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NUMERICAL ANALYSIS OF THE WAKE CONTROL BEHIND A CIRCULAR CYLINDER WITH OSCILLATORY ROTATION

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Summary In this study, the wake flow is controlled via open-loop oscillatory rotation of a circular cylinder. The Kármán vortex street is suppressed with this method of control, both, in experiment and in simulation. The results of natural and actuated numerical flow simulations are used as the input for POD analysis. With this approach the spatial distribution of empirical eigenmodes are elucidated. Actuation pushes the Kármán mode downstream if the amplitude and frequency of the rotation are adequately chosen. Thus, the modal energy contains only a fraction of it original value of natural shedding.

INTRODUCTION

Suppression of the flow unsteadiness is of interest in fluid mechanics for many practical reasons. In particular, forces due to the unsteady bluff-body wakes need to be reduced in off-shore oil rigs, high-lift airfoils and other bluff bodies. A benchmark problem for wake control strategies is the flow around circular cylinder. This flow is characterized by a Kármán vortex street at $Re > 47$. This periodic wake dominates the flow even at very large Reynolds numbers. Focus is placed on the investigation of the laminar wake targeting an enhanced understanding and the control of the wake phenomena at high Reynolds numbers. Flow control of the wake is mostly performed with the active methods. These methods can be classified in terms of closed-loop and open-loop control. The real-time implementation of closed-loop control is complicated by the large dimension of the flow problem in many practical situations. However, controller and observer design which is based on low-dimensional Galerkin models of the flow may be successfully implemented in simulations [1] and supposedly soon in experiments. In open-loop forcing of the flow, the lock-in phenomenon is often observed. This phenomenon typically leads to an *increase* of the fluctuation level. In the considered example, however, open-loop control leads to a suppression of the Kármán mode. It should be emphasized that suppression of instabilities typically requires more sophisticated closed-loop strategies.

FLOW SIMULATION

The two-dimensional incompressible flow is simulated with the FEM and penalty formulation as described in [2]. Steady flow solution is used as the input for the disturbance equation:

$$\dot{\acute{V}}_i + \acute{V}_j \bar{V}_{i,j} + \bar{V}_j \acute{V}_{i,j} + \acute{V}_j \acute{V}_{i,j} + \acute{P}_{,i} - \frac{1}{Re}\acute{V}_{i,jj} = 0 \quad (1)$$

$$\acute{V}_{i,i} = 0 \quad (2)$$

The problem is solved as the initial value problem in the rectangular domain $-5 \leq x \leq 15$, $-5 \leq y \leq 15$ with no-slip boundary on the cylinder, uniform inflow $V_x = 1$, $V_y = 0$ and stress-free outflow.

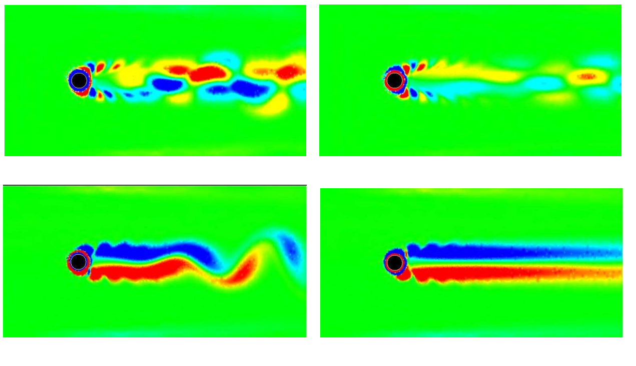

Figure 1. Disturbance vorticity (-5,5) for the fully controlled case ($Re = 100$, $A = 5$, $f/f_{nat} = 4.5$), for time $T = 33.6$ (left) and $T = 200$ (right) and respective sum of the disturbance with the steady flow solution.

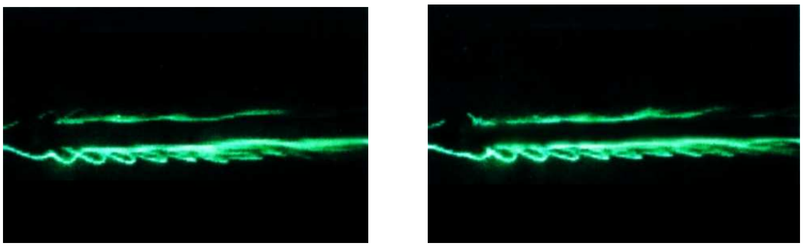

Figure 2. Results of the experiment - flow visualisation for A=5 and $f/f_{nat} = 4$ (left) and for $f/f_{nat} = 5$ (right)

RESULTS OF THE SIMULATION

The results presented here (Fig. 1) are obtained at Re=100, at the amplitude of rotation A=5, and at two frequencies. At $f/f_{nat} = 4.5$ (f_{nat} denotes the frequency of the vortex shedding) the substantial reduction of the Karman mode is obtained. This case we denote as "fully controlled". At $f/f_{nat} = 5$, a large controlled region can be seen behind the cylinder. Vortex shedding emerges only near the outflow. The results of the numerical simulation can be compared with the experimental visualisation depicted in Fig. 2. More details about the experiment can be found in [3].

POD ANALYSIS

In POD analysis is based on a set of "snapshots" of the flow field at different instances. The flow is approximated by a generalized Galerkin ansatz

$$V = \bar{V} + V_s + \sum a_k V_k \tag{3}$$

where $\bar{V}$ is the steady flow solution, V_s is the mean-field correction ("shift mode") and a_k and V_k are the Karhunen-Loéve coefficients and modes, respectively. The results obtained for the optimal values of amplitude and frequency of the cylinder rotation are shown in Fig. 3. The first modes are pairs of the first harmonics. The Kármán mode appears as the 5th and 6th mode with the negligible energy. The first four modes have energy 81.32%, 18.50%, 0.06%, 0.04% respectively. For less favourable amplitudes and frequencies, the Karman mode has much higher energy content and is already present in mode 3 with 9.75% energy. In this case, the fluctuation maximum is located near the outflow and can be seen as the vortex street in the reconstruction.

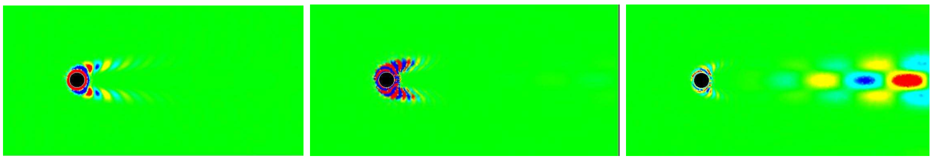

Figure 3. POD mode 1,3 and 5 vorticity (-5,5) for "fully controlled" case

CONCLUSIONS

The wake behind a controlled wake behind a circular cylinder is numerically simulated. The computations are consistent with experimental findings. Active control with adequate frequency and amplitude of the rotation suppresses vortex shedding in the whole computational domain. The Karhunen-Loéve decomposition provides information about the regions of flow dominated by particular modes. Future investigations target the development of Galerkin model for wake control with oscillatory rotation.

References

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