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Closed-loop control of an open-cavity flow with magnetically actuated microvalves

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Abstract

The open-cavity is a commonly studied geometry in flow control applications. Its dynamics has been studied since Roshko [1], Pereira [2] or Plumblee *et al* [3] and makes it a convenient test-bed to test new actuators or control approaches. The complex dynamics developing in an open-cavity flow has been described by Rossiter [4] and consists in a boundary layer developing upstream the cavity, separating at the upstream corner and forming the shear layer. This shear layer undergoes hydrodynamic instabilities over the cavity and impacts the downstream corner of the cavity, where acoustic waves are generated. They propagate upstream the cavity and excite the shear layer instabilities. This results in self-sustained oscillations in the flow, which can induce structural vibrations and noise radiation [5], therefore damping these oscillations is of interest.

We integrate a linear array of 15 MMMS (Micro-Magneto-Mechanical Systems) microvalves [6] to an open-cavity upstream edge to perform closed-loop flow control experiments. The microvalves can generate both quasi-steady and pulsed jets and have the advantage to be able to follow arbitrary command signals, which is a key for closed-loop flow control. To induce pulsed jets, which consist in a modulation of the outlet velocity around a mean value, a source of pressurized air has to be supplied to the actuators, alongside with an electrical source.

The closed-loop control strategy relies on several steps. Firstly, a transfer function is identified between the actuators command and the pressure sensors placed at the cavity downstream edge, where the open-cavity flow dynamics is the most amplified. Secondly, using a structured H_∞ loop-shaping synthesis, an optimized controller is derived based on the identified transfer function. Thirdly, the obtained controller is implemented in the Dspace MicroLabBox real time controller and the controller command signal is fed to the microvalves.

For a freestream velocity of 20 m/s, the open-cavity flow consists in a low frequency periodic flow regime characterized by a resonant frequency of 128.6 Hz. Closed-loop flow control experiments have been carried out for several microvalves driving pressures. Particularly, for a driving pressure of 140 mbar for the entire array of actuators (corresponding to a flow rate of 12 L/min), the open-cavity resonant frequency sound pressure level is reduced by 14 dB in closed-loop, compared to the unforced case. Further experiments show the controller robustness towards modification of the freestream velocity by $\pm 5\%$ and investigate the required number of actuators to reach the same reduction in the flow resonant frequency amplitude.

As a conclusion, this study shows the straightforward use of the MMMS microvalves (with the ability to be driven with any type of signal, as required in closed-loop) in the closed-loop control of a periodic open-cavity flow and constitutes a first step towards the closed-loop control of more complex flows such as quasi-periodic open-cavity flows.

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