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FINAL DEGREE PROJECT

Reference : **DMPE-2025-09**

Location : Toulouse

Department : Multi-physics for Energetics (DMPE)

Phone :

Supervisors: José Cardesa, Hugues Deniau

Email : hdeniau@onera.fr , jcardesa@onera.fr

PROJECT DESCRIPTION

Keywords : Computational Fluid Dynamics, Hypersonic Flows, Laminar-turbulent transition

Project Type : Required for completion of a Master's degree (STAGE M2)

Title: Hypersonic flow simulations of transitional boundary layers controlled by a porous wall

<u>Background</u>

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], is known to be damped when suitable porous coatings are used on the wall surface [2]. This passive control strategy is particularly appealing, yet extremely challenging to model numerically because of the scale of the pore sizes to be meshed for Computational Fluid Dynamics (CFD) simulations.

<u>Numerical simulations</u>

To circumvent the difficulty of representing the pore microstructure under a hypersonic boundary layer, our in-house CFD code dedicated to high-fidelity simulations[1] implements a type of boundary condition that can avoid the need to mesh the micro pores. The acoustic response of the porous material is modeled via an impedance boundary condition [3].

During this project, the student will learn how to use the CFD code to run simulations of laminar, hypersonic boundary layers on curved geometries subject to incoming disturbances. The damping effect of the porous wall on the flow disturbances is the physical mechanism that needs to be reproduced, quantified and understood.

<u>Prerequisites</u>

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.

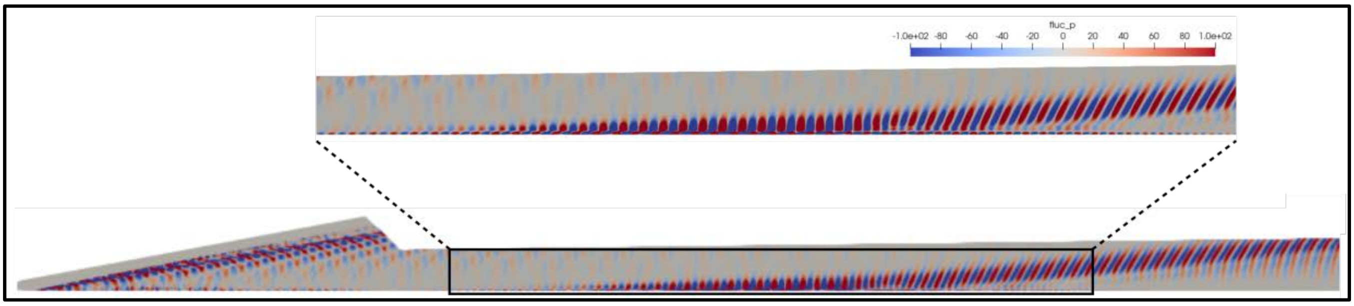

Fig. 1. Flucuating pressure in a 2D hypersonic laminar boundary layer subject to non-linear forcing (wall blowing/suction) causing a Mack second mode to develop. Numerical simulation carried out with JAGUAR.

References

[1] Kuehl, J.J., *AIAA Journal, 56(9), pp. 3585-3592*. **2022**
[2] Rasheed, A., Hornung, H.G., Fedorov, A.V., Malmuth, N.D., *AIAA Journal, 40(3), pp. 481-489.* **2002**
[3] Roncen, R., Cardesa, J.I., *Journal of Sound and Vibration*, 554, p. 117691. **2023**

Project duration : Minimum : 4 months Maximum : 5 months

Possible period span by the project : February - September 2025

CANDIDATE PROFILE

Required knowledge in :	Higher education :
Computational fluid dynamics, compressible flow, programming, linux environment.	Enrolled in a Master’s degree in engineering, physics or applied mathematics.