic anemometers used in scientific study are examined.