Aeroelastic dynamic feedback control of a Volterra's airfoil

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Abstract. The control of aerodynamic wings is essential to avoid both the conditions of structural fluid instability, and to keep the control performance high in terms of efficiency and power. The wings are characterized by memory effects, due to aeroelastic phenomena which are usually difficult to incorporate in optimal control logics unless quantized numerical solvers are used, which require onerous computational efforts. In this paper a feedback control based on the theory of optimal control is proposed, which incorporates the memory effects described through the Volterra integral. Eventually, the results are corroborated by numerical simulations.

Introduction

Aeroelastic systems are characterized by complex non-linear phenomena due to structural oscillations coupled with the fluid dynamic. The coexistence of phenomena, such as limit cycle oscillation and chaotic vibrations induced by the fluid, can lead the dynamic systems to instability such as flutter (see Figure 1) which can decrease the system performance, as well as the damage of the structure itself.

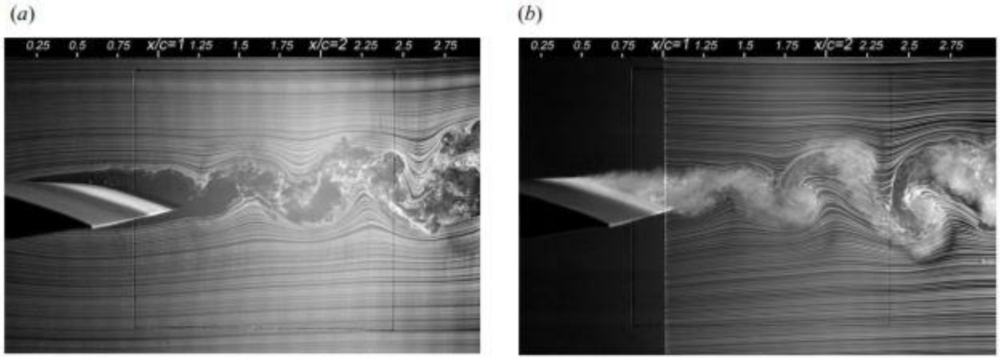

Figure 1: Vortex shedding of an airfoil in low-Reynolds-number flows. (a) upstream smoke wire; (b) downstream smoke wire. [1]

In the literature several authors have provided extensive reviews of non-linear control methods for the minimization of limit-cycle oscillations of elastic wings and aircraft, and in recent years a large number of control strategies for flutter avoidance have been developed [1].

Results and discussion

This paper presents a new optimal control strategy, called Proportional-Nth-order-Integral control, PI(N), which belongs to the category of Variational Feedback Controls (VFC), applied to integral differential equations which includes the Volterra-type integrals. These integrals are typically used to describe the Theodorsen and Wagner effects, i.e. the effect of unsteady (harmonic) aerofoil motions. The solution of the optimal problem is provided through a particular solution of the Riccati's equation including the memory terms generated by the past system evolution. The structure of the control law shows how the optimal solution is related to the kernel function order, i.e. of the Volterra integral typology. Normally, the optimal control problems applied to this type of integro-differential equations are solved by direct methods, implying the discretization and solution of the problem passing through a nonlinear programming. Instead, the proposed indirect method permits to solve the problem minimizing the computational efforts that usually grows at a nonlinear rate with the number of grid points used for the quantization by permitting a feedback formulation obtainable thanks to special properties of the kernel [2].
Numerical results show how is possible to control an aerofoil surface when nonlinear memory effects approximated by convolution Volterra integral are acting on it, thanks to the optimal feedback PI(N) control avoiding instability states and exhibiting excellent performances.

References

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