

PROPOSITION DE STAGE EN COURS D'ETUDES

Référence : DMPE-2026-07 (à rappeler dans toute correspondance)	Lieu :	Toulouse
Département/Dir./Serv. : DMPE/STAT	Tél. :	
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DESCRIPTION DU STAGE

Thématique(s) : Matériaux énergétiques, émissions et dispersion atmosphérique

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

Title: Dynamics of Unstable Modes in Hypersonic Flow Simulations of 2D Boundary Layers

Background

Almost every aspect of the aerodynamic design of hypersonic vehicles benefits to a large degree from accurate knowledge of the laminar-turbulent transition location. The list of key properties affected by this prediction include the drag, the heat transfer, the aerodynamic response to control surface actuation and the efficiency of air-breathing engine intakes, to name a few. Hence, controlling or predicting the boundary layer state is of high interest from a practical point of view.

In the hypersonic regime, which concerns vehicles such as the SR-72 or the X-51, a notoriously important instability mechanism that contributes to transition is the so-called Mack second mode. It is an instability which, because of its acoustic nature [1], consists of trapped acoustic waves between the wall and the height up to which the mode disturbance is supersonic with respect to the flow [2]. The strength of the instability and its relative importance with respect to other instability types is known to depend on the wall temperature, with cooler walls (with respect to the flow) destabilizing the second Mack mode and hot walls enhancing the first Mack mode. The early stages of these instabilities can be studied by means of local linear stability theory, while numerical simulations capturing the full Navier-Stokes are able to analyse non-linear interactions.

Numerical simulations

To elucidate the dynamics of the different modes excited during time-dependent high-fidelity simulations in terms of acoustic, vortical and thermal energy components [3], a data-base of time-resolved snapshots obtained with an in-house CFD code¹ will be analyzed using coherent structure identification and tracking techniques. During this project, the student will learn how to use the CFD code to run simulations of laminar, hypersonic boundary layers in 2D domains subject to time-dependent forcing, and post-process the generated datasets to quantitatively obtain dynamical trends according to geometric overlaps between different types of structures. The methodology will be validated by relying on local linear stability analysis predictions before applying the methodology to the non-linear regime of disturbance growth.

Prerequisites

Candidates would benefit from having previous experience with

- Numerical analysis (spatial discretization & time integration schemes, CFL condition...)
- Programming (Python, Fortran...)
- Meshing (GMSH)
- Flow visualization (Paraview)

A strong background in fluid mechanics is expected, and knowledge of stability theory would be appreciated.

¹ JAGUAR, an unstructured CFD code co-developed by ONERA and CERFACS based on the spectral difference scheme.

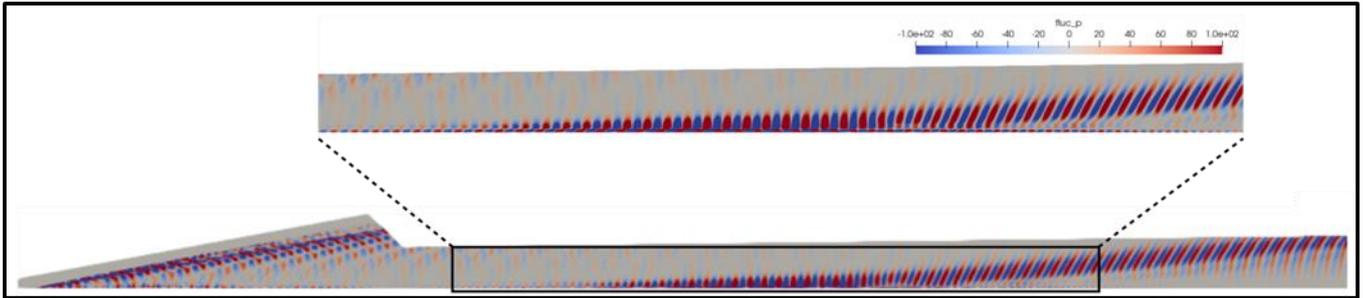


Fig. 1. Fluctuating pressure in a 2D hypersonic laminar boundary layer subject to non-linear forcing (wall blowing/suction) causing a Mack second mode to develop. Numerical simulation carried out with JAGUAR.

References

[1] Kuehl, J.J., *AIAA Journal*, 56(9), pp. 3585-3592. **2022**
 [2] Fedorov, A. (2011). Transition and stability of high-speed boundary layers. *Annual review of fluid mechanics*, 43(1), 79-95.
 [3] Doak, P. E. (1989). Momentum potential theory of energy flux carried by momentum fluctuations. *Journal of sound and vibration*, 131(1), 67-90.

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

Méthodes à mettre en œuvre :

- | | |
|---|--|
| <input type="checkbox"/> Recherche théorique | <input type="checkbox"/> Travail de synthèse |
| <input checked="" type="checkbox"/> Recherche appliquée | <input checked="" type="checkbox"/> Travail de documentation |
| <input type="checkbox"/> Recherche expérimentale | <input type="checkbox"/> Participation à une réalisation |

Possibilité de prolongation en thèse : Non

Durée du stage : Minimum : 4 months | Maximum : 5 months

Période souhaitée : February - September 2025

PROFIL DU STAGIAIRE

Connaissances et niveau requis Computational fluid dynamics, compressible flow, programming, linux environment.	Ecoles ou établissements souhaités : Enrolled in a Master's degree in engineering, physics or applied mathematics.
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