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PROPOSITION DE SUJET DE THESE

Intitulé : Boundary Layer Transition Induced by Periodic Surface Roughness

Référence : **MFE-DAAA-2026-21**
(à rappeler dans toute correspondance)

Lien de candidature *: https://emea3.recruitmentplatform.com/apply-app/pages/application-form?jobId=PVOFK026203F3VBQB68LOF6HI-6147*

Début de la thèse : from June to October 2026	**Application deadline: 30 April 2026**

Keywords

Boundary layer flow transition: Distributed Roughness ; Bloch waves and homogenization theory

Candidate Profile and Required Skills:

Master's degree in Mechanical Engineering, Aerospace Engineering, or Applied Mathematics, with a strong interest in mathematical and physical modeling. Prior experience in linear stability analysis or fluid–structure interaction would be considered an asset.

Presentation of the individual PhD project: context and objectives

Understanding roughness-induced transition is crucial, as it leads to increased skin-friction drag and can significantly impact the **aerodynamic performance of vehicles**. Over the past decade, the **transition of subsonic boundary-layer flows** induced by **isolated roughness elements** of various shapes has attracted considerable attention. Direct Numerical Simulations (DNS) of the unsteady wake generated by an isolated cylindrical roughness element (Figure 1, left) were performed by *Loiseau et al.* (2014). The emergence of such unsteady wakes was subsequently examined through **global stability analyses** of the corresponding three-dimensional steady base flows**.** The authors showed that sinuous **and** varicose eigenmodes—associated with distinct physical mechanisms—become unstable once the roughness height exceeds a critical threshold. A similar methodology was employed by *Citro et al.* (2015) to study the flow past a semi-hemispherical roughness element, confirming the existence of analogous instability mechanisms. More recently, *Bucci et al.* (2018) investigated subcritical transition around a cylindrical roughness element by combining experimental measurements with numerical simulations. To elucidate the amplification mechanisms underlying the experimentally observed transition, the authors conducted a **resolvent analysis**, providing new insights into the subcritical amplification processes.

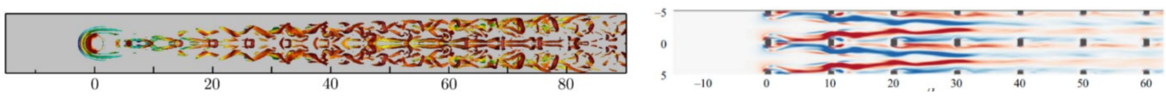

Figure 1 – Flow structures in a boundary layer induced by (Left) an isolated surface roughness (figures from Loiseau et al, 2014) and (Right) periodically distributed surface roughhness (figures from Ma and Mahesh 2023).

The objective of this PhD thesis is to investigate subsonic boundary-layer transition induced by **periodically distributed surface roughness**. *Ma and Mahseh* (2023) recently conducted a related study combining Direct Numerical Simulations (DNS) with global stability analysis**,** providing valuable insight into the instability mechanisms at play. However, such high-fidelity numerical approaches are **computationally prohibitive**, which limits their applicability to a restricted set of parameters and configurations.

In this project, we aim to develop **novel analytical and reduced-order numerical methods** to investigate the flow dynamics induced by periodic roughness while **drastically reducing the computational cost** compared to full DNS or global stability analyses. These approaches will make it possible to explore **broader parametric spaces**—including variations in roughness geometry, spacing, and Reynolds number—and to address **more realistic configurations** relevant to **aeronautical and industrial applications**.

The first approach considered in this project will leverage the spatial periodicity of the surface roughness. **Bloch theory** provides a rigorous framework for analyzing **wave propagation in spatially periodic, non-dissipative media**, such as electromagnetic, elastic, or acoustic waves in metamaterials. In the present context, it will be applied to **investigate the non-modal amplification of flow perturbations** decomposed into Bloch waves. This formulation enables the singular value problem arising in resolvent analysis to be discretized within a **single unit cell**. The Bloch wavenumber remains a continuous control parameter**,** allowing one to explore the amplification of disturbances with **arbitrary wavelengths**. Figure 2 show the most amplified spatial structures computed in a boundary-layer flow over **two-dimensional periodic roughness**, for low (left) and high (right) excitation frequencies. In both cases, the entire analysis is performed on the **unit cell** highlighted in blue. For low frequencies and long wavelengths (left) the analysis recovers the classical **Tollmien–Schlichting waves** characteristic of smooth-wall boundary layers. At higher frequencies and shorter wavelengths (right), **shear-layer instabilities** emerge, revealing the **strong influence of surface periodicity** on the dynamics of short-wavelength perturbations.

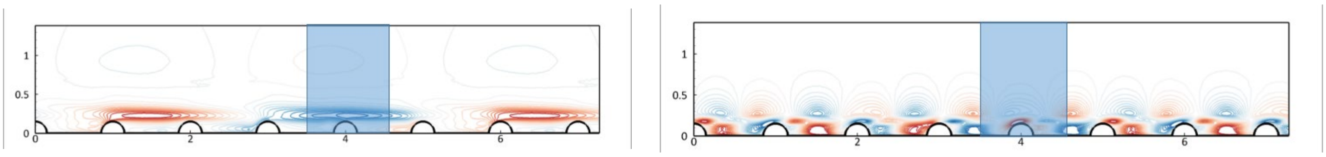

Figure 2 – (Left) Low-frequency Tollmien-Schlichting modes and (Right) high-frequency shear-layer modes computed with a resolvent analysis performed on the unit cell (blue)

The second approach explored in this project will rely on **homogenization theory**. Asymptotic homogenization provides a rigorous framework for describing the macroscale behavior of media containing fine-scale heterogeneities**.** It does so by replacing the rapidly varying microscopic properties of the medium with equivalent, effective macroscopic parameters. This approach can be used to **derive effective boundary conditions** defined on a **smooth virtual surface**, which acts as the boundary of the macroscale problem (Zampogna et al., 2019). In this way, the **computationally demanding resolution of the flow inside each individual roughness element** is avoided. Within this framework, we will develop and implement methods to **compute** steady boundary-layer flows over rough surfaces and subsequently **to** analyze the amplification of unsteady perturbations using the same homogenized formulation. A key question that naturally arises is whether this approach is capable of capturing the high-frequency shear-layer modes (Figure 2, right), which are strongly influenced by the fine-scale geometry of the surface roughness.

During the **first year**, the PhD candidate will become familiar with the underlying mathematical frameworks (Bloch theory and homogenization) and the existing numerical tools, by investigating the **transition of boundary-layer flows over two-dimensional surface roughness**. The influence of roughness size, shape, and spacing on both the steady base flow and the amplification of perturbations will be systematically analyzed using both approaches. To perform these parametric studies efficiently**,** the candidate will develop **algorithms** capable of **tracking resolvent modes** as parameters vary, thus significantly **reducing the overall computational cost**. In the **second and third years**, the study will be extended to **three-dimensional roughness configurations**, requiring the development of dedicated numerical tools optimized for high-performance computing environments. Results will be systematically compared with those obtained for isolated roughness elements, providing new physical insight into the **collective effects of periodic roughness** on boundary-layer transition. Beyond the individual research program described above, the candidate will also participate, together with the other **FairCFD doctoral researchers**, in a **network-wide multidisciplinary initiative** addressing the **environmental and societal impacts of numerical simulation**, in line with the objectives of the Marie Skłodowska-Curie Actions.

Description of the FairCFD project

This PhD position is part of the **FairCFD Doctoral Network**, funded by the **European "Marie Skłodowska-Curie Actions" (MSCA)** programme. The network aims to define and promote **numerical sustainability** in the field of **Computational Fluid Dynamics (CFD)**. The successful candidate will join a cohort of **15 doctoral researchers** distributed across **9 European countries**, benefiting from access to **cutting-edge training events**, **advanced scientific and technical courses**, and **secondments** in both **academic and industrial** environments.

Description of the PhD position

The successful candidate will be primarily hosted at the **Department of Aerodynamics, Aeroelasticity and Acoustics** of **ONERA – The French Aerospace Lab**, located in **Meudon, France**. He will receive an attractive gross salary in accordance with the MSCA regulations for Doctoral Researchers. The exact (net) salary will be confirmed upon appointment and is dependent on local tax regulations and on the country correction factor (to allow for the difference in cost of living in different EU Member States). The salary includes a living allowance, a mobility allowance, and a family allowance (if applicable*). The guaranteed PhD funding is for 36 months (i.e., EC funding, additional funding is possible, depending on the local Supervisor, and in accordance with the regular PhD time in the country of origin).

Eligibility conditions

In accordance with the mobility rule of the Marie Skłodowska-Curie Actions Doctoral Networks (MSCA-DN), applicants must not have resided or carried out their main activity (work, studies, etc.) in France for more than 12 months within the 36 months preceding the start of the PhD. Candidates must also not already hold a doctoral degree. Subject to these eligibility criteria, applications are welcome from outstanding Research Master's graduates worldwide. The selected candidate will also be required to obtain security clearance in order to be recruited at ONERA.

Application process and oral interview:

In the first stage, applicants are required to submit a CV, academic transcripts, a letter of motivation, and a project report to the PhD director and supervisors. All applicants will be informed of the outcome of this initial selection. Candidates shortlisted for the second stage will be invited to a 30–45 minutes oral interview. During the first 20 minutes, they will present their background and a previously completed scientific project. The remainder of the interview will be dedicated to a presentation of the PhD proposal and a discussion with the selection committee. At the end of the interview, candidates will have the opportunity to ask additional questions.

References :

J.-C. Loiseau, J.-C. Robinet, S. Cherubini, and E. Leriche. *Investigation of the roughness-induced transition: global stability analyses and direct numerical simulations.* Journal of Fluid Mechanics, 760:175–211, 2014.

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Zampogna, G. A., Magnaudet, J., & Bottaro, A. (2019). Generalized slip condition over rough surfaces. *Journal of Fluid Mechanics*, *858*, 407-436.

Collaborations

At least **two secondments**, i.e. **research visits of a minimum duration of two months**, will be planned in **partner universities** of the project (IMFT, University of Salerno, University of Cambridge, TU Berlin).

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