EAS 535 Laboratory Exercise
Anemometer Calibration

Lab Objectives:

Calibration of 5 anemometers in preparation for deployment on profile mast at Cherry Lane.

Materials required:
5 Anemometers
1 AC-DC converter box
1 DT-50 data logger
1 PC with installed Determinal software and serial cable
1 Sling psychrometer w/ distilled water wash bottle
and other humidity/temp measurement device
1 Psychrometric computer
1 Davis weather station console for measuring pressure + correction
1 Wind tunnel (Prof. Collicot, 4-5131)
Vans for transportation to airport

Background:

The purpose of this lab exercise is to carefully calibrate anemometers over a wind speed range of about 0–15 m s\(^{-1}\). These sensors are intended for deployment on a 100-foot instrument mast in order to measure wind profiles in conjunction with temperature profiles measured by the AD590s calibrated in the thermometer calibration exercise. Students will be divided up into teams and each team will be responsible for the calibration of one anemometer.

The anemometers we will be using produce a sinusoidal (alternating current, or AC) voltage that is proportional to the anemometer's rotation rate. The frequency of the AC voltage is also proportional to rotation rate. In principle, there could be two ways to measure wind speed: (1) measure the frequency of the AC signal; (2) measure the voltage. The first method would be more precise and less subject to interference and signal degradation; however, it also requires somewhat more complex electronic circuitry. The second approach is simpler in that the DT50 data logger is equipped to directly log voltage values.

The only complication is that the DT50 does not know how to deal with an AC signal. Since it merely samples an instantaneous voltage at regular intervals in time, the voltage it detects depends on where the sample occurs in relationship to the sinusoidal input. This voltage can fall anywhere between the peak positive voltage and the peak negative voltage at a given instant in time. The solution is to pass the signal from the anemometer through a circuit which rectifies and filters the AC signal, converting it to a DC signal whose voltage is proportional to the amplitude of the original AC signal. Thus, the complete setup includes the anemometer itself, the datalogger, and a "black box" AC-DC converter between the two.

Your team's task will be to install your anemometer in the wind tunnel and log the output voltage of the anemometer and AC-DC converter for a series of calibrated wind speeds. You will then use these measurements to derive a calibration function \( U(V) \), where \( U \) is the wind speed and \( V \) is the measured voltage.
Measurements:

One team at a time will perform the calibration runs in the wind tunnel for their anemometer.

1. Physically install the anemometer on the stand in the wind tunnel and make the electrical connections. The anemometer should be reasonably close to the pitot tube, which will be used to measure the actual wind speed in the wind tunnel, so as to ensure that both are sensing the same wind speed.

2. Plug the anemometer leads into the matching channel on the upper row of the AC-DC converter and complete the connection to the appropriate channel of the DT-50 (if not already done).

3. The calibration standard will be a water manometer, which is connected to the pitot tube. Changes in wind speed create changes in the dynamic pressure sensed by the pitot tube. The pressure change is indicated by the level of the water in the manometer tube. Before beginning the experiment, accurately read the water manometer on the tunnel when the tunnel is turned off. This reading (in units of inches of water) gives the baseline for zero wind speed. Record this baseline value, $p_0$, in your notes. It represents your first calibration point (for zero wind speed). Calculations of all non-zero wind speeds will be based on the difference between the corresponding manometer readings and the zero (baseline) value. If you have to wait your turn for the use of the wind tunnel, this would be a good time to skip ahead to step 7 and calculate the target manometer readings for your third and subsequent calibration points.

Note that although a log sheet will be provided for your observations, you are still responsible for noting all the accessory information in your lab notebook, including sketches. The log sheet should be glued or taped into your lab notebook.

4. With the DT-50, log approximately 30 seconds of anemometer voltage at 1 second intervals with the wind tunnel turned off. Note in your lab notebook the approximate anemometer voltage during this time period and the time. This will help identify the values for that observation in the recorded data file.

5. You will need to convert dynamic pressure to the actual wind speed. The relationship between pressure and wind speed depends on the density $\rho$ of the air, which in turn depends on the virtual temperature $T_V$ and pressure $p$. You must therefore use a sling psychrometer to measure the dry bulb and wet bulb temperatures of the ambient air in the wind tunnel lab and make use of one of the Davis weather stations to check these values. Write down these values in your notes. Use a psychrometric computer to convert $T$ and $T_w$ to dewpoint $T_d$ in the first step, and then convert $T_d$ to RH in the second step. Write all values down in your notes. Write down the pressure, temperature, relative humidity and dewpoint temperature from the Davis weather sensor. (we will assume that the static pressure is the same inside and outside the wind tunnel). Calculate the density from these measurements using the equations at the appendix of this document.

6. Adjustable baffles on the wind tunnel control the wind speed inside the tunnel. Turn both handles clockwise to close (less wind), turn handles counter clockwise to open (more wind). Initially, they should be shut completely. Start the wind tunnel motor, and after allowing things to stabilize, check whether the anemometer is rotating slowly. Accurately record the level on the water manometer. It should be slightly higher than when the tunnel was turned off. Once again, log approximately 30 seconds of anemometer voltage at 1 second interval and note in your lab notebook the approximate anemometer voltage.

7. You should now go through a cycle of opening the baffles further to increase the wind speed, letting the wind tunnel and anemometer assembly settle down for at least 15 seconds, accurately noting the water manometer level, recording the time and the approximate voltage, and then electronically logging...
approximately 30 seconds of anemometer voltage with the DT-50. Target manometer displacements are approximately the following:

0.005, 0.01, 0.02, 0.03, 0.04, 0.08, 0.15, 0.30, and 0.50 inches above $p_0$.

Add these values to the baseline value you observed with the tunnel off in order to get the approximate values you want to see indicated on the manometer. Note that it is not necessary to hit these values exactly, provided only that the value doesn’t change during the observations, and that you carefully note the ACTUAL values displayed to the best accuracy you can get. Record the value from the manometer right AFTER the 30 seconds of data have been logged. Also, note that you may have to drop the lowest target value (if it is less than or equal to the minimum value when the baffles are completely shut) and/or the highest value(s) (if the anemometer output exceeds the range that the DT-50 can record). In the latter case, use the highest speed that doesn't lead to logger errors.

8. Calculate the wind speed from the manometer pressure using the following formula for the relationship between manometer pressure and wind speed

$$U = \sqrt{\frac{2(p_t - p_o)}{\rho}}$$

where $p_t$ is the manometer pressure measured in inches of H$_2$O, $p_o$ is the manometer reading with the wind tunnel turned off, and $\rho$ is the air density in kg/m$^3$. Keeping all values in SI units will ensure that the speed $U$ is in m/sec. Fill in the chart for all values of $p_t - p_o$.

Note: (1 in H$_2$O = 249Pa)

9. In the next part of the lab, you will plot the value of $U$ on the y-axis and the approximate anemometer voltage you noted on the x-axis. Is there a linear relation between the voltage and $U$?

10. In time for the next lab period, the data recorded from the DT-50 will be made available for you to copy to your home account, from which it can then be read in by EXCEL. The manometer measurements and other data from your notes must be entered into your EXCEL spreadsheet by hand. An electronic copy of the spreadsheet will be provided for this purpose.

**EXCEL work:**

Note: Make sure that your equations are dimensionally correct. Always examine your numerical results for reasonableness, for example by comparing your calculated wind speed values with the approximate values observed on the water manometer. Also, be sure to annotate all of your calculations with explanatory text, and clearly indicate which anemometer (unit 1–5) your team is calibrating. In excel you will come up with an exact calibration relationship between anemometer voltage and wind speed by averaging the voltage measurements to obtain a more accurate value.

1. Data files from the DT-50 will be provided. There will be a separate file for each anemometer. The file names will be something like "airport1.xls", "airport2.xls", etc. The "1" or "2" indicates the sensor number.

2. Set up the formulas in excel you need to convert the observed dynamic pressure in inches of water to actual wind speed $U$ in SI units (m s$^{-1}$). Among other things, you will need the Ideal Gas Law, formulas for computing specific humidity $q$ from $T_d$, and virtual temperature $T_v$ from $T$ and $q$. In addition, you will need the following formula for the relationship between manometer pressure and wind speed.
\[ U = \sqrt{\frac{2(p_t - p_o)}{\rho}} \]

where \( p_t \) is the manometer pressure and \( \rho \) is the air density. (1 in H\(_2\)O = 249Pa)

3. For each anemometer run with a given manometer pressure, compute the actual wind speed \( U \) in m s\(^{-1}\) from \( p_t - p_o \). Store these values in a column whose number of elements is the same as the number of runs (including the run with the wind tunnel turned off, for which \( U = 0 \)). [Note: If there seems to be a mismatch between the number of logged runs and the number of values you recorded for \( p_t \), then you will have to determine which measurement(s) were extras and skip over them.]

4. For each of your team's anemometer runs, determine which of the logged anemometer voltages correspond to the given manometer setting from the time in your lab notebook or the approximate voltage value that was noted in your lab notebook. Use built-in EXCEL functions to (a) automatically determine the sample size \( N \), (b) compute the average voltage \( \overline{V} \), (c) compute the standard deviation \( \sigma_V \) of the voltage, and (d) determine the statistical uncertainty (or standard error) \( \sigma_{\overline{V}} \) in the computed mean voltage \( \overline{V} \). This last variable is given by:

\[ \sigma_{\overline{V}} = \frac{\sigma_V}{\sqrt{N}}. \]

5. Plot \( \overline{V} \) from step 4 versus the true wind speed \( U \) from step 3. Use error bars to indicate the uncertainties represented by \( \sigma_{\overline{V}} \) (hopefully, these error bars will be almost invisible, since the expected errors are small).

6. Verify that the relationship between voltage and wind speed looks reasonable. The relationship should be quite linear for wind speeds above about 5 m s\(^{-1}\). At lower wind speeds, there could be a kink in the curve reflecting a somewhat lower sensitivity (flatter response) of the anemometer. If any of your plotted points appear to fall noticeably outside of the expected curve, check for possible errors in the values you entered.

7. Calculate the calibration equation of the form \( U = m \overline{V} + b \) from your values.

8. Once you have confidence in your calibration data set, copy your \( \overline{V} \) vector and your \( U \) vector to a single page in a separate excel file and copy the values \( m \) and \( b \). Make a third column where you calculate a predicted value of wind speed \( U' \) using your calibration equation. Make a fourth column where you subtract \( U \) from \( U' \). Are these differences close enough to confirm that your calibration equation is accurate. Compare to other teams values for the other anemometers. Email this separate one page excel file to the instructor, in addition to providing the lab report with your results.

**Appendix:**

Here are some equations that you may need:

\[ \rho = \frac{p}{R_d T_v} \]

where
\[ R_d = 287 \frac{J}{kg \cdot K} \]

and

\[ T_e = T(1 + 0.61r) \]

where \( r \) is specific humidity (dimensionless) and \( T \) is absolute temperature;

\[ r = \frac{\varepsilon e}{p - e} \]

where \( \varepsilon = 0.622 \); and

\[ e_s(T_C) [Pa] \approx 611.2 \exp \left( \frac{17.67T_C}{T_C + 243.5} \right) \]

where \( T_C \) is the temperature in degrees Celsius. If you substitute \( T_d \) for \( T \) in the above, then you get \( e \) rather than \( e_s \).

Also, if your instrument measures relative humidity rather than dewpoint, you can get the vapor pressure, \( e \), using

\[ \frac{RH}{100\%} = \frac{e}{e_s} = \frac{q}{q_s} \]