# PROPOSITION DE SUJET DE THESE

**Intitulé : Active control of subsonic and supersonic cavity flows**

Référence : **MFE-DAAA-2024-26**
*(à rappeler dans toute correspondance)*

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| **Début de la thèse :** 01/10/2024 | **Date limite de candidature :** 31/05/2024 |

**Mots clés**

Experimental fluid mechanics, real-time control, compressible flows, metrology

**Profil et compétences recherchées**

Mechanical/Aerospace engineer (master recherche, grande école généraliste)

**Présentation du projet doctoral, contexte et objectif**

The flow over an open cavity is prone to an aero-acoustic feedback loop [1] leading to self-sustained pressure oscillations of large amplitudes (see figure 1b). This phenomenon leads to structural fatigue and aero-optic distortion in the compressible case. Aerospace applications range from landing gear and telescope bays to weapon bays, where flows oscillations may impede safe munition delivery. In this context, active flow control over supersonic cavity flows is identified as a key technology for the development of future military aircraft.

The challenges associated with active flow control at high speeds are high frequencies, typically beyond

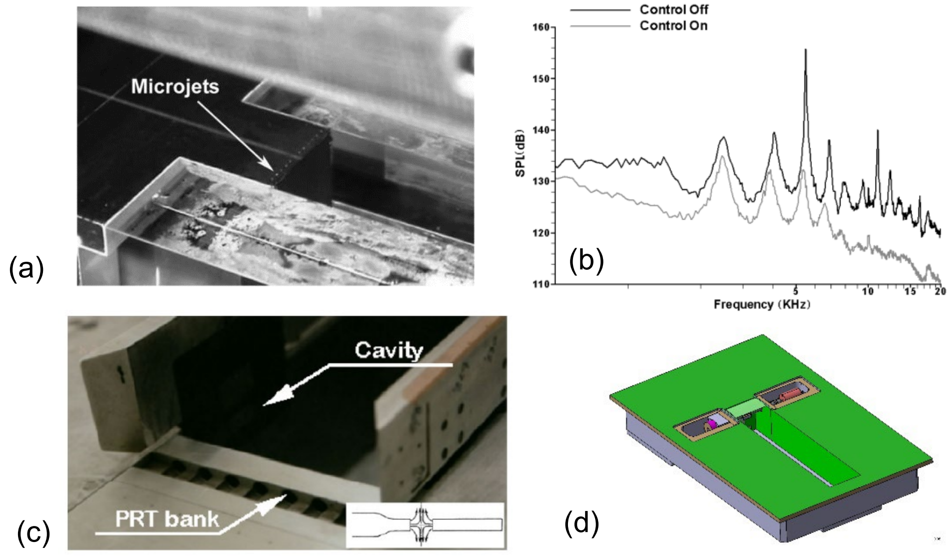


*Figure 1: (a) Control by sonic microjets blowing perpendicular to upstream edge of cavity in supersonic flow [2]; (b) sound pressure level with/without blowing measured near downstream edge of cavity [2] ; (c) powered resonance tubes upstream of cavity [3]; (b) ONERA cavity model for feedback control using oscillating flap near leading edge.*

1kHz, and weaker instabilities compared to incompressible flows, requiring both faster and stronger actuation. Multiple physical mechanisms may be exploited to reduce aerodynamic loads. Constant blowing at the leading edge (see figure 1a) may deviate and thicken the shear layer hence weakening the aero-acoustic feedback loop [2]. Acoustic forcing at high frequency (see figure 1c) may target small dissipative scales and indirectly affect the energetic large scales at lower frequencies through nonlinear interactions [3]. These two open-loop paradigms are proven to work in the supersonic regime but the mechanism of open-loop control by high-frequency forcing is still open to debate [1]. Finally, the most promising alternative is closed-loop control of flow instabilities, but this approach is extremely challenging at high speeds because of the need for large actuator bandwidth and authority. Last but not least is the challenge of designing an optimal control law for a strongly nonlinear system, both from the standpoint of fluid dynamics and actuator saturation. This question is far from resolved yet even in the subsonic case.

In this PhD project, two experiments will be investigated, as stepping stones towards the goal of closed-loop control of supersonic cavity flow. The first one is subsonic (*M* = 0.1 in the S19Ch wind tunnel) and will be used as a test bench for novel closed-loop control strategies using an oscillating flap at the leading-edge, driven by a piezo-electric actuator (see figure 1d). The focus here will be on implementing innovative control strategies among which model-predictive control [4] with recursive model adaptation and other adaptive schemes such as extremum seeking [5]. The second experiment is supersonic (*M* = 1.6 in the S8Ch wind tunnel) and will be used to thoroughly investigate the physical mechanisms of supersonic cavity oscillations in the presence and absence of open-loop flow control using continuous blowing (see figure 1a) and powered resonance tubes generating a high-frequency tone (see figure 1c). The focus here will be on high-speed metrology as the flow will be characterized using pressure probes, fast-response pressure-sensitive paint [6], schlieren imaging, particle image velocimetry. The analysis will help elucidate the mechanism for control of shear-layer oscillations by high-frequency forcing.

The oscillation frequencies in the S8Ch wind tunnel are too fast (up to 5kHz) for closed-loop control with a mechanical flap. However, both the S19Ch and S8Ch experiments are key steps towards the development of a future closed-loop experiment in the larger supersonic wind tunnel S3Ch, where oscillation frequencies can be decreased by using a model of greater dimensions, closer to the end application.

The PhD will interact with multiple technicians, engineers and researchers at ONERA, in the context of an internal research project on high-speed cavity flows involving high-fidelity CFD as well. As a result, the candidate should be a good team player with a clear taste for experiments, metrology and active control.

[1] Cattafesta III, L. N., Song, Q., Williams, D. R., Rowley, C. W., & Alvi, F. S. (2008). Active control of flow-induced cavity oscillations. *Progress in Aerospace Sciences*, *44*(7-8), 479-502.

[2] Zhuang, N., Alvi, F. S., Alkislar, M. B., & Shih, C. (2006). Supersonic cavity flows and their control. *AIAA Journal*, *44*(9), 2118-2128.

[3] Stanek, M., Raman, G., Kibens, V., Ross, J., Odedra, J., & Peto, J. (2000). Control of cavity resonance through very high frequency forcing. In *6th Aeroacoustics Conference and Exhibit, AIAA Paper 2000*1905.

[4] Korda, M., & Mezić, I. (2018). Linear predictors for nonlinear dynamical systems: Koopman operator meets model predictive control. *Automatica*, *93*, 149-160.

[5] Kim, K., Kasnakoglu, C., Serrani, A. & Samimy, M. (2009). Extremum-seeking control of subsonic cavity flow. *AIAA Journal* 47(1). 195-205.

[6] Flaherty, W., Reedy, T. M., Elliott, G. S., Austin, J. M., Schmit, R. F. & Crafton, J. (2014). Investigation of cavity flow using fast-response pressure-sensitive paint. *AIAA Journal*, 52(11), 2462-2470.

**Collaborations envisagées**

N/A.

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