# Flow Control: an Overview

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Current airframes being already highly optimized nowadays, further aerodynamic performance improvements may only be reached by the implementation of flow manipulation techniques. The sixth issue of Aerospace Lab Journal is aimed at providing the reader with a comprehensive overview of the current developments of these methods.

The papers presented successively review main aspects of flow control, both from the point of view of technology and that of the applications. Technologies consist not only in fluidic and plasma actuator development, but also in the specific know-how relative to closed-loop algorithms, reduced order models and actuator effect on the flow. Additionally, the potential of flow control techniques is presented on civil aircraft (both for low speed and cruise conditions), helicopters and turbomachinery applications.

## A historical perspective

The beginning of the 20th century has witnessed the introduction of the seminal concept of boundary layer by L. Prandtl. The relevance of this concept was in particular shown by implementing boundary layer suction, which eventually became the first flow manipulation technique of the modern era. The investigation of blowing techniques followed in the late twenties. A theoretical step was passed in 1948 by Poisson-Quinton, who introduced the momentum coefficient and the important distinction between boundary layer control and circulation control. Concomitantly with these theoretical progresses, many applications of the circulation control concept were proposed in the fifties. This period witnessed its operational use on military aircraft and its large scale evaluation on the Boeing 707 prototype. Nevertheless, this concept suffers from its inherent complexity and added weight and, in the last fifty years, the only flow control technique routinely used, in particular on Boeing commercial airplanes, is the passive vortex generator. With the development of the stability theory and of the important idea that a flow can be supersensitive to some specific, well-chosen perturbations, flow control has been the subject of renewed interest, the general idea being that the introduction of unsteady perturbations is a much more efficient way to manipulate a flow than a steady actuation. These progresses and the current difficulties to further improve already well-optimized airframes have given a new impetus to flow control, which is now a very active research topic. The sixth issue of the Aerospace Lab Journal is aimed at making a survey of the current development in this field.

## Control objective

Inherent to the idea of flow control are the notions of control objective and of the state that the flow should eventually reach. Currently, most of the effort of the community is devoted to separation control and this issue of Aerospace Lab Journal is no exception [4][5][6][9][12]. Nevertheless, keeping the flow laminar remains an important topic, which is treated in ref [2], and the reduction of the fluctuations in cavity flows is the objective of ref. [8].

## Actuators & sensors

Actuators are the common denominator of all of the study presented. The development of these devices, which necessitate multi-disciplinary teams skilled in micro-technologies, has been impressive during the last decade. Paper [3] provides a comprehensive overview of fluidic actuator development at Onera. Highly innovative plasma synthetic jets are presented in ref. [10] and an example of the application of DBD actuators to transition control can be found in ref. [2]. A crucial point is that specific means must be developed, both to characterize their performance and to correctly interpret subsequent flow control experiments. Comparatively, sensors are less developed, since existing devices are sufficient for most separation control applications. Nevertheless, one can anticipate that sensor improvement will be necessary for drag reduction related applications.

## Closing the loop

In order to maximize flow control efficiency, the characteristics of the perturbations introduced in the flow (frequency, flow rate, movement) must be adapted as quickly as possible. This necessitates not only sensors and actuators, but also a close-loop control algorithm in between. The theoretical basis of the control theory is presented in ref. [7]. In some cases, a model representing the relationship between sensors and actuators must be built. A possible treatment of this specific issue relying on NARX (Non-linear Auto-Regressive with eXogeneous input) modeling is proposed in ref. [6].

## Simulation & Experiments

Nowadays, the evaluation of flow control concepts strongly relies on numerical simulation. It raises the issue of the way in which actuators are introduced in the simulation. The scale disparity between the individual actuator and the airframe to be controlled induces a significant additional computational cost. In practice, computations of controlled flows can be based either on a full representation of the actuator, as in refs. [1],[4],[9] and [12], or on approximated models, as in Ref [5]. The experimental basis for a new model is proposed in ref. [11]. Close-loop control is currently assessed numerically, either using Direct Numerical Simulation (DNS), as in [7], or using unsteady RANS as in ref. [6]. Even though simulation has been at the origin of significant progresses, the experimental demonstration is still indispensable to substantiate the developed flow control strategy. Examples of experimental validation of the latter can be found in references [1],[2],[4],[5],[9],[10] and [12].

## Applications

The reader of this sixth issue of the Aerospace Lab Journal may be convinced that relevant flow control strategies exist for civil aircraft, both in the low speed [5][12] and the high speed flight domains [1]. Interesting perspectives have been reported for helicopters and for turbomachinery applications in refs. [4] and [9] respectively. For every aforementioned application, a global systemic analysis of the proposed control strategies must be undertaken in close collaboration with industrial partners ■

**References**


[1] J. DANDOIS, P. MOLTON, A. LEPAGE, A. GEERAERT, V. BRUNET, J.-B. DOR, E. COUSTOLS - *Buffet Characterisation and Control for Turbulent Wings*. Aerospace Lab Issue 6, June 2013

[2] A. KURZ, S. GRUNDMANN, C. TROPEA, M. FORTE, A. SERAUDIE, O. VERMEERSCH, D. ARNAL, N. GOLDIN, R. KING - *Boundary Layer Transition Control using DBD Plasma Actuators*. Aerospace Lab Issue 6, June 2013

[3] F. TERNOY, J. DANDOIS, F. DAVID, M. PRUVOST - *Overview of Onera Actuators for Active Flow Control.* Aerospace Lab Issue 6, June 2013

[4] A. LE PAPE, C. LIENARD, J. BAILLY - *Active Flow Control for Helicopters*. Aerospace Lab Issue 6, June 2013

[5] V. BRUNET, J. DANDOIS, C. VERBEKE - *Recent Onera Flow Control Research on High-Lift Configurations*. Aerospace Lab Issue 6, June 2013

[6] J. DANDOIS, P.Y. PAMART - *NARX Modeling and Extremum-Seeking Control of a Separation.* Aerospace Lab Issue 6, June 2013

[7] D. SIPP, P. J. SCHMID - *Closed-Loop Control of Fluid Flow: a Review of Linear Approaches and Tools for the Stabilization of Transitional Flows*. Aerospace Lab Issue 6, June 2013

[8] S. YAMOUNI, C. METTOT, D. SIPP, L. JACQUIN - *Passive Control of Cavity Flows*. Aerospace Lab Issue 6, June 2013

[9] J. MARTY, L. CASTILLON, J.-C. BONIFACE, S. BURGUBURU, A. GODARD - *Numerical and Experimental Investigations of Flow Control in Axial Compressors*. Aerospace Lab Issue 6, June 2013

[10] D. CARUANA, F. ROGIER, G. DUFOUR, C. GLEYZES - *The Plasma Synthetic Jet Actuator, Physics, Modeling and Flow Control Application on Separation.* Aerospace Lab Issue 6, June 2013

[11] T. YEHOSHUA, A. SEIFERT - *Empirical Model for the Evolution of a Vortex-Pair Introduced into a Boundary Layer*. Aerospace Lab Issue 6, June 2013

[12] V. CIOBACA, J. WILD - *An Overview of Recent DLR-Contributions on Active Flow-Separation Control Studies for High-Lift Configurations.* Aerospace Lab Issue 6, June 2013