Optimal Input/Output Analysis of Globally Unstable Low-Density Jet for Guiding Efficient Open-Loop Control

PARTENAIRES

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Key words: jet, control, stability, resolvent

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JOB DESCRIPTION:

Several previous studies have explored how time-harmonic axial or transverse (azimuthal) forcing affects the global instability of an axisymmetric low-density jet [1-2], particularly the transition to synchronisation (1:1 lock-in) under varying degrees of frequency detuning between the forcing frequency f_f and the natural global mode frequency f_n. These different routes to lock-in influence how the natural mode is quenched [2]. Under axial forcing with small detuning, synchronisation is achieved, but only through strong amplification of the forced mode, resulting in high overall oscillation levels (not shown in Fig. 1). With larger detuning ($f_f/f_n = 1.17$, Fig. 1a), the natural mode is more cleanly suppressed, though significant energy persists in the response due to axisymmetric mode alignment. In contrast, transverse forcing spatially decouples the natural and forced modes, allowing both synchronous and asynchronous quenching with minimal amplification. Here, the natural mode decays before lock-in, and the forced mode remains weak throughout (Fig. 1b), leading to more effective and robust suppression of the instability. Thus, transverse forcing offers a more reliable and less intrusive route to synchronisation and quenching, especially at large detuning, achieving lock-in through suppression without exciting strong resonant dynamics. This makes it a promising open-loop control strategy for eliminating the limit cycle and stabilising the flow.

While these proof-of-concept studies underscore the benefits of azimuthal over axial forcing, a systematic theoretical framework to predict the optimal azimuthal structure and frequency detuning for this category of globally unstable jets is still lacking. This stage aims to fill that gap by performing state-of-the-art optimal linear input/output analyses—specifically, 'harmonic' and 'mean' resolvent analyses [3-4]. Through singular value decomposition (SVD) of the resolvent operator, this approach will identify the most energy-amplifying forcing and response modes, providing a basis for optimally placing actuators and sensors in both open- and closed-loop control strategies.

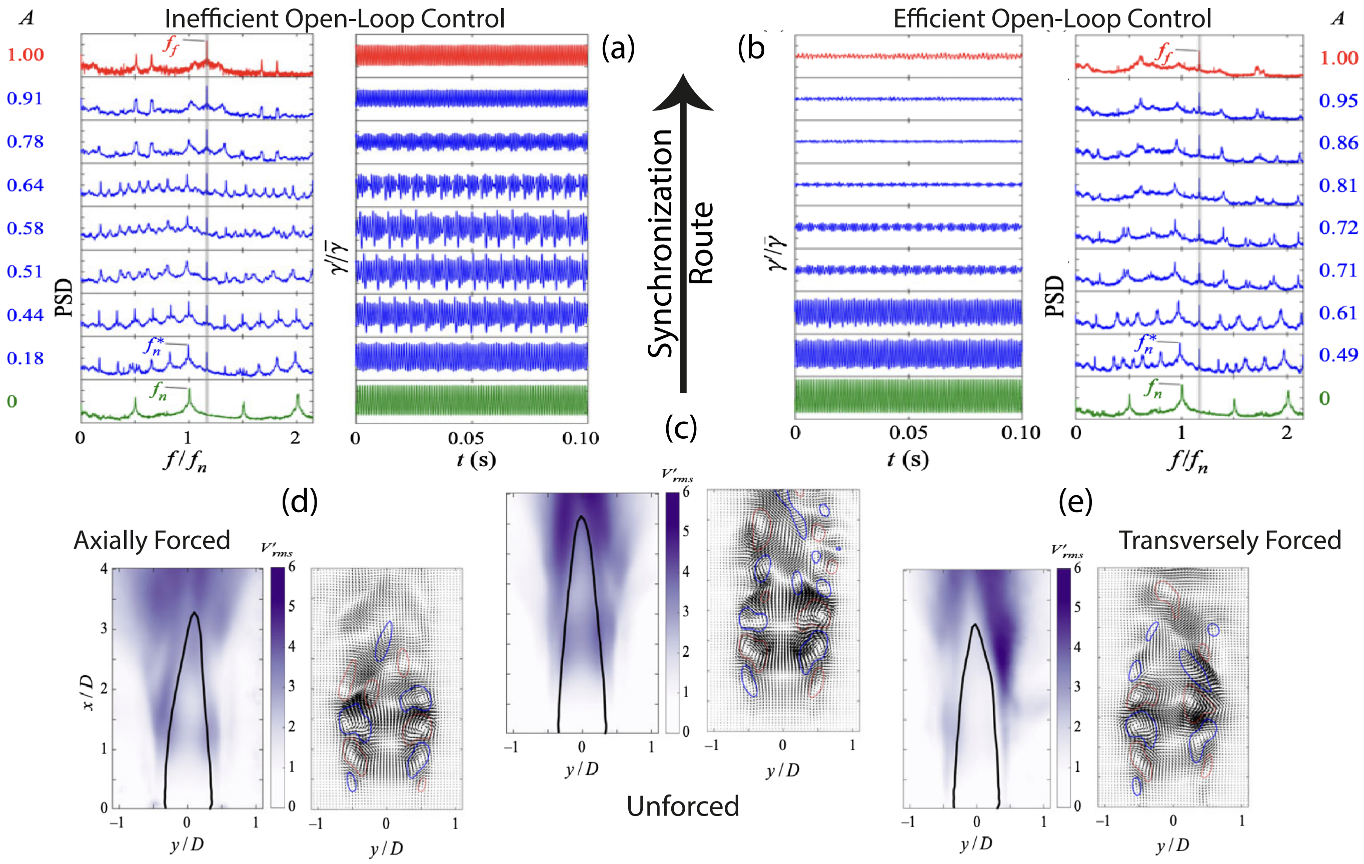

Figure 1: (a) Synchronisation dynamics of the jet when forced axially at a frequency far from its natural global frequency, i.e. $f_f/f_n = 1.17$. Power Spectral Densities (PSD) and associated time-traces for increasing forcing amplitude A are reported, respectively, on the left and right panels. (b) Same as in (a) but for a transverse forcing. Note how the final amplitude is drastically lowered: this vis-à-vis comparison clearly identifies transverse forcing as an efficient strategy for open-loop control. (c)-(e) Spatial distribution of the jet dynamics, as measured with PIV by Kushwaha et al. [2]. The left panels show the root-mean-square of the total velocity fluctuation V'_{rms}; the black line designates the boundary of the jet potential core; the effectiveness of the different forcing can be appreciated by the reduction of fluctuations within the potential core. The right panels show the jet coherent structures extracted via Dynamic Mode Decomposition. A $\pi\backslash 2$-phase shift between the left and right shear layers is visible in (e) and is due to the axisymmetry breaking induced by the control forcing.

MISSIONS:

This research aims to advance flow-control methodologies through state-of-the-art linear input/output analyses—specifically, harmonic and mean resolvent analyses. By leveraging SVD of the resolvent operator, the study seeks to identify the most energetically significant forcing and response modes, providing a rigorous framework for the optimal placement of actuators and sensors in both open- and closed-loop control systems.

REQUIRED PROFILE:

A strong background in fluid dynamics, linear algebra, and programming is required. A preliminary knowledge of advanced numerical methods is also required. An excellent command of Python and PETSc library is highly desirable. The interested candidates need to contact by email the supervisors. The curriculum vitae of the student should be attached to the email together with previous university transcripts.

COMPENSATION: 4,35€ /hour – 35 hour-per-week

DURATION: 6 MOIS

LOCATION: TOULOUSE

RESPONSIBLE OF THE SUBJECT:

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APPLICATION PROCESS:

Applications (CV and transcripts) should be sent to gabriele.nastro@isae-supaero.fr and alessandro.bongarzone@onera.fr

REFERENCES:

[1] L. Lesshafft, P. Huerre & P. Sagaut 2007 Frequency selection in globally unstable round jets Phys. Fluids 19 (5), 054108.

[2] A. K. Kushwaha, N. A. Worth, J. R. Dawson, V. Gupta & L. K. B. Li 2022 Asynchronous and synchronous quenching of a globally unstable jet via axisymmetric breaking J. Fluid Mech. 937, A40.

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