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PROPOSITION DE STAGE EN COURS D'ETUDES

Référence : **DAADA-2025-19**
(à rappeler dans toute correspondance)

Lieu : Meudon

Département/Dir./Serv. : DAAA / MASH

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DESCRIPTION DU STAGE

Thématique(s) : Contrôle des écoulements pour l'aérodynamique, l'aéroacoustique et l'aéroélasticité

Type de stage : ☒ Fin d'études bac+5 ☒ Master 2 ☐ Bac+2 à bac+4 ☐ Autres

Intitulé : Data-based control of turbulent flows using tools from statistical physics

Sujet : In feedback control theory, a linear time-invariant (LTI) model of the input-output dynamics is generally required. Since in frequency domain, a LTI dynamics indicates the existence of a system's transfer function, one can ask how to define a mean transfer function for time-varying, statistically steady flows, i.e. turbulent flows. The common choice in aerodynamics consists in linearising the governing equations, e.g., the compressible Navier-Stokes equations, around the time-averaged meanflow [1-2]. However, despite its popularity promoted by its technical advantage and physical interpretation, this choice is justifiable only under precise conditions [3].

Recently, Leclercq & Sipp (2023) [4] proposed a new definition of a mean transfer function, best characterizing the input-output behaviour in statistically steady flows. This novel definition extends that of the usual transfer function about the meanflow and suggests that any analysis done with the latter may, in principle, also be done with the new one. This includes reduced-order modelling, data assimilation of second-order statistics, input-output analysis, flow control, machine learning, etc. Nevertheless, successfully performing one of these tasks hinges on developing suitable numerical methods to extract such a mean transfer function.

In contradistinction to standard and intrusive techniques employing external small harmonic forcing and based on time-costly ensemble average over many realizations [4], the project proposed for this internship aims at exploring and developing more efficient techniques capable of identifying the system's mean transfer function non-intrusively, by exploiting exclusively information from the spontaneous nonlinear flow dynamics without additive forcing.

By noticing that the mean transfer function defined in [3] is essentially the frequency-domain representation of the mean linear impulse response to external forcing, we can draw connections with concepts from response theory in statistical physics, such as the Fluctuation-dissipation theorem (FDT) [6], that will be tentatively exploited to our purposes. Specifically, the main goal of the internship will consist in implementing and testing different algorithms for an efficient computation of lagged autocorrelation matrices in the Frequency-Laplace domain, whose definition is strictly connected with that of the mean transfer function.

While the long-term objective of this internship targets the application of the developed methodology to complex aerodynamic flows, e.g. turbulent jets [7] and open-cavity flows [8] (see figure 1), preliminary tests will be conducted by considering the complex Ginzburg-Landau equation (see figure 1) [9]: this archetypal problem will offer us the possibility to quickly span and test the developed algorithms over a wide range of intricate dynamical configurations reminiscent of realistic features manifesting in engineering flows.

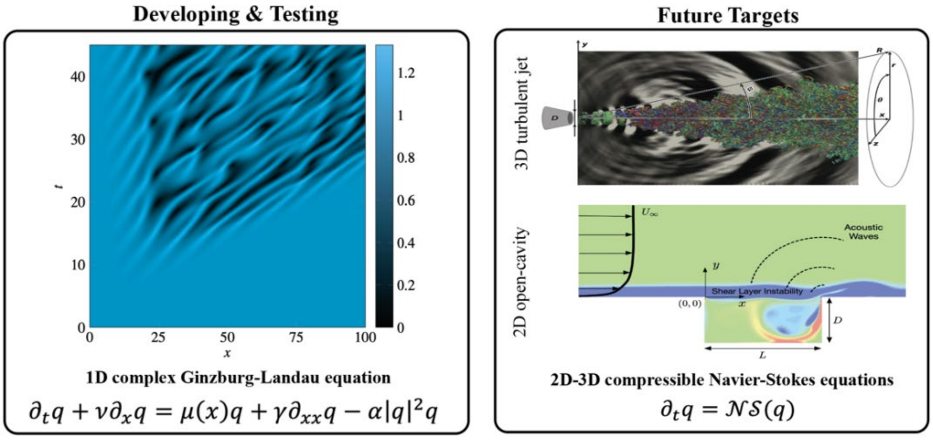

*Figure 1: **Left**: phase turbulence in the one-dimensional complex Ginzburg-Landau equation with non-zero advection. **Right**: large-eddy simulation of a subsonic 3D turbulent jet [7] and computational configuration for a two-dimensional subsonic open-cavity flow [8].*

[1] D. Sipp & A. Lebedev 2007 Global stability of base and mean flow: a general approach and its application to cylinder and open cavity flows. *J. Fluid Mech.*, 593, 333-358.

[2] B. J. McKeon & A. S. Sharma 2010 A critical-layer framework for turbulent pipe flow. *J. Fluid Mech.*, 685.

[3] S. Beneddine, D. Sipp, A. Arnault, J. Dandois & L. Lesshafft 2016 Conditions for validity of mean flow stability analysis. *J. Fluid Mech.*, 798.

[4] C. Leclercq & D. Sipp 2023 Mean resolvent operator of a statistically steady flow. *J. Fluid Mech.*, 968.

[5] M. C. Cross & H. Greenside 2009 Pattern formation and dynamics in nonequilibrium systems. *Cambridge University Press*.

[6] D. Ruelle 2009 A review of linear response theory for general differentiable dynamical system. *Nonlinearity*, 22(4), 855.

[7] P. Jordan & T. Colonius 2013 Wave packets and turbulent jet noise. *Annu. Rev. Fluid Mech.*, 45:173-195.

[8] Y. Sun, A. G. Nair, K. Taira, L. N. Cattafesta, G. A. Brès & L. S. Ukeiley 2014 Numerical simulation of subsonic and transonic open-cavity flows. *AIAA*, 2014-3092.

[9] K. K. Chen & C. W. Rowley 2011 H2 optimal actuator and sensor placement in the linearised complex Ginzburg-Landau system. *J. Fluid Mech.*, 681, 241-260.

Est-il possible d'envisager un travail en binôme ? A renseigner

Méthodes à mettre en œuvre :

☒ Recherche théorique ☐ Travail de synthèse

☐ Recherche appliquée ☐ Travail de documentation

☐ Recherche expérimentale ☐ Participation à une réalisation

Possibilité de prolongation en thèse : A renseigner

Durée du stage : Minimum : 5 mois Maximum : 6 mois

Période souhaitée : de mars à août 2025

PROFIL DU STAGIAIRE

Connaissances et niveau requis :	Ecoles ou établissements souhaités :
Programmation python, mécanique des fluides	Grande école d’Ingénieur ou Master Recherche en mécanique, physique ou mathématique appliquées