PROPOSITION DE SUJET DE THESE

Intitulé : Long range instabilities: Physical mechanisms and reduced order model

Référence : **MFE-DMPE-2025-08**
(à rappeler dans toute correspondance)

Début de la thèse : Octobre 2025	**Date limite de candidature :** Juillet 2025

Mots clés

Linear stability, long-range instabilities, acoustics, reacting flows

Profil et compétences recherchées

Master of science or engineering degree in physics, fluid mechanics or applied mathematics.

Skills: Applied mathematics, fluid mechanics, numerical methods.

Please send your CV, a motivation letter and the transcripts of your master or engineering school.

Présentation du projet doctoral, contexte et objectif

Turbulent motion is ubiquitous in nature. While the vortex dynamics associated to turbulence necessarily involves a large range of scales, the large coherent structures supporting the fluid motion are commonly issued from a fluid instability. The nature of fluid instabilities is commonly classified as absolute and convective [1]. In the latter case (convectively unstable), the amplitude associated to the instability grows in a moving frame of reference, whereas in the former case (absolutely unstable) it grows at the location of the source, and subsequently spreads elsewhere. Giannetti et al. [2] introduced the concept of structural sensitivity to identify the wave-maker, that is, the spatial region where the mechanism that sustains the instability is active. This concept was later generalized to include base-flow changes, saturation and non-linear effects [3, 4, 7, 8, 10, 12]. While, for many fluid instabilities, the spatial distribution of the structural sensitivity is highly localized, e.g., the flow past a rotating particle [13] or the flow past a spinning cylinder [9], many other flow configurations exhibit fluid instabilities underpinned by a non-local feedback-loop. In these cases, the core of the instability is not localized in space and we could further break down these instabilities based on the underpinning physical mechanisms. The first corresponds to the case when the instability is supported by an acoustic-hydrodynamic feedback loop, for instance in cavity flows [5], impinging jets [14] or the tonal noise emitted by the flow past an airfoil [6]. The second case corresponds to thermoacoustic instabilities where vortical fluctuations induce oscillations in the heat released by the flame, which in turn produce an acoustic wave that closes the feedback loop. A deep understanding of the exchange mechanisms leading to the instability is of paramount importance in engineering designs and in the fundamental understanding of these flows. In addition, the spectrum resulting from global linear stability analysis is characterized by an arc-branch with modes with nearly equidistant frequency. As a result, in these configurations it is common to observe mode-switching and hysteresis behavior [15].

In this proposal in order to identify the physical mechanisms and to unveil the localized nature of long-range instabilities we would like to first propose a decomposition of the structural sensitivity and in a second step to propose a weakly nonlinear modeling of the resonant dynamics in the case of global unstable flows (resonators) and globally stable flows (amplifiers), in the latter case extending the work of [11].

To do so, here we would like to extend the decomposition of the structural sensitivity proposed in [17]. The decomposition of the structural sensitivity will be based on a splitting of the global mode or optimal response using Doak's decomposition [15]. In a second step, the adjoint would be decomposed following a decomposition of the acoustic, hydrodynamic and entropic forcing. Such analysis will be applied to canonical cases of interest: an impinging jet, cavity flow and flow past an airfoil for feedback loops underpinned by an acoustic-hydrodynamic mechanism; and for a V-flame in order to analyze intrinsic and classical thermoacoustic instabilities [18].

Subsequently, in order to study in detail mode-switching of these resonator flows, weakly nonlinear modeling will be applied to the laminar configuration for a globally unstable flow, and in a turbulent case around a mean flow, where the arc-branch of modes is stable and nearly neutral. As a result of this study, it is expected to obtain a bifurcation diagram which it is a fundamental representation of the dynamics of the staging phenomenon. Comparisons with experiments and data assimilation from Pprime are possible in order to determine the validity of the model.

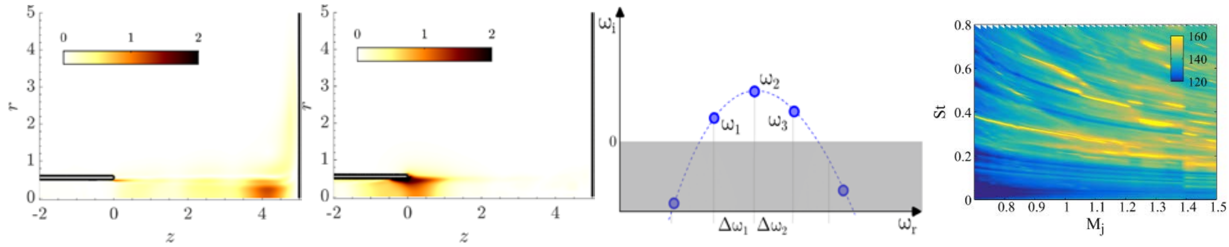

Fig 1. Decomposition of the structural sensitivity in an impinging jet case: Closure of the feedback loop, region where the acoustic response is triggered by the vortical component of the flow (first); active region of the flow where the acoustic component of the flow triggers a vortical response starting the feedback loop (second). The third is a diagram which sketches the quantization of the spectrum. Frequency evolution with respect to the jet Mach number of an impinging jet displaying mode switching for a plate to nozzle distance equal to four (extracted from [16]).

References

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Collaborations envisagées

The PhD will be in co-tutelle between ONERA and Università degli studi di Salerno. External collaborations with IMFT, Pprime and KTH may take place during the PhD.

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