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On open cavity flow control in the age of artificial intelligence

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The flow dynamics, resulting from the interaction between a boundary layer and a wall cavity open to the main flow, can be adjusted to obtain more or less pronounced nonlinear interactions between the instability modes of the resonant mixing layer and intracavity spanwise centrifugal instabilities [1]. This configuration provides a particularly challenging benchmark for testing the effectiveness of control procedures in fluid systems. With the aim of suppressing cavity resonance, we propose a closed-loop control experiment whose controller results from an automatic learning procedure based on a genetic programming algorithm enhanced with a gradient method (gMLC) (gMLC) [2].

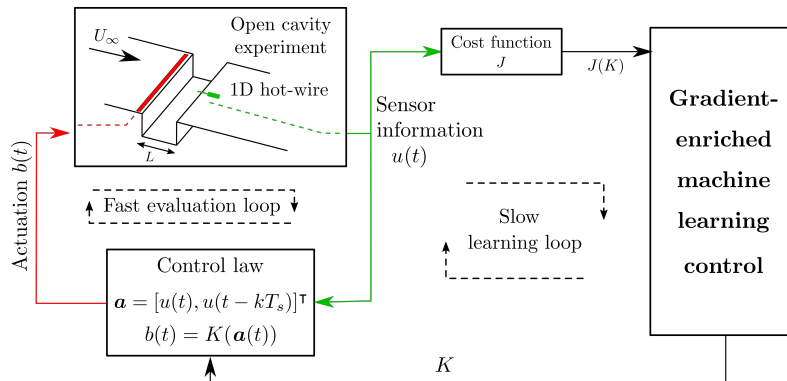


Fig. 1. Diagram of the machine learning control process. The evaluation of one individual constitutes the fast evaluation loop, operating at 250 Hz. The slow learning loop updates the control laws following the gMLC algorithm; it operates at $\sim O(10-2 \text{ Hz})$.

In this experimental study, two open cavity flows are controlled: a narrow-bandwidth regime with a single dominant frequency and a mode-switching regime where two frequencies compete [3]. The flow is forced by a dielectric barrier discharge actuator located at the leading edge and is monitored by a downstream hot-wire sensor over the trailing edge. The feedback law is optimized with respect to the monitored fluctuation level. As reference, the self-oscillations of the mixing layer are mitigated with steady actuation. Then, a feedback controller is optimized with gMLC. After a day-long experiment, gMLC learns a feedback control law stabilizing the open cavity flow up to 1 % of its original fluctuation level with approximately 1% of the actuation energy required for similarly effective steady forcing. Intriguingly, optimized laws learned for one regime perform well for the other untested regime as well. The proposed control strategy can be expected to be applicable for many other shear flow experiments. [4].

It should be noted that, in this study, stabilization of the natural self-sustaining oscillations of the cavity is not the result of flow forcing. With control established, the electrode's action is shown to be virtually nil, both in terms of mean and intensity of fluctuations, while the persistence of the feedback loop

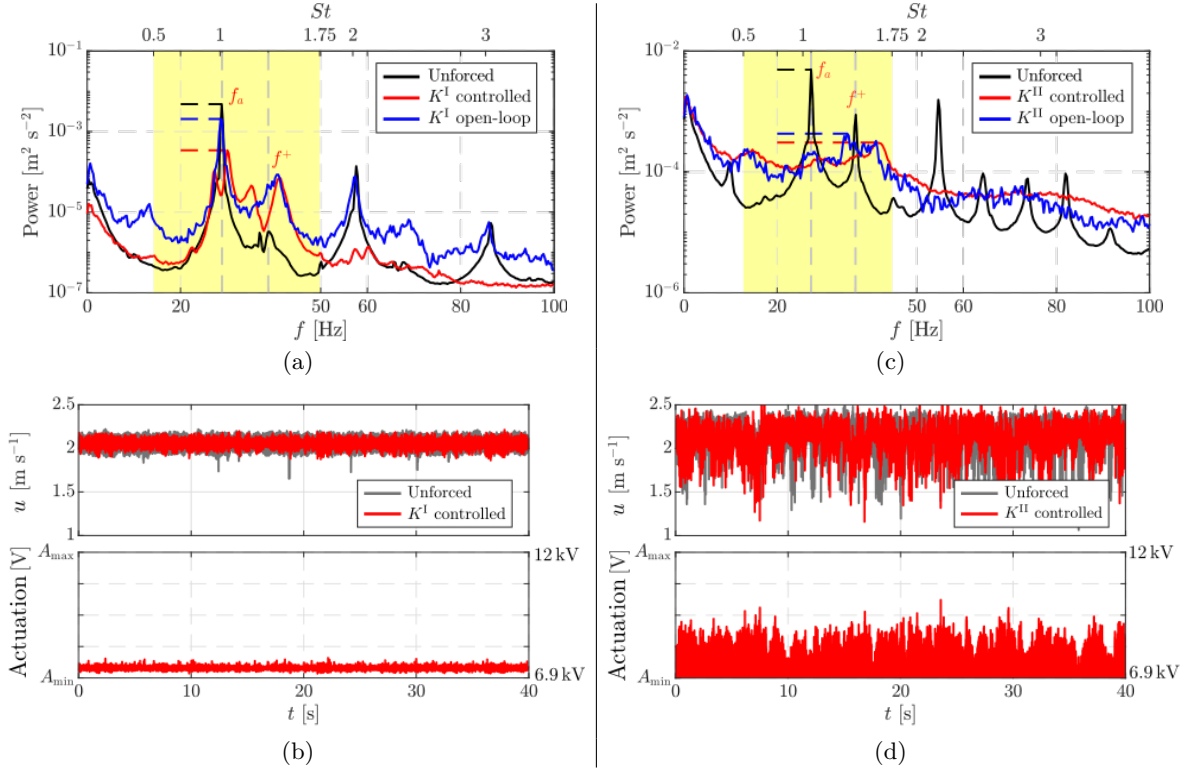


Fig. 2. Characteristics of the best control law controlling the narrow-bandwidth regime (left-hand column) and the mode-switching regime (right-hand column).

(a & c) Power spectra of the velocity measured downstream. Black is for the unforced flow, red for the flow controlled and blue for the flow controlled with the recorded actuation employed as an open-loop control. The spectra for the unforced flow (black) and the closed-loop controlled flow (red) are averaged over 20 realizations. The horizontal dashed lines denote the maximum of the spectra in the observation window (yellow background). The vertical axis is in log₁₀ scale.

(b & d) Time series of the velocity measured downstream and voltage level at the terminals of the DBD actuator. A short window is enlarged to display the behavior close to A_{\min} (the proportions are not kept).

is shown to be essential to the controller’s robustness. The organization of the spatio-temporal structure of the flow under control, and the transient towards the controlled state, have not yet been studied, but these questions will be addressed at the end of the presentation.

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