Title of PhD project:

Microfluidic oscillators for active flow control

Place : Toulouse (ICA / INSA) and Orléans (Laboratoire PRISME / Polytech'Orléans)

Supervisors: Dr. Lucien BALDAS and Dr. Nicolas Mazellier

Context:

Over the last past decade, flow control has received an increasing attention with the aim to improve the effectiveness of a number of engineering applications such as road and aerospace vehicles. Indeed, control strategies targeting lift increase, drag mitigate or stability improvement are an attractive solution to match the requirements of reliable and sustainable transports. Usually, flow control ranges from passive methods, which rely on add-on devices to locally modify the shape of the body, to active methods, which require external power supply. However, in the former case, the efficient of the control devices is often restricted to a narrow range of operating conditions, while in the latter case, the costs related to the energy penalty of the actuators are not taken into account to evaluate the net benefit of the flow control.

Both the design of the control system and the choice of its parameters are challenging issues, which have to be properly addressed to guarantee the control effectiveness. For unsteady control systems, the main control parameters are the momentum injection rate and the actuation frequency. In a recent work dedicated to the physical analysis of separating/reattaching flows, which will be at the core of this study, Stella et al. (2017) have evidenced the multi-scale nature of the driving mechanisms. Their findings may have great implications in the design of control systems. Indeed, it suggests that strategies targeting either small-scale forcing (see e.g. Wiltze & Glezer (1993)) or large-scale forcing (see e.g. Dandois et al. (2007)) can both achieve separation modification. The former approach implies high frequency/low energy forcing, whereas low frequency/high energy forcing is required for the latter. Furthermore, Berk et al. (2017) proposed recently an attractive framework to unify the mechanisms governing the interaction between the flow and the actuator.

In addition, although the advantages of the miniaturization of the actuators have clearly been shown [Tardu & Michelutti, 04], only few studies concern the problems linked to the size reduction which can lead to a reduction of the actuators performances.
A collaboration between the Fluid Mechanics Institute of Toulouse and the Clément Ader Institute in Toulouse (ICA) has permitted the experimental and numerical characterization of sub-millimetric synthetic jet actuators, both in quiescent air and in the presence of transversal flow. Moreover, the efficiencies of 3 kinds of fluidic actuators (synthetic jet, pulsed jet and continuous jet) on the control of a separated wall flow have been compared, showing higher performances for the synthetic jet actuator [Batikh et al, 10].
More recently, interactions between two adjacent synthetic jet actuators have been numerically and experimentally characterized [Ghozlani, 11], and it has been shown that the resulting jet direction can be controlled by the phase lag between the two actuators, which can lead to an improvement of the actuator efficiency for separation control.
In parallel, an actuator without any moving part and producing two pulsed jets has been developed [Khelfaoui & al., 09]. This sub-millimetric fluidic oscillator, designed thanks to CFD numerical models, is able to generate pulsed jets at a frequency close to the one of the synthetic jets studied previously. In the framework of the PhD thesis of Shiqi Wang, several prototypes have been fabricated and tested experimentally to validate the numerical models allowing a

better understanding of the physical phenomena controlling the internal flow dynamics in this type of actuator [Wang & al., 16]. In addition, an array of miniaturized oscillators has been developed and integrated on a ramp installed in a wind tunnel to test the capability of this type of actuators to delay the flow separation [Wang, 17]. The first results are very promising showing an improved efficiency in comparison with other types of fluidic actuators, but have to be confirmed by additional experimental campaigns.

This PhD project aims at addressing these fundamental issues by *i.* developing a new generation of actuators capable to outperform the control devices currently available and *ii.* bringing new insights about the physical mechanisms underlying the interaction between the actuator and the flow.

Project description:

In the continuity of the previous studies, the proposed PhD project will have two main objectives and will benefit from the complementary skills and means of the two research teams:

- Workpackage 1: physics of the active flow control using switching jet actuators

  On one hand, the detailed analysis of the effect of the controlled flow using the switching jet actuation will have to be completed with 2 purposes: *i.* identify the optimal operating conditions of the actuators (e.g. actuation frequency, jet velocity …) and ii. identify the physical mechanisms governing the controlled flow. In addition, the integration of the array of micro-actuators within a closed-loop control will also be targeted. This part will conducted in the axis Flows and Aerodynamic Systems (ESA) of the Multidisciplinary Research Laboratory in Systems Engineering, Mechanics and Energetics (PRISME) of Orléans University, thanks to the experimental and numerical competences of this group in the characterization of compressible external flows and the experimental facilities developed in the framework of the "Flow Separation Control" national network ("Ahmed body" generic vehicle shape with a 25° slant, with control by various fluidic actuators). The actuators developed in the framework of this PhD project will be tested on this test bench, using the measurements facilities of the Laboratory (PIV, Laser Doppler Velocimetry, sting balance, pressure sensors…). In addition, it will be possible to use on local work stations or on regional and national computing centers the existing numerical codes of the ESA axis to complete this study.

- Workpackage 2: development and characterization of new oscillators prototypes

  On the other hand and according to the results of the experimental campaigns described above, new oscillator prototypes will be developed with the aim to reach optimal performances in relation with the control objectives. In particular, it will be interesting to explore new designs allowing the easy modification of the oscillators working frequency and the possibility to develop actuators with reduced dimensions for an easier integration in the wall near the separation point. For this purpose, numerical models developed in the framework of the previous PhD thesis will be modified in order to improve their capability to predict the structure of the jets generated by the oscillators and to take into account rarefaction effects which could appear when reducing the size of the devices or the operating pressure. In these cases indeed, the very low dimensions of the devices, in particular at the outlet orifices (of the order of few tens of microns) and the very low pressure levels (e.g. a few hundreds of mbars when the actuator works on an airplane wing at high altitude) can lead to Knudsen numbers (ratio of the mean free path of the molecules on the characteristic length of the flow, here the diameter or the width of the outlet orifice of the actuator for example) high enough to reach rarefied flow conditions (slip flow or transition regimes). Experimental validations of the numerical simulations will also be done thanks to the available facilities: test bench for the measurements of gas micro-flow rates, hot-wire anemometry, micro PIV and micro MTV (Molecular Tagging Velocimetry) set-ups. For this phase of the project, the PhD student will benefit from the experience of the Microsystems group at ICA in the field of numerical simulation, modeling and experimental characterization of gas microflows.

Requirements for the applicants:

- a Master degree in Physics or Mechanical Engineering with high standard results;
- very strong background in fluid mechanics;
- excellent communication skills and written/verbal knowledge of the French or English languages;
- if the candidate has some experience in microfluidics and/or in experimental techniques adapted to fluid flows, this would be a benefit.

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