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# Wind tunnel integration of Micro-Magneto-Mechanical Systems (MMMS) microvalves for flow control experiments

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**Abstract**— Flow control techniques can be defined as methods changing a flow natural dynamics. The control of a flow can be achieved with actuators affecting the flow momentum. Therefore, a MMMS microvalve was designed and characterized. The micro-actuators have then been integrated to a wind tunnel on the upstream corner of a cavity. Open-loop flow control experiments have been performed.

**Keywords**—Micro-Magneto-Mechanical Systems (MMMS), cavity, flow control, quasi-steady jets, pulsed jets

## I. INTRODUCTION

The open cavity is a common geometry. The flow developing over such a geometry, illustrated in Fig. 1, has been extensively studied since Roshko [1] and complex dynamic phenomena develop in it.

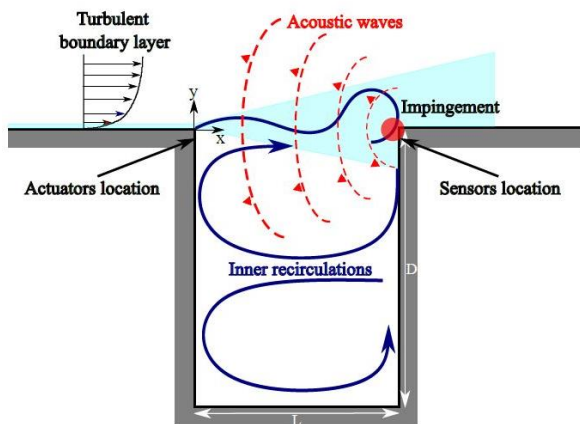


Figure 1: Features of the flow developing over a cavity and indications of actuators and sensors locations

The shear layer destabilizes over the cavity and impacts the downstream corner. The acoustic waves generated from this location propagate upstream and excite the shear layer instabilities at the upstream corner. This results in self-sustained oscillations in the flow, which can induce structural vibrations and noise radiation [2]. Therefore damping these oscillations is of interest.

## II. MMMS MICROVALVES

We propose a Micro-Magneto-Mechanical Systems (MMMS) microvalve design [3] in order to implement an open-loop flow control strategy on a cavity. The MMMS design, presented in Fig. 2, consists in a pressurized air inlet, a channel surmounted by a flexible resonator made in elastomer material (Silastic) and a submillimetric outlet. A NdFeB permanent magnet is fixed on the flexible resonator enabling the channel height modulation and hence modulating the outlet velocity, when an electrical current runs in the coil surrounding the magnet.

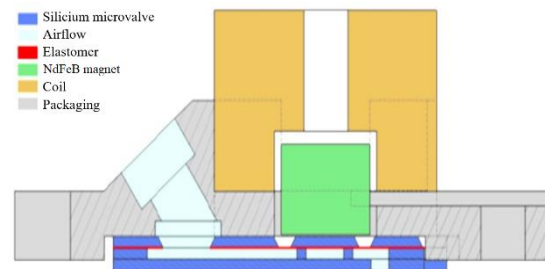


Figure 2: Schematic description of a MMMS micro-valve.

The microvalve can deliver a high-speed jet with an outlet velocity up to 150 m/s (for a submillimetric outlet), corresponding to a mass flow of 4 L/min, pulsed at frequencies

up to 500Hz [4]. The actuators outlet design was adapted to the control of the cavity flow. Therefore, the submillimetric outlet was modified in order to obtain an outlet velocity spread over a slot, as depicted in Fig. 3. The slot exit fabricated with fast prototyping techniques such as stereolithography induce an outlet angle. Therefore, the outlet jet is located in a (XY) plane rotated by  $45^\circ$  around the Z axis.

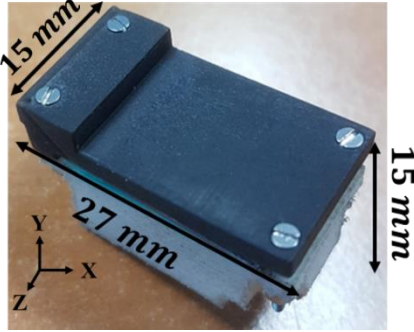


Figure 3: Assembled microvalve with its jet adapter. Packing dimensions are indicated with arrows

Performances of these micro-actuators were assessed with hot wire measurements once assembled as a linear array. A DANTEC 55P11 hot wire probe was used and measurements were done at different points over a duration of 1s with a sampling frequency of 20 kHz. A quasi-steady jet mapping is presented in Fig. 4 for a driving pressure of 150 mbar. It can be observed that the jet maximum velocity for this supply pressure is about 25 m/s and that the jet spreads over 3 mm for  $Z = 3$  mm.

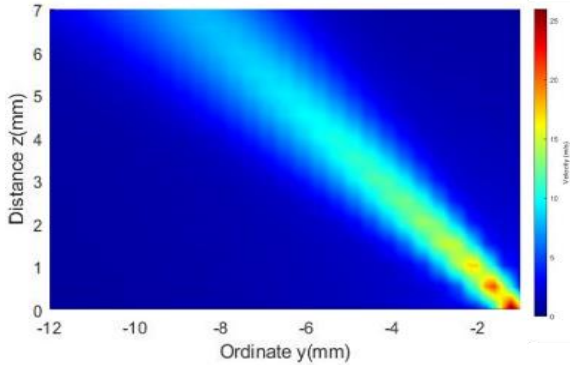


Figure 4: Quasi-steady jet characterization in a (XY) plane

Cavity flow control physics require mass flow rates of the order of 1 L/min up to 2 L/min, which make MEMS technologies suitable for these applications.

### III. OPEN-CAVITY FLOW CONTROL

For the first time, a linear array of 15 MMMS microvalves has been integrated to the upstream wall of an open-cavity placed in a wind tunnel, as presented in Fig. 5 and Fig. 6.

For a chosen flow regime, effects of quasi-steady and pulsed jets on the cavity oscillations were assessed through unsteady pressure measurements. Depending on the microvalves performances and the flow regime, quasi-steady jets enabled a decrease of 20 dB in the cavity fundamental frequency sound pressure level. The cavity spectrum without control and with the effect of the quasi-steady jets for a driving pressure of 290 mbar is presented in Fig. 7. Regarding pulsed jets, depending on the forcing induced by the actuators a locking phenomenon was observed. Therefore, the actuators authority proved to be

sufficient to shift the cavity natural oscillation frequency towards the microvalves actuation frequency. Flow control experiments were therefore successfully carried out with Micro-Electro-Mechanical Systems (MEMS) technologies on an open-cavity.

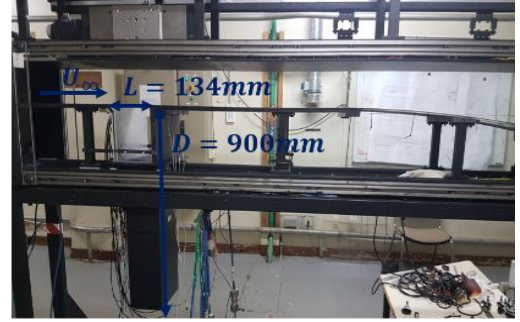


Figure 5: Picture of the S19 wind tunnel with the cavity dimensions



Figure 6: Picture of the integrated actuators to the upstream wall of the cavity

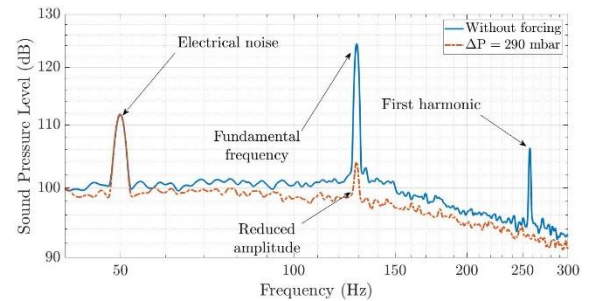


Figure 7: Flow spectra for a freestream velocity of 20 m/s and for a driving pressure of 290 mbar generating quasi-steady jets.

### IV. CONCLUSION

To conclude, this paper presented cavity flow control experiments carried out with MMMS micro-valves developed at the IEMN. Once characterized with hot wire measurements, a set of 15 micro-valves was mounted as a linear array and integrated onto a cavity upstream corner. The micro-actuators jets successfully interacted with the flow developing over the cavity and enabled to damp the cavity flow oscillations.

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