PhD thesis project in scientific computing/CFD

Development of numerical strategies for the computation of multiscale compressible multiphase flows

- Recruitment grade: Master level
- Location: University of Pau, France
- Starting date: October, 1st, 2025
- Duration : 3 years
- Gross salary: 2220 €/month.
- Contact: vincent.perrier@inria.fr and kevin.schmidmayer@inria.fr

Detailed work

This PhD thesis project is part of a general effort in the INRIA CAGIRE team for developing accurate and robust numerical methods for the computation of multiphase flows. It will be co-advised by Vincent Perrier and Kevin Schmidmayer.

Compressible multiphase flows are known to be complicated to address because of their essentially multiscale nature: even when starting from a flow with well resolved large scale interfaces, the evolution of the flow may lead to very small droplets or bubbles.

Several strategies can be used for the computation of multiphase flows

- **Sharp interface methods** These methods include for example the *Level-set methods* [8] or the *Volume-of-fluid* methods [6]. In these methods, all the interfaces are resolved, and all the inclusions must be resolved with the mesh. This make them unaffordable in the case of very dispersed inclusions (small droplets or bubbles).
- **Kinetic methods** In kinetic methods, see e.g. [11], the flow is no more described exactly, but rather statistically, through the approximation of the probability density function of a polydispersed phase in a carrier phase. These are also costly methods, because a discretization in the phase space is necessary, in addition to the classical spatial discretization.
- **Diffuse interface methods** These methods [1, 10] are in between the two previous methods, in the sense that they can correctly address interface flows, even if they are more diffusive than the sharp interface methods, but can also be seen as the first moment of kinetic methods.

The aim of this PhD project is to develop novel diffuse interface methods. The team recently proposed a new model for compressible two-phase flows in disequilibrium (velocity, pressure, and temperature) [9]. Based on [5], this model uses a simple stochastic approach to evaluate interface and relaxation terms, determining the local topology of the mixture. It employs a few additional variables to describe sub-grid topology, compromising some generality compared to kinetic methods but reducing computational cost. This allows a continuous transition from dispersed phase to resolved interface models, potentially constituting a breakthrough modelling method, enabling simultaneous and dynamic computation of multiscale flows.

The hired PhD will contribute to the following tasks:

- The development of a code for *ab-initio* one-dimensional multiphase computations. By *ab-initio*, we mean the development of a code in which all interfaces between phases are resolved.
- The development of one-dimensional and multi-dimensional two-phase models based on stochastic ideas.
- The development of numerical methods for these models.
- The implementation and the validation of these numerical methods.
- The benchmarking of the numerical method with respect to identified test cases such as
  - Interface instabilities [7, 4].
  - Essentially multiscale multiphase flows [3, 2].

Skills required

- Master in scientific computing or master in computational fluid dynamics.
- Interest in programming.
- Would be a plus:
  - Experience with numerical methods for compressible flows.
  - Experience with compiled languages (C++, C, Fortran).

References

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[2] Luc Biasiori-Poulanges and Kevin Schmidmayer. A phenomenological analysis of droplet shock-induced cavitation using a multiphase modeling approach. *Physics of Fluids*, 35(1), 2023.

[3] Spencer H. Bryngelson, Kevin Schmidmayer, and Tim Colonius. A quantitative comparison of phase-averaged models for bubbly, cavitating flows. *International Journal of Multiphase Flow*, 115:137–143, 2019.

[4] Benedikt Dorschner, Luc Biasiori-Poulanges, Kevin Schmidmayer, Hazem El-Rabii, and Tim Colonius. On the formation and recurrent shedding of ligaments in droplet aerobreakup. *Journal of Fluid Mechanics*, 904:A20, 2020.

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[6] Cyril W. Hirt and Billy D. Nichols. Volume of fluid (VOF) method for the dynamics of free boundaries. *Journal of Computational Physics*, 39(1):201–225, 1981.

[7] Shahab Mirjalili, Christopher B. Ivey, and Ali Mani. Comparison between the diffuse interface and volume of fluid methods for simulating two-phase flows. *International Journal of Multiphase Flow*, 116:221–238, 2019.

[8] Stanley Osher and Ronald P. Fedkiw. Level set methods: an overview and some recent results. *Journal of Computational Physics*, 169(2):463–502, 2001.

[9] Vincent Perrier and Enrique Gutiérrez. Derivation and closure of Baer and Nunziato type multiphase models by averaging a simple stochastic model. *Multiscale Modeling & Simulation*, 19(1):401–439, 2021.

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[11] Shankar Subramaniam. Lagrangian–Eulerian methods for multiphase flows. *Progress in Energy and Combustion Science*, 39(2-3):215–245, 2013.