Wind measurements exercise – Calibrating and using a cup anemometer

Introduction

You have seen cup anemometers in the lectures. These are the most common instruments for measuring wind speed in wind energy. Cup anemometers rotate at a speed that is very linearly proportional to the wind speed. However, the physics are so complex that it is necessary to calibrate the instrument in a wind tunnel in order to find the transfer function between rotational speed and wind speed. In this exercise, you will calculate the transfer function of the cup anemometer and then use this to determine some calibrated wind speeds from raw cup anemometer signals.

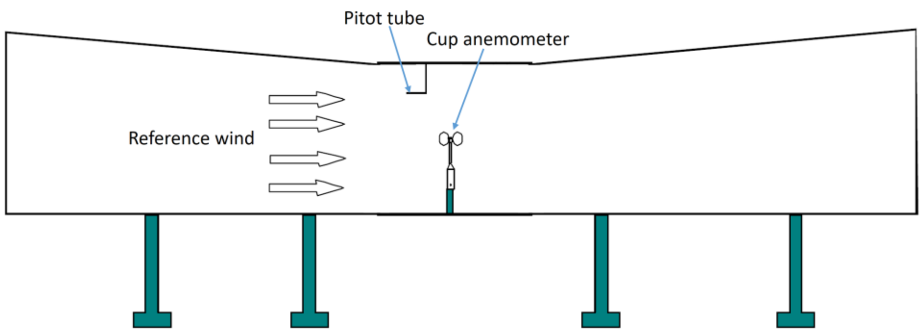
Learning objectives:

On completion of this exercise, you will be able to:

- Explain how a cup anemometer measures wind speed
- Calculate a cup anemometer calibration from wind tunnel measurements
- Use a cup anemometer calibration to calculate calibrated wind speeds from field data.

Cup anemometer calibration

The first step is to determine the transfer function between cup rotational speed and wind speed. To do this, we put the cup anemometer in a wind tunnel as shown below.



The reference wind speed can be controlled and is set to a number of different values in succession. For each different wind speed, the rotational frequency of the cup anemometer is determined from its electrical signal and the differential pressure measured by the pitot tube is simultaneously logged. Such a set of recordings is available to you in file Calibration_data.txt. Now perform these steps:

1) Load this data into a spreadsheet, a Python data-frame or something similar

2) From the differential pressure dP, calculate the reference wind speed V for each row of the dataset, using the equation

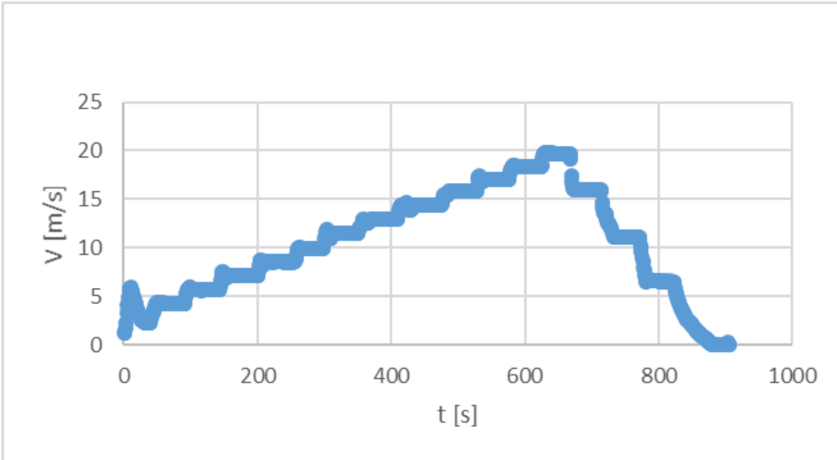
$$V = \sqrt{\frac{2. dP}{\rho}}$$

where ρ is the air density. For the test period, the air temperature t was 27.2 °C and the barometric pressure B was 1007.0 hPa. Use the equation

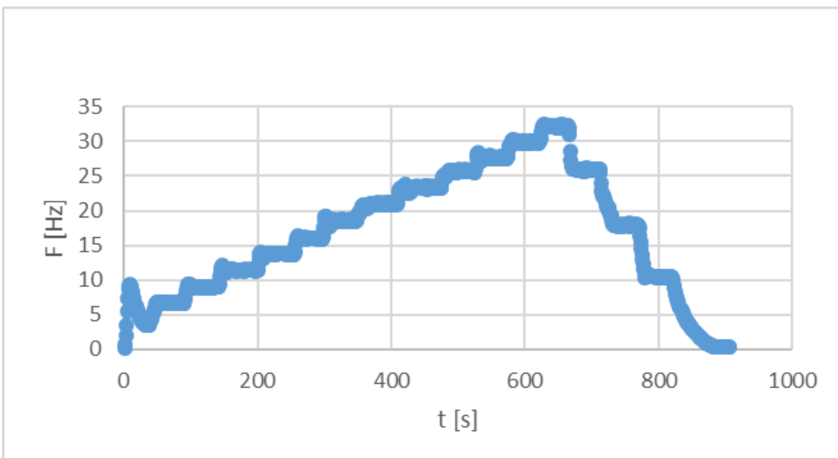
$$\rho = 1.225 \, \frac{288.15}{t + 273.15} \, \frac{B}{1013.3} \; [\frac{kg}{m^3}]$$

to obtain the value of ρ for the actual conditions under the calibration.
[Hint: For a differential pressure of 20.55 Pa (10^{th} line of the file) the wind speed will be 5.94 m/s.]

3) Plot the time series of reference wind speeds (the data are recorded at 1 scan/sec). You will see a 'staircase' of wind speeds increasing up to about 20 m/s and then returning in 3 steps back to zero:

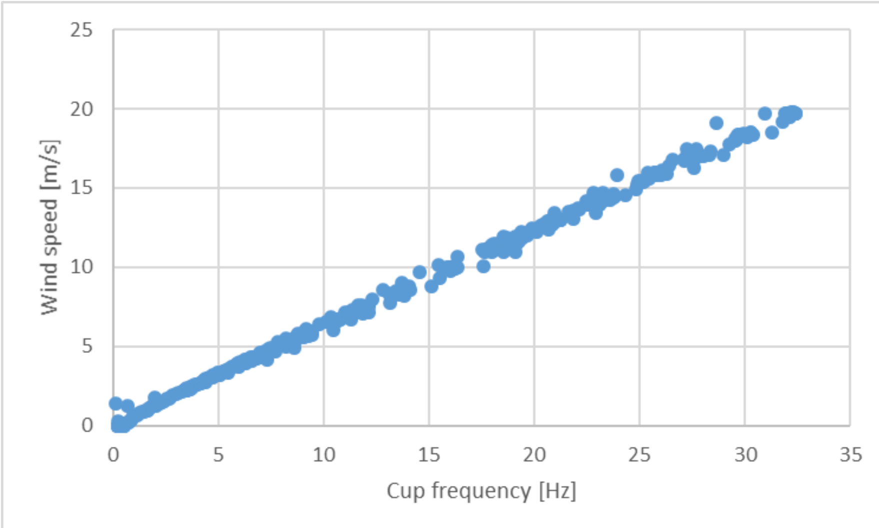


4) Plot the time series of the cup frequencies:



Notice that this looks very similar to the wind speed plot, just with different values and units on the y axis. This indicates that the speed and frequency are quite highly correlated.

5) Make a scatter (X-Y) plot of the wind speed (y-axis) and frequency (x-axis):



The very high linear correlation is confirmed although there are a couple of 'outliers', probably when the tunnel wind speed is changing very rapidly.

6) Insert a linear regression in the scatter plot. Now you are able to express the wind speed as a function of the cup rotational frequency : $V_{cup} = A\,f_{cup} + B$ What are your values for A and B ? A non-zero (positive) value for the offset B is expected. It represents the wind speed necessary to start the cup anemometer.

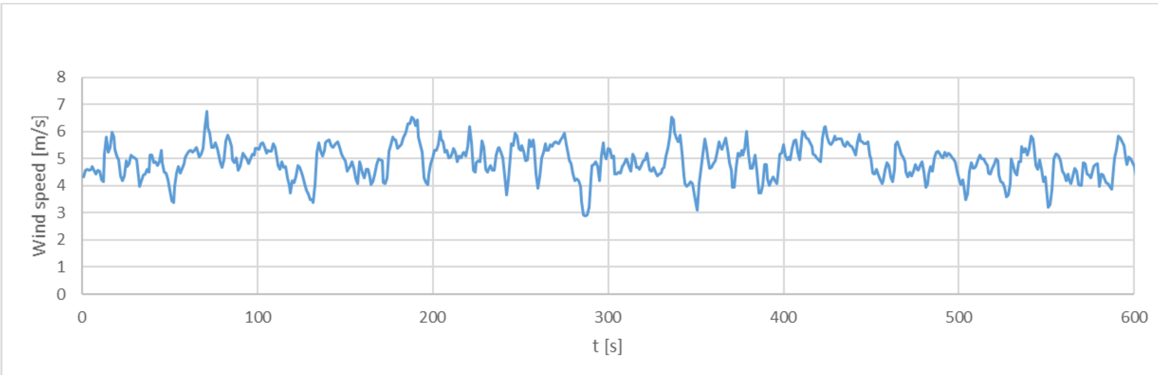
7) You can test your results by going back to the input file and now calculating a new column of wind speeds based on the your calibration values A and B and the cup frequencies. These new wind speeds should be very close to the speeds you calculated from the pitot tube

Congratulations. Now you have (almost) made a cup calibration! In real life, we do things a little differently but the basic principle is exactly the same. In particular we would do the following things for a professional calibration:

- have specific calibrations for the pitot tube
- correct for the area that the cup fills in the tunnel cross-section (blockage)
- Perform the linear regression using mean values from the staircase plots where conditions are constant (avoiding the outliers when the speed changes). You can try this if you like.
- Calculate the uncertainty of the calibration.

Calibrate field data and calculate 10-minute mean and turbulence intensity.

Load the file winddata.txt into a spreadsheet or workbook. The first column is a time stamp (spaced by 1s) and the second column is the measured cup rotational frequency. Apply the calibration values obtained from the previous section to obtain a third column of wind speeds. Plot this. It should look something like this:



What is the mean wind speed $\bar{V}$?
What is the standard deviation σ_v ?
What is the turbulence intensity ti ?

$$(ti = \frac{100\,\sigma_v}{\bar{V}}\ [\%])$$