Offer #2024-07326

PhD Position F/M Numerical modelling of cavitation bubbles interacting with biomaterials (IDP 2024)

Contract type : Fixed-term contract

Level of qualifications required : Graduate degree or equivalent

Fonction : PhD Position

Context

In this context, CAGIRE wants to expand its work on multiphase compressible flows. Indeed, understanding and controlling complex and physically rich flows, such as unsteady multiphase compressible flows, are of great importance in various fields such as aeronautics, automotive, aerospace, nuclear energy or naval. Although these compressible flows have received little to no interest in medicine, they appear to be crucial in numerous biomedical applications involving cavitating flows [1], such as in lithotripsy (treatment for kidney stones) [2] or, more recently, histotripsy (non-invasive treatment for cancers) where cavitation bubbles, induced by shock waves, laser energy deposit or high-intensity focused ultrasound waves, violently collapse and interact with biomaterials. Despite the efforts established so far to partially respond to the problems linked to these multiphase compressible flows, major challenges still remain and new ones appear when biomedical aspects are explored, particularly when multiple physical phenomena are to be considered, such as phase change, viscoelasticity or more generally interactions with soft solids. A possible way of investigation is to use benefits of numerical simulations to analyse in detail these flows where experiments are challenged by spatial and temporal resolutions and unable to access key quantities. Hence, this work aims to tackle the particularly challenging modelling of the dynamics of cavitation bubbles in and near biomaterials where numerous scientific and technical obstacles remain to be overcome.

[1] C. E. Brennen. “Cavitation in medicine”. Interface focus, 5 (5), 20150022, 2015.

[2] Y. A. Pishchalnikov, W. Behnke-Parks, K. Schmidmayer, K. Maeda, T. Colonius, T. Kenny, D. J. Laser. “High-speed video microscopy and numerical modeling of bubble dynamics near a surface of urinary stones”. The Journal of the Acoustical Society of America, Vol. 146 (1), Pages 516–531, 2019.

Assignment

At fully resolved interface scale, the numerical models for the fluids are now mature enough to correctly treat a non-condensable-gas bubble collapse without any numerical instabilities and with reliable robustness when at the vicinity of hard-solid surface [3, 4]. Further, several advances on simulation of bubble collapse and its impact on walls (soft or hard) have been done in the past, mainly using different codes coupled together to model the fluid–structure interactions, but interactions with biomaterials are yet to be done and require significant modelling efforts. The modelling of biomaterials under a fluid-mechanics formulation including visco-elasto-plastic behaviour and realistic equations of state will be undertaken. This formulation will be based on a theory for hyperelastic models including visco-plastic effects that has been developed for impact applications [5]. Unlike other approaches, it becomes possible to include this solid model in a multiphase model to avoid a particular and expensive treatment of the coupling between fluids and solids. Pressure wave propagation, including shear waves, is natural, and no external coupling of codes is necessary. However, this theory was based on a Maxwell model, suitable for some polymers and metals, and was introduced into a first-order method. A generalized and hyperbolic formulation is necessary to later model different types of soft solids. All these models will be directly implemented, gathered and tested in a same and unique code, ECOGEN (https://code-mphi.github.io/ECOGEN/), developed by the coordinator and his colleagues under an open-source license. Various test cases, with large deformation in particular, will be carried out in order to assess the accuracy, robustness, as well as efficiency of the model. Although comparisons with fracture models available in the literature will be done, we will accentuate our efforts toward modelling and comparisons with experiments of kidney-stone breakage by single bubbles or bubble clouds generated by either laser, ultrasound or shock waves. These peculiar experiments will be carried out by partners at the The European Synchrotron Radiation Facility (ESRF) which involves X-ray flow visualization and micro-tomography of the stone at different stages of the complete breakage process. These state-of-the-art technologies will allow for unprecedented information which is extremely valuable for both validation of the modelling and for enabling, in harmony between experiments and simulations, precise studies of fundamental physics.

[3] K. Schmidmayer, S. H. Bryngelson, T. Colonius. “An assessment of multicomponent flow models and interface capturing schemes for spherical bubble dynamics”. Journal of Computational Physics, Vol. 402, 109080, 2020.

[4] T. Trummler, S. H. Bryngelson, K. Schmidmayer, S. J. Schmidt, T. Colonius, N. A. Adams. “Near-surface

dynamics of a gas bubble collapsing above a crevice". Journal of Fluid Mechanics, Vol. 899, A16, 2020.

[5] S. Ndanou, N. Favrie, S. Gavrilyuk. "Multi-solid and multi-fluid diffuse interface model: Applications to dynamic fracture and fragmentation". Journal of Computational Physics, 295, 523–555, 2015.

Main activities

- Literature on multiphase compressible flows and biomaterials
- Construction of models and algorithms
- Implementation within ECOGEN software developed by the team and its collaborators
- Tests to assess the quality of the modeling
- Study the interaction of bubbles with biomaterials
- Diffusion of results (conferences, publications)

Skills

Strong knowledge of at least one of the following is recommended: fluid mechanics (particularly compressible flows), solid mechanics, finite volume method, partial differential equations, c++ language.

Benefits package

- Subsidized meals
- Partial reimbursement of public transport costs
- Possibility of teleworking and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Remuneration

- 2100€ / month (before taxs) during the first 2 years,
- 2190€ / month (before taxs) during the third year.

General Information

- **Theme/Domain :** Numerical schemes and simulations
  Scientific computing (BAP E)
- **Town/city :** Pau
- **Inria Center :** Centre Inria de l'université de Bordeaux
- **Starting date :** 2024-10-01
- **Duration of contract :** 3 years
- **Deadline to apply :** 2024-05-03

Contacts

- **Inria Team :** CAGIRE
- **PhD Supervisor :**
  Schmidmayer Kevin / kevin.schmidmayer@inria.fr

About Inria

Inria is the French national research institute dedicated to digital science and technology. It employs 2,600 people. Its 200 agile project teams, generally run jointly with academic partners, include more than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the interface with other disciplines. The Institute also employs numerous talents in over forty different professions. 900 research support staff contribute to the preparation and development of scientific and entrepreneurial projects that have a worldwide impact.

The keys to success

Mechanical engineering or applied mathematics Master degree with a strong appetence for scientific computing.

Warning : you must enter your e-mail address in order to save your application to Inria. Applications must be submitted online on the Inria website. Processing of applications sent from other channels is not guaranteed.

Instruction to apply

Thank you to send:
- CV
- Cover letter

- Master marks and ranking
- Support letter(s)

Defence Security :
This position is likely to be situated in a restricted area (ZRR), as defined in Decree No. 2011-1425 relating to the protection of national scientific and technical potential (PPST).Authorisation to enter an area is granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated in a ZRR would result in the cancellation of the appointment.

Recruitment Policy :
As part of its diversity policy, all Inria positions are accessible to people with disabilities.