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# POD analysis of the recovery process in wind turbine wakes

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## INTRODUCTION

Harnessing wind energy and converting it in electric energy require the design and installation of large wind farms, constituted by hundreds of turbines. When grouped together, a great part of the wind turbines operates in the wake of upwind turbines, so that the velocity deficit and the turbulence level of the incoming flow induce additional power losses and fatigue blade loading. Thus, understanding the dynamics of wind turbine wakes is crucial for the design and efficiency improvement of wind turbines and farms.

The wake of a wind turbine is characterized by the coexistence of several coherent structures, such as tip and root vortices, tower's vortex shedding etc.

High turbulence levels promote wake recovery, through turbulent kinetic energy flux (entrainment), however how individual coherent structures contribute to wake recovery, is still an open problem.

## OBJECTIVES

- Identifying and isolating the main flow features characterizing the wake dynamics of a three-bladed wind turbine using a three-dimensional Proper Orthogonal Decomposition (POD) of numerical data obtained by large eddy simulation (LES).
- Evaluating how each POD mode contributes to wake recovery through mean kinetic energy entrainment.

## METHODOLOGY

### • Large eddy simulation (LES)

- Smagorinsky model with  $C_s = 0.09$ .
- Actuator line model (ALM) [1] for rotor blades.
- Immersed boundaries [2] for tower and nacelle.
- Domain dimensions:  $12.5D \times 5D \times 3D$  in the streamwise (x), vertical (y) and transverse (z) directions.
- Computational grid:  $2048 \times 512 \times 512$  grid-points in x,y and z directions.
- Krogstad model wind turbine [3] at tip-speed ratio  $\lambda = 3$ .
- Diameter-based  $Re = 6.5 \times 10^5$ .
- Uniform, laminar inlet velocity profile.

### • Proper orthogonal decomposition (POD)

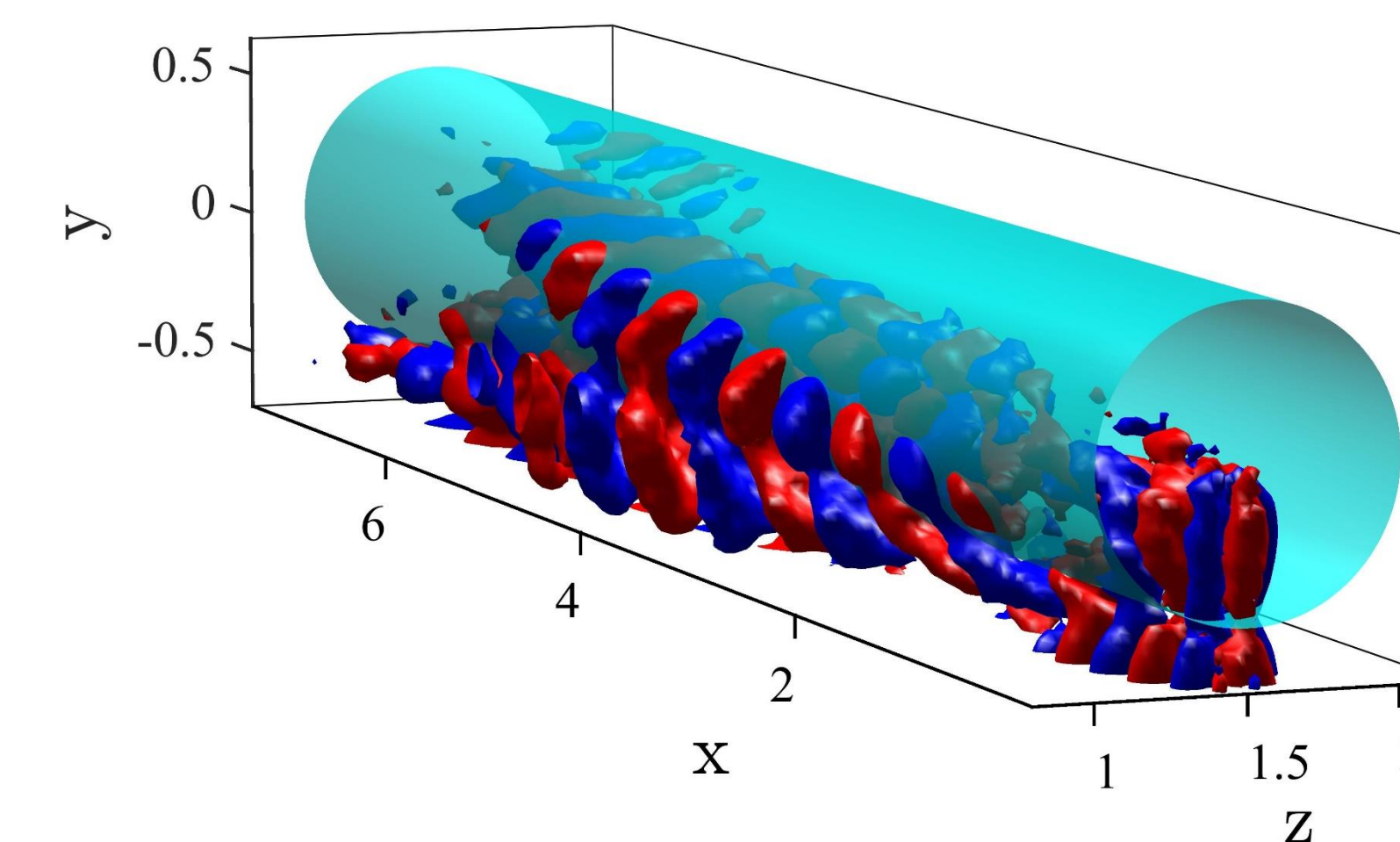
- M = 2361 snapshots of the velocity field.
- Sampling frequency: 1 snapshot every  $10^\circ$  rotation.
- SVD method.

### • Mean kinetic energy (M.K.E.) entrainment

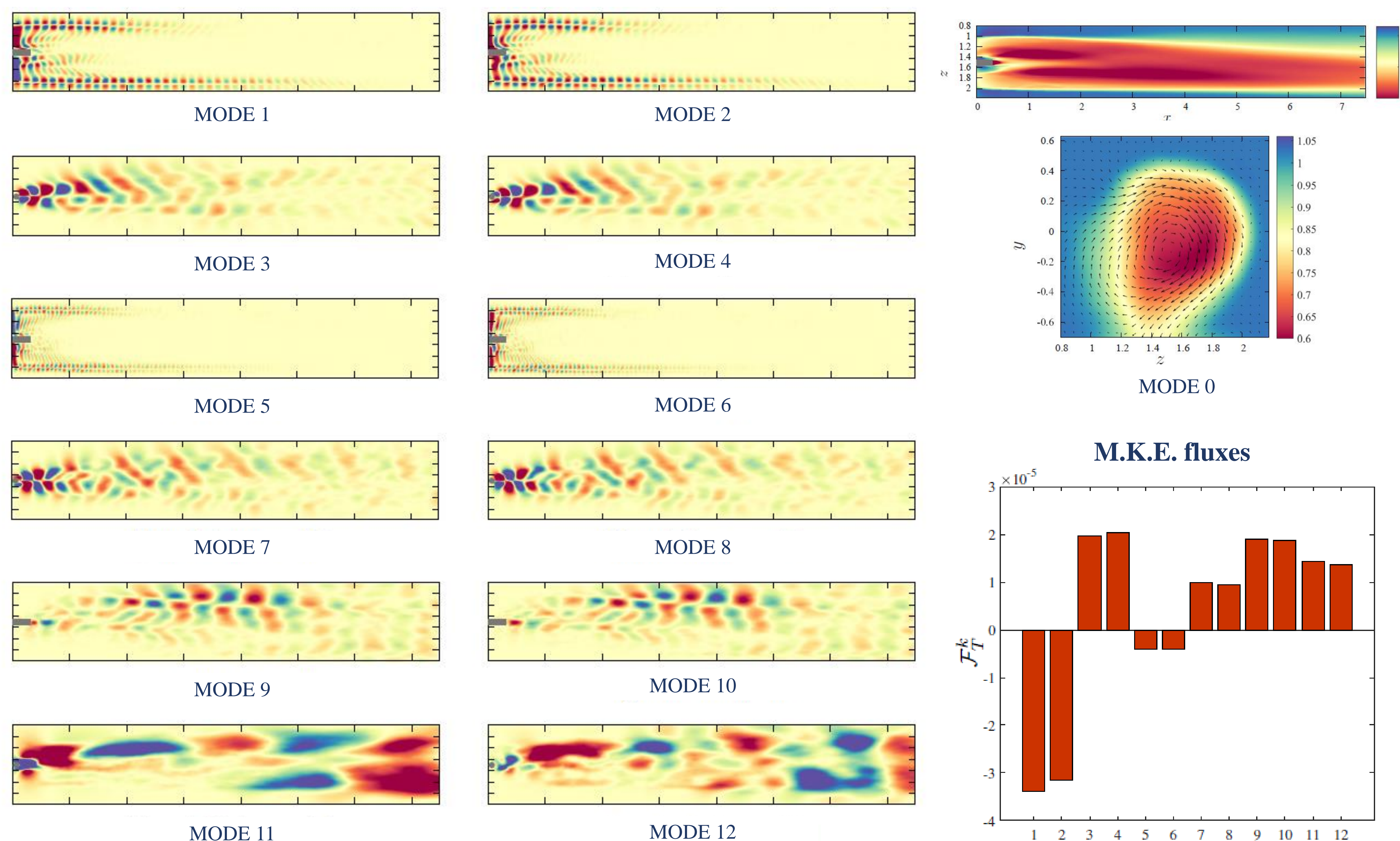
The M.K.E. flux entering a cylindrical surface  $S$  of radius  $R = 0.5$  provided by each mode is computed as:

$$\mathcal{F}_T^k = \frac{1}{S} \int_S -\bar{u}_i \lambda_k \phi_i^k \phi_j^k dS_j$$

where  $\bar{u}_i$  is  $i$ -th component of the time-averaged velocity,  $\lambda_k$  is the eigenvalue related to the  $k$ -th mode,  $\phi_i^k$  is the  $i$ -th component of the  $k$ -th POD mode.



## RESULTS



## SUMMARY

- The most energetic POD modes are associated with the tip and root vortices and their harmonics. Then, two pair of modes connected with the von Karman vortices shed by the tower follow. Other energetic modes show low-frequency oscillations that could be related to the wake-meandering phenomenon.
- Positive values of M.K.E. flux were found for the POD modes linked to the tower's vortex shedding, to the Kelvin-Helmholtz instability and to the wake meandering, which have, therefore, a beneficial effect on the wake recovery.
- POD modes related to the tip vortices show negative M.K.E. fluxes, therefore they sustain the wake and slow down its recovery, despite producing a high turbulence intensity.
- The present analysis suggests that neglecting the presence of tower and nacelle in the simulation of clustered turbines can lead to an underprediction of the energy production.

## REFERENCES

- [1] Sørensen J N and Shen W Z 1999 - Proc. of European Wind Energy Conference EWEC '99, Nice
- [2] Orlandi P and Leonardi S 2006 - Journal of Turbulence
- [3] Krogstad P Å, Eriksen P E 2013 - Renewable Energy

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