Modal Decomposition Short Course: SPOD Exercise

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In this exercise, we will apply SPOD to a set of planar, two-component, time-resolved PIV measurements made in the wake of a vertical axis wind turbine (VAWT). The data were taken by Daniel Araya as part of his Ph.D. thesis with John Dabiri at Caltech; results and interpretations from this data set may be found in [1]. The data is also used as an example in [2]. The notation here is slightly different from the reference.

To do the exercise, you should use the SPOD package `spod_matlab` which can be obtained at `https://github.com/SpectralPOD/spod_matlab`

The PIV data consists of 7 different fields of view taken in 7 independent experiments. It was pody-processed to obtain (u, v) velocity components on a regular grid (x, y) at 9000 uniformly spaced time instances. The setup is depicted figure 1. In the data files, the 7 PIV windows are referenced as windows 3 through 9 from left to right. There is one data file for each window. Note that some of the data is blanked out in window 3 where shadows from the turbine blades interfered with the laser sheet, but artifacts can also be seen above the blade. In general the data in window 3 is only reliable downstream of the turbine itself. For your analysis, you need not worry about this and simply use all the data from window 3.

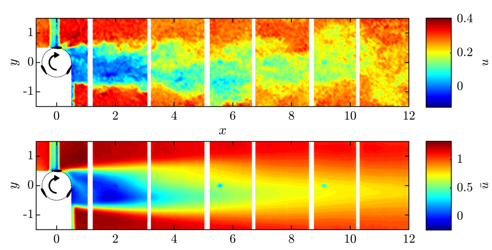

Figure 1: Instantaneous (top) and mean (bottom) streamwise velocity for the VAWT

The function `getiv.m` loads the PIV data for the corresponding window (the argument is the filename). It also re-normalizes lengths with the turbine diameter, and velocities with the free-stream velocity. The time step is also normalized with these variables so that it is a nondimensional Strouhal number on output.

Using this data, perform the following analyzes:

1. **Spectral estimation parameters**. Compute the SPOD spectrum for window 3 and vary the principle estimation parameter: the FFT block size. This controls the spectral bin size (resolution in frequency space). The overall time series is broken down into (possibly overlapping) blocks. The longer the block, we get better frequency resolution but the fewer number of segments there are, and consequently the uncertainty increases. Plot the total SPOD spectrum (sum of POD eigenvalues), which represents the 2D total (integrated over space) power spectral density of kinetic energy in the PIV window using several different block sizes, and determine a "good" value for NFFT for the remaining questions. Look for spectral features in the plots and physically interpret any peaks in the data. Is there any low rank behavior in the data? The solution to this part is given in `problem1.m`.

2. **Examine structures near turbine**. You will have found in the last problem that there is a strong periodic, low-rank structure in window 3, which corresponds to vortices being cyclically shed from the blades. The fundamental frequency is the blade-passing frequency of the turbine. Now, for each of the 7 PIV windows, find the most energetic structure at this frequency. Note again that the windows are independent and, apart from empirically trying to "stitch together" the data from the different windows, there is no way to relate the energy level of the structure from one window to another. The solution for this part isn't given, but results for it are given in the references.

3. **Examine structures in wake**. At a frequency near $St = \frac{fD}{U_\infty} = 0.2$, there is vortex shedding in the wake of the turbine. Repeat the last part for this peak in the frequency. How do the results compare to vortex shedding from circular cylinders (either at low or high Reynolds number)? The solution for this part isn't given, but results for it are given in the references.

References

[1] D. B. Araya, T. Colonius, and J. O. Dabiri. Transition to bluff-body dynamics in the wake of vertical-axis wind turbines. *Journal of Fluid Mechanics*, 813:346–381, 2017.

[2] O. T. Schmidt and T. Colonius. A guide to spectral proper orthogonal decomposition. *submitted to J. Fluid Mech.*, 2019.