PROPOSITION DE SUJET DE THESE

Intitulé : Experimental Investigation of Metamaterials for Laminar Flow Control in Aerodynamics

Référence : **MFE-DAAA-2026-10**
(à rappeler dans toute correspondance)

Début de la thèse : October 2026	**Date limite de candidature : June 2026**

Mots clés

Metamaterial, flow control, wind tunnel, transition to turbulence

Profil et compétences recherchées

- M.Sc. in Fluid Mechanics, Aerospace Engineering, Mechanical Engineering, or related fields.
- Basic knowledge of Hydrodynamic Stability.
- Basic knowledge of Solid Mechanics and Solid Dynamics.
- Marked interest for Experimental Fluid and Solid Mechanics.
- Familiarity with data processing tools such as MATLAB and Python.

Strong interest in transdisciplinary research at the intersection of fluid mechanics and material science.

Présentation du projet doctoral, contexte et objectif

The development of low-drag aircraft wings is crucial for facilitating the future of low-emission and emission-free aviation. Achieving extended laminar flow can significantly reduce aircraft drag, leading to more efficient and sustainable air travel. Taking the inspiration initially from the surprising ability of swimming animals to move fast without spending too much energy [1], compliant surfaces have been proposed to passively reduce the skin-friction drag of slender bodies by extending the laminar flow [2]. For laminar boundary layers, flexible wall may attenuate the Tollmien-Schlichting (TS) waves, which are responsible for the laminar-turbulent transition over rigid wall, and, thus, reduce the skin-friction drag. However, compliant materials found in nature have inherent drawbacks for such as their large density compared to air, thus limiting their use to water flow.

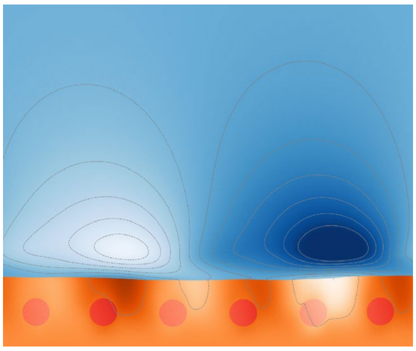

Figure 1 Example of attenuation of coupled fluid-structural waves) with phononic surface from [4]

An alternative to these *natural* materials in considering microstructured compliant layers using the unique properties of metamaterials, such as phononic surfaces. These are made from periodic composite structures and engineered to control the wave propagation within the solid medium. This allows for the possibility of tailoring the properties of the compliant surface to exhibit static and dynamic behaviors not found in natural materials and, therefore, enable the use of compliant surfaces for flow control [3]. As an example, periodic scatterer arrangements can create band gaps that block acoustic wave propagation in certain frequency ranges within the solid phase. Along this line of research, a recent numerical study by the supervisory team [4], conducted in a water-equivalent flow, has demonstrated a promising metamaterial design capable of attenuating TS waves, while also avoiding fluid-structural instabilities observed in compliant walls, namely traveling-wave flutter.

The present PhD thesis aims to experimentally investigate the influence of novel metamaterials on boundary-layer transition, with a particular focus on delaying TS wave development in air flows. Considering light fluids, such as air, with respect to water presents its own challenges because of the high solid-to-fluid density ratio. This work will build upon, compare, and possibly combine two design strategies of the metamaterial design proposed in [4] and [5] to achieve an efficient configuration for air experiments.

This doctoral project lies at the intersection of fluid mechanics and materials science, following a truly transdisciplinary approach. A phononic surface will be 3D printed, dynamically characterized, and integrated into a boundary-layer setup within the subsonic wind tunnel at ONERA Meudon. Complementary experiments will be conducted at TU Delft [5], where the facility allows the implementation of deep metamaterial configurations, enabling tests for instance of a series of subsurface phononic layers arranged along the streamwise direction, rather than a single layer as in previous work of [4].

The research plan includes:

- Conducting wind tunnel experiments to characterize the TS wave generator.
- Designing, fabricating, and characterizing the metamaterial in collaboration with the materials department (DMAS at ONERA and Munich University of Applied Sciences).
- Performing wind tunnel experiments to study the effects of metamaterials on transition to turbulence at ONERA and TU Delft
- Implementing advanced measurement techniques, including Particle Image Velocimetry (PIV), near-wall hot-wire anemometry, and panel deformation methods such as Digital Image Correlation (DIC).
- Publishing findings in high-impact peer-reviewed journals and presenting results at international conferences.
- A visiting period at TU Delft (last year of the thesis + short visits within the first two).

References

[1] Kramer, M. O. (1961). The dolphin's secret. Naval Engineers Journal 73 (1), 103–108.

[2] Carpenter, P. W. (1990). Status of transition delay using compliant walls. Viscous drag reduction in boundary layers, 123, 79-113.

[3] F. Avallone, F. Bosia, Y. Chen, G. Colombo, R. Craster, J. M. De Ponti, N. Fabbiane, M. R. Haberman, M. I. Hussein, W. Hwang, U. Iemma, A. Juhl, M. Kadic, M. Kotsonis, V. Laude, O. Marquet, F. Mery, T. Michelis, M. Nouh, D. Ragni, M. Touboul, M. Wegener & A. Krushynska (2025): Metamaterials and fluid flows. arXiv (preprint): 2509.05371.

[4] Fabbiane, N., Marquet, O., Pierpaoli, L., Cottereau, R., & Couliou, M. (2025). Phononic compliant surfaces for the suppression of travelling-wave flutter instabilities in boundary-layer flows. Journal of Fluid Mechanics, 1020, A47.

[5] Michelis, T., Putranto, A. B., & Kotsonis, M. (2023). Attenuation of Tollmien–Schlichting waves using resonating surface-embedded phononic crystals. Physics of Fluids, 35(4).

Collaborations envisagées

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