International Journal of Offshore and Polar Engineering (ISSN 1053-5381)
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Vol. 15, No. 1, March 2005, pp. 7–13

Optimization of Vortex Shedding in 3-D Wakes Using Belt Actuators

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This paper discusses the control of cylinder wakes via tangential wall velocity modifications. The wall velocity is piecewise constant (corresponding to belt actuators), and its amplitude is optimized using a clustering real coded genetic algorithm. This type of control significantly affects the vortical structures being shed in the wake, and it is shown that the flow gets significantly modified, resulting in a 3-dimensional body shedding 2-dimensional vortical structures in the near wake of the body. Depending on the energy involved in the control, one can also obtain a dramatic decrease of shedding amplitude.

INTRODUCTION

We are interested in the manipulation of vortex shedding of 3-D wakes and the associated drag reduction in the canonical case of a 3-D cylinder. Control is performed by means of tangential velocities on the body, which in practice can be translated as wall parallel belt actuators or tangential local jets. We develop suitable numerical methods to solve numerically the 3-D Navier-Stokes equations and implement clustering genetic algorithms in order to optimize the actuator parameters.

In order to compute these flows accurately, we developed a vortex-in-cell method using a coupling between grids and particle. Vortex methods make the nonlinearity of the transport terms vanish from the Navier-Stokes equation, thus alleviating the related stability condition usually encountered in Eulerian schemes that can be very restrictive on the time-step. This advantage of the Lagrangian method is counterbalanced by a lack of accuracy, especially for vortex methods based on random walks. The coupling between particles and grids permits the overcoming of this difficulty as well as the reduction of the computational cost of evaluating the velocity field (even when compared to multipoles methods for the Biot-Savart laws). The associated integrals and derivative operators can be computed with good accuracy. This has been validated in Cottet and Koumoutsakos (2000), Cottet and Poncet (2002, 2003, 2004), and Poncet (2002, 2004).

In order to perform a control by means of a tangential wall velocity (belt actuators), we first consider the 2-D problem. This has been obtained by a genetic algorithm, whose histogram and most probable solution are in Milano and Koumoutsakos (2002) and in this paper.

This 2-D profile of velocity is then fitted by a smooth symmetric function and applied on 3-D flows. (See the article by Poncet, Cottet and Koumoutsakos, to appear in *C. R. Mécanique.*) In these 3-D simulations one can observe the behavior of 3-dimensionality, the drag reduction and shedding cancellation (in the sense of force oscillation, i.e., drag and mean vorticity variations). One can also check that the property of shedding reduction is still valid when a full 3-D profile of velocity is applied on the body.

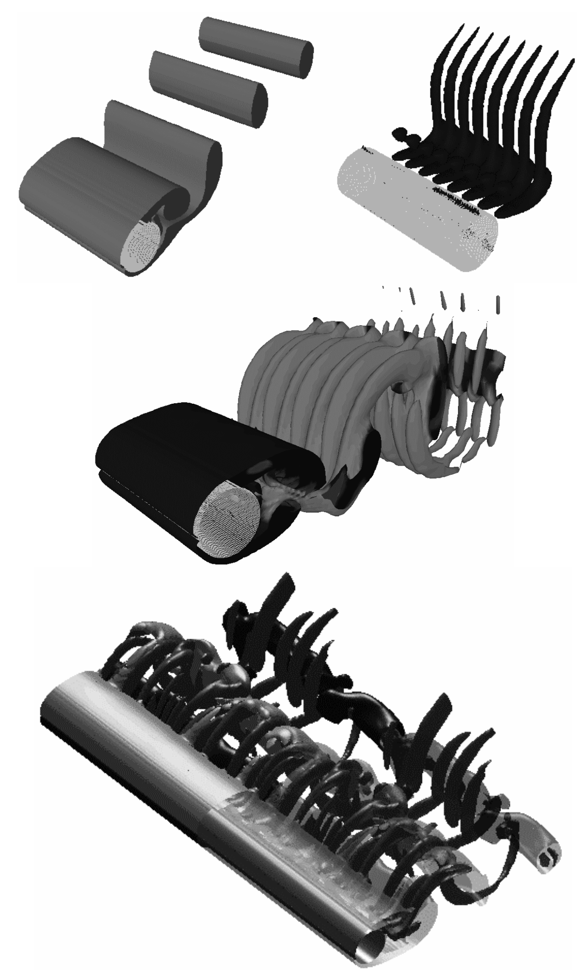

Fig. 1 Dynamics of cylinder wake in 3-D at Re = 300: 2-D wake (top left), first signature of instability (top right), resultant 3-D wake before saturation (middle), and post-transient established 3-D flow with fully developed hydrodynamic instabilities (bottom, from Poncet, 2004)

Received August 24, 2004; revised manuscript received by the editors December 15, 2004. The original version (prior to the final revised manuscript) was presented at the 14th International Offshore and Polar Engineering Conference (ISOPE-2004), Toulon, France, May 23–28, 2004.

KEY WORDS: Shedding manipulation, genetic algorithms, 3-D wakes, vortex methods, hydrodynamic instabilities.