

PROPOSITION DE SUJET DE THESE

Titre : Flow-Induced Vibrations in Heat Exchanger Tube Arrays

Référence : **MFE-DAAA-2026-22**
(à rappeler dans toute correspondance)

Début de la thèse : from May to October 2026

Date limite de candidature : 30 April 2026

Key words

Flow-induced vibration ; Bloch waves ; Mean-flow analysis

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

A **shell-and-tube heat exchanger** is one of the most widely used and versatile types of heat exchangers in industry. It consists of a bundle of tubes enclosed within a cylindrical shell, as illustrated in the figure (left). Its purpose is to transfer heat between two fluids—one flowing inside the tubes and the other flowing outside the tubes but within the shell—without allowing the fluids to mix. In specialized heat exchangers developed for **air-breathing rocket engines** (Varvill, 2010), the strong reduction in tube diameter may lead to **excessive tube failures** caused by **flow-induced vibrations** (Pettigrew & Taylor, 2003). While flow-induced vibrations of single cylinders have been extensively studied, fewer investigations have addressed the case of **multiple interacting cylinders** (Tang et al., 2020; Zhao et al., 2024). Using direct numerical simulations of the interaction between turbulent flow and moving cylinders, Zhao et al. (2024) identified three distinct interaction regimes as the flow velocity increases: **turbulence-induced vibration**, **vortex-induced resonance**, and **fluid–elastic instability**, with vibration amplitudes progressively increasing from one regime to the next.

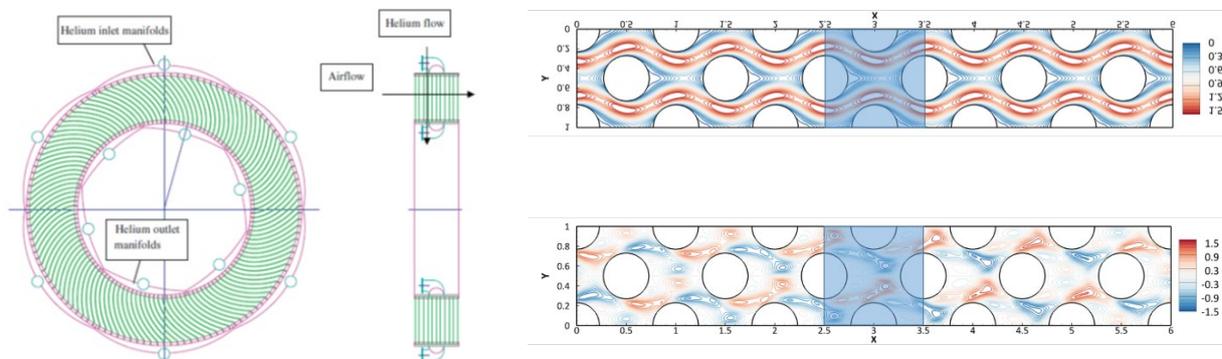


Figure 1 (Left) Sketch of a heat exchanger where a bundle of tube (green) are used to cool down the air flow inside the cylindrical shell (purple). (Right) Results of a Bloch wave analysis in an array of cylinders. Top : spatially-periodic time-independent flow. Bottom ; unsteady flow perturbations breaking the spatial periodicity. Both are computed on the unit cell (blue) by considering classical or generalized periodicity conditions on the left and right boundaries.

The objective of this PhD thesis is to investigate the **mechanisms underlying these regimes** using **linear stability and bifurcation analyses**. The small-amplitude motion of the cylinders, coupled to perturbations developing around a time-independent mean flow, can be studied by determining the eigenvalues of an operator describing the coupled dynamics between fluid and structural perturbations. Such analyses have been successfully applied to the **flow-induced vibrations of a single rigid cylinder** (Mittal 2016) and of an **elastic splitter plate** (Pfister et al. 2020). Applying the same framework to the present configuration would, however, require **tremendous computational resources**, as it would involve the coupled dynamics of all cylinders in the array.

On the other hand, the tubes are usually arranged in a **periodic lattice**, a property that can be exploited to **reduce the modal analysis to a single unit cell**, i.e. the **elementary pattern** forming the lattice. **Bloch theory** provides a classical framework for investigating **wave propagation in spatially periodic, non-dissipative media**, such as electromagnetic, elastic, or acoustic waves in metamaterials. This decomposition can also be applied to analyze the **growth or decay of flow perturbations in dispersive, spatially periodic mean flows**. In this approach, the **perturbation wavenumber** becomes a free parameter that can be varied to investigate disturbances of arbitrary wavelength, while the **eigenvalue problem** is discretized over a single unit cell only. As an illustration, the **steady flow in an infinite array of cylinders** is shown in the figure (right, top). This **spatially periodic flow** becomes unstable to **flow waves** (figure, right, bottom) that

clearly **break the spatial periodicity**. Although the results are displayed over a computational domain containing six unit cells, both the **steady base flow** and the **unsteady perturbations** were computed on the **single unit cell** highlighted in blue, by imposing **generalized periodic boundary conditions** on its left and right boundaries.

Recently, this formalism was extended to study the **interaction between flow waves and the motion of cylinders mounted vertically on springs**, that are introduced to model the **flexibility of the tubes in heat exchangers**. After getting familiar with the existing **mathematical formalism** and **numerical tools**, you will **develop new algorithms** to efficiently **track the eigenvalues of interest**, thereby further **reducing the computational cost** of the method. During the **first year**, you will focus on the **flow transition around rigid and spring-mounted cylinders at low Reynolds numbers**, considering various configurations (e.g. cylinder size, flow orientation, array geometry, natural vibration frequency of springs). In the **second year**, you will extend the analysis to **turbulent mean flows** described by the **Reynolds-Averaged Navier–Stokes (RANS) equations**, in order to obtain a **more realistic description** of the flow conditions encountered in industrial heat exchangers. Finally, a **mathematical framework** will be developed to analyze the **nonlinear saturation** of the unstable modes and their **collective interactions** over a range of wavenumbers.

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:

Varvill, R. (2010). Heat exchanger development at Reaction Engines Ltd. *Acta Astronautica*, 66(9-10), 1468-1474.

Pettigrew, M. J., & Taylor, C. E. (2003). Vibration analysis of shell-and-tube heat exchangers: an overview—Part 1: flow, damping, fluidelastic instability. *Journal of fluids and structures*, 18(5), 469-483.

Tang, D., Liu, D., Ding, Z., Zhu, H., & Yuan, W. (2020). Numerical investigation on the interactions of flow induced vibrations among neighboring cylinders in a cylinder bundle. *Annals of Nuclear Energy*, 140, 107156.

Zhao, H., Gao, P., Li, X., Tian, R., Wei, H., & Tan, S. (2024). The interaction between cross-flow induced vibration and convection heat transfer in tube bundle at subcritical Reynolds number. *Applied Thermal Engineering*, 236, 121920.

Mittal, S. (2016). Lock-in in vortex-induced vibration. *Journal of Fluid Mechanics*, 794, 565-594.

Pfister, J. L., & Marquet, O. (2020). Fluid–structure stability analyses and nonlinear dynamics of flexible splitter plates interacting with a circular cylinder flow. *Journal of Fluid Mechanics*, 896, A24.

