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PROPOSITION DE SUJET DE THESE

Intitulé : Flexible surfaces designed with metamaterials for the control of flow waves

Référence : **MAS-DAAA-2024-36**
(à rappeler dans toute correspondance)

Début de la thèse : 09/2024	**Date limite de candidature :** 03/2024

Mots clés

- Passive flow-control
- Fluid-structure interaction

Profil et compétences recherchées

- Master in fluid/solid mechanics or applied mathematics
- Python
- Numerical fluid dynamics (preferred)
- Numerical solid mechanics (preferred)
- Flow stability and control (preferred)

Présentation du projet doctoral, contexte et objectif

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 in laminar [2] or turbulent flow regimes. For laminar boundary layers, flexible wall may attenuate the Tollmien-Schlichting (TS) waves that are responsible for the laminar-turbulent transition over rigid wall, thus reducing the skin-friction drag. Thanks to the classical work of Benjamin [3] it is known that new instabilities (divergence and travelling waves flutter) appear as a result of the flow interaction with the flexible wall, thus counterbalancing its positive effect on the TS waves. The material anisotropy [4] or viscoelasticity [5] have been considered in the design of compliant surface to counteract this negative effect, but materials found in nature have inherent drawbacks such as their large density compared to air, thus limiting their use to water flow.

The use of compliant surfaces for the passive control of flow waves has regained in interest thanks to the surprising properties of metamaterials and phononic crystals that could be used to design compliant surfaces [6]. Metamaterials are artificially engineered materials designed to induce customized behaviors that are not naturally found in bulk materials [7]. They are made from periodic patterns fashioned from composite materials such as metals and plastics, at scales that are smaller than the wavelength of the phenomena they influence. Appropriately designed metamaterials can for instance affect the propagation of electromagnetic or acoustics waves in a manner not observed in bulk materials. For instance, artificial materials made of periodic arrangement of scatterers embedded in a matrix may strongly alter the propagation of acoustic waves in the solid and more precisely forbid the waves propagation in certain ranges of frequencies (band gaps)

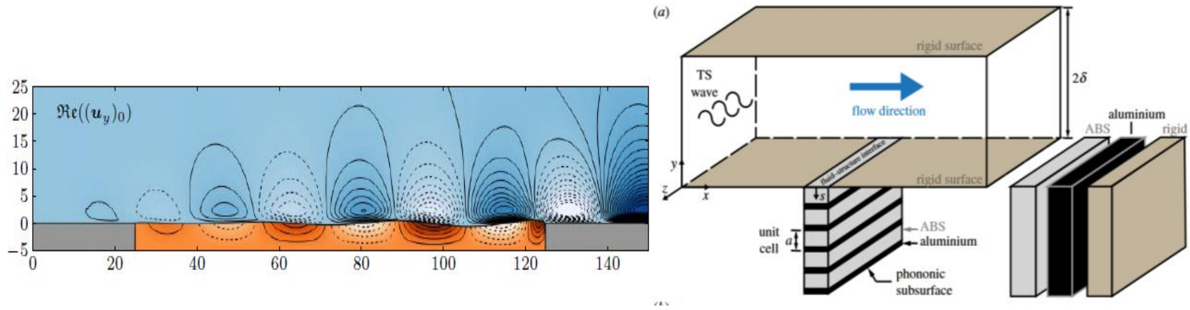

Figure 1. Example of the attenuation of Tollmien-Schlichting waves with flexible walls [10] (left) and with phononic subsurface [8] (right)

Hussein and co-workers [8] recently designed a phononic subsurface that demonstrate an attenuation of TS waves in a channel air flow. Such subsurface is made of periodic layers of aluminum embedded in an elastomer matrix, the latter interacting with the flow. The interesting band gap property of these periodic layers is exploited to obtain a displacement of the fluid-solid interface that is out-of-phase with the flow pressure excitation. However, this subsurface was too large to realistically embed within a wing's surface, since phononic crystals effect wavelengths on the order of their periodicity. Barnes and co-workers [9] recently investigated the use of resonant metamaterials that are capable of controlling dispersion and resonance structures at wavelengths much larger than the lattice spacing of the material.

The objective of this multidisciplinary PhD project is the **design of flexible walls with metamaterials for controlling flow waves**. To understand how such surface can be designed, we propose first to investigate a well-known case – the **attenuation of TS waves** with flexible walls – that was recently studied [10] at the Department of Aerodynamics, Aeroelasticity and Acoustics (DAAA) of ONERA. We also propose to use **an impedance approach for designing such surface**. The impedance expresses for each frequency the linear relation between the velocity of the fluid-structure interface and the fluid force exerted on it. Once the impedance properties of the surface have been specified to attenuate the TS waves, we propose to **design the metamaterial** so as to achieve the desired behaviour. In the case of a subsurface made by stacking heterogeneous layers, we could for instance act on the properties of the fibers and matrices. The inclusion of other scatterers, such as holes, inside a homogeneous material could also be considered to create band gaps and avoid the destabilization of structural modes by the flow, at the origin of the travelling waves flutter. After developing the design principle and defining an adequate metasurface, we will set up **numerical simulations of the fluid-structure problem**. Fully coupled linear fluid-structure analyses will be performed to quickly assess the effect of the metasurface on the growth of linear flow and fluid-structural waves. Nonlinear temporal simulation could be also performed to confirm the effect on the laminar/turbulent transition process further downstream the metasurface. In a last part of the PhD, the metamaterial will be 3D-printed and **tested in wind tunnel** in order to make an experimental demonstration of the passive control capability of such metasurface.

References

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[2] Carpenter, P. W. (1990). Status of transition delay using compliant walls. Viscous drag reduction in boundary layers, 123, 79-113.
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[7] Willis, J. R. (2011). Effective constitutive relations for waves in composites and metamaterials (article). Proceedings of the Royal Society A, 467(2131), 1865-1879.

[8] Hussein, M. I., Biringen, S., Bilal, O. R., & Kucala, A. (2015). Flow stabilization by subsurface phonons. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 471(2177), 20140928.
[9] Barnes, C. J., Willey, C. L., Rosenberg, K., Medina, A., & Juhl, A. T. (2021). Initial computational investigation toward passive transition delay using a phononic subsurface. In AIAA Scitech 2021 Forum (p. 1454).
[10] Pfister, J. L., Fabbiane, N., & Marquet, O. (2022). Global stability and resolvent analyses of laminar boundary-layer flow interacting with viscoelastic patches. Journal of Fluid Mechanics, 937, A1

Collaborations envisagées

Laboratory of Mechanics and Acoustics (LMA), CNRS/Aix-Marseille University;

Laboratoire d'accueil à l'ONERA	**Directeur de thèse**
Département : Aérodynamique, Aéroélasticité, Acoustique	Nom : O. Marquet, R. Cottereau
Lieu (centre ONERA) : Châtillon	Laboratoire : ONERA /LMA
Contact : N. Fabbiane, M. Couliou	Tél. :
Tél. : +33 (0)1 46 73 46 00 Email : nicolo.fabbiane@onera.fr, marie.couliou@onera.fr	Email : olivier.marquet@onera.fr; cottereau@lma.cnrs-mrs.fr

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