Closed-loop fluid flow control using a low dimensional model

L. Mathelin[1], M. Abbas-Turki[2], L. Pastur[1,3] & H. Abou-Kandil[2]

[1] LIMSI-CNRS, BP 133, 91403 Orsay cedex, France

[2] SATIE, Ecole Normale Supérieure, 94235 Cachan cedex, France

[3] Université Paris-Sud 11, 91405 Orsay cedex, France

With constantly increasing environmental constraints, the need for ever more efficient aeronautical systems has driven fundamental research in many areas including mechanical engineering, fluid mechanics, materials, ... In particular, the active control of open flows has long been identified as a potential key factor to reduce the drag, enhance manoeuvrability, noise attenuation, etc. In this view, we are interested in developing a real-time control strategy to achieve drag reduction of bluff bodies. To investigate efficient strategies, we consider the test case of the flow around a cylinder which exhibits many of the fundamental features involved in more realistic configurations.

For numerical model handling, the Navier-Stokes equations need to be discretized but still lead to a large number of degrees-of-freedom. This rises issues in particular for real-time control synthesis. To overcome this difficulty, it is necessary to further reduce the size of the problem at hand. It is thus desirable to rely on a model of the physical phenomena as simple as possible while remaining physically relevant. Many approaches may be followed and we here approximate the fluid flow with a truncated modal decomposition. To this end, the classic Karhunen-Loeve statistical reduction is employed and the N most representative modes are retained. We thus obtain a finite (small) set of modes which time dependency allows to build a dynamical system. The physical system is fully described by the state vector constituted by its components in the phase space. To simulate the system time-evolution, several approaches exist and we here resort to the mapping technique introduced in [1]. It basically consists in approximating the evolution of the state vector over a given time-horizon. The approximation relies on a N-dimensional polynomial of given order for each component of the state vector. The state vector at a given time $n+1$ is then simply given by a polynomial operator acting on the state vector at time n. The dynamical system can then be time-integrated by successive mapping applications.

An optimal orbit in the phase space, minimizing the drag at a low control cost, is computed off-line using an open-loop control strategy. Hence, the operating points are defined as (x_*^k, μ_*^k), with x_*^k and μ_*^k corresponding respectively to the optimal state space variables and control (figure 1). In order to control the system in actual conditions (real physical system, fluctuating Mach number, ...), the closed loop feedback control is required and consists in compensating deviations from this optimal orbit Δx^k. Since the deviations are meant to remain small, the non-linear flow model can be linearized around the optimal orbit at each time and multi-objective robust closed-loop control tools can be employed to compute $\Delta\mu^k$ [2].

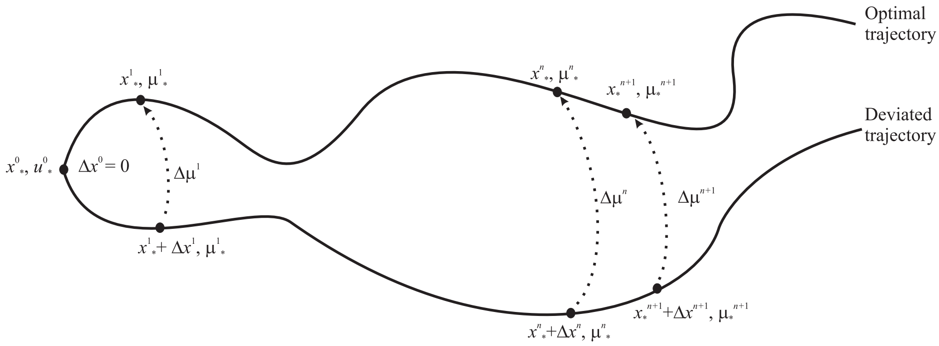

Figure 1: *Closed-Loop control objective*

References

[1] Le Maître O. & Mathelin L., Equation-free model reduction for complex dynamical systems, *Int. J. Numer. Meth. Fluids*, submitted, 2009.

[2] Abbas-Turki M., Duc G., Clement. B & Theodoulis S., Robust gain scheduled control of a space launcher by introducing LQG/LTR ideas in the NCF robust stabilisation problem, *46th IEEE Conference on Decision and Control, New Orleans, USA*, dcembre 2007.