	INTERNSHIP 6 MONTHS **YEAR 2024**
Internship tutors: - Annafederica URBANO Email: annafederica.urbano@isae-supaero.fr - Sébastien TANGUY Email: sebastien.tanguy@imft.fr	-Internship with ISAE SUPAERO – Toulouse - March/April – September /October 2024 (6 months) Location: **ISAE SUPAERO and IMFT**

TITLE: Direct numerical simulation of single bubble cavitation and boiling in zero gravity conditions at the wall

Context

Cryogenics fuels, like hydrogen and methane, are used in liquid rocket engine for space access because of the high specific impulse they can provide if burnt with oxygen. These propellants are usually stored at a few bars and at very low temperatures (20 K for H2, 110 K for CH4). Pressure and temperature in the tank need to be controlled. A decrease in pressure or an increase in temperature induce phase change and vapor formation [1]. As a consequence, the pressure in the tank increases and some gaseous propellant need to be vented in order to retrieve the nominal conditions. The uncertainties in the available heat transfer correlations make it difficult to predict the amount of propellant that will be lost during a mission. Increasing the accuracy of the modeling of these phenomena will ultimately permit to reduce these uncertainties and reduce the amount of wasted propellant. Besides, temperature and pressure in the tank need to be controlled in order to ensure a correct behavior of the engine. In particular, in case of long coasting phases, there is a need to pre-condition the propellants before engine ignition to avoid cavitation in the pump. This can be done with pressure cycles in order to sub-cool the propellants. To master the process, it is fundamental to be able to model the propellant phase change induced by pressure and temperature variation under zero gravity conditions [2].

When a bubble is nucleated and growth at the wall, in particular for wettable fluids like cryogens, a micro-region having an extension of a few tens of nanometers exists at the contact line [5]. High phase change mass flow rates are associated to the micro-region which cannot be captured by classical continuum based numerical methods. Sub-grid models are required in order to consider the micro-region effect over the bubble growth. It is not clear what the effect of the contact line velocity could have over the micro-region behavior. This could have a strong impact on several phenomena such as pool cavitation and nucleate boiling with micro-layer (see Fig. 1).

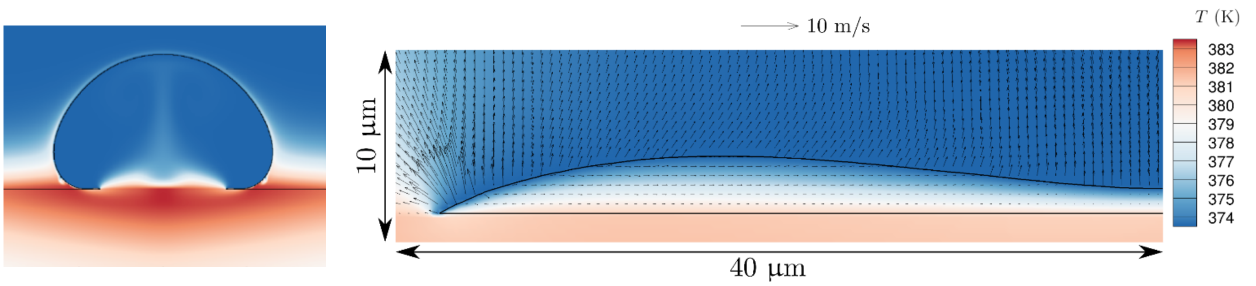

Figure 1 : Numerical simulation of a bubble over a heated wall in micro-layer regime (left) and zoom over the velocity field and temperature field in the micro-layer (right).

Goals of the internship

The goal of the present internship is the investigation of the impact of the contact line velocity over the micro-region. The application will be the study of a single bubble growth at the wall induced by cavitation under zero gravity conditions. The coupling of a micro-region model with direct numerical simulation solver for incompressible two-phase flows with phase change has been recently carried out applied to the study of nucleate boiling in micro-gravity conditions (in isobaric conditions) [5]. The micro-region model has been recently implemented in a compressible numerical solver for multi-phase flows which is based on a pressure-based equation for the energy and Level Set/Ghost Fluid approach to handle the interfaces [3,4]. Cubic equation of state (EOS) are used for the liquid and vapour phases and for saturation conditions at the interface. A phase change model, based on fundamental principles and jump conditions, allows to simulate the phase change induced by pressure and temperature variations of single species fluids. Presently the micro-region model only includes thermal effect and the contact line velocity impact is not accounted for. During the present internship the impact of the micro-region over the cavitation of a bubble having a large contact velocity will be investigated.

Work plan

- *State of the art*: micro-region model, numerical simulation of two-phase flows with phase change, hydrodynamic and pool cavitation
- *Development*: micro-region model development in order to include state of the art models for the contact line velocity
- *Simulation:* single bubble cavitation under zero gravity conditions

Team
The internship will take place at the SaCLab (Space Advanced Concept Laboratory) in the DCAS department at ISAE SUPAERO and will be co-supervised by IMFT (Prof. S. Tanguy).

References

[1] A Urbano, S. Tanguy and C. Colin "Direct numerical simulation of nucleate boiling in zero gravity conditions", *Int. J. of Heat and Mass Trans.*, 143:118521 (2019)
[2] C.B. Muratov, "Issues of Long-Term Cryogenic Propellant Storage in Microgravity", NASA/TM–2011–215988 (2011)
[3] A. Urbano, M. Bibal, and S. Tanguy. A semi implicit compressible solver for two-phase flows of real fluids. *J. Comput. Phys.* , 456:111034, 2022.
[4] M. Bibal, M. Deferrez, S. Tanguy and A. Urbano, "A compressible solver for two phase- flows with liquid-vapor phase change. Applications to bubble cavitation." *J. of Comp. Physics*, (10.2139/ssrn.4509360)
[5] L. Torres, A. Urbano, S. Tanguy and C. Colin, "On the coupling between Direct Numerical Simulation of Nucleate boiling and a Micro-Region model at the contact line". *J. of Comp. Physics*, accepted (10.2139/ssrn.4523256)

Profile: Master 2 student, basics in computational fluid dynamics, basics in two phase flows, programming.

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Perspectives: possibility to apply for a PhD position after the internship.