MASTER DEGREE INTERNSHIP – 5-6 MONTHS

First half of 2024

Determining the velocity field of confined and rarefied gas flows by using molecular tagging velocimetry measurements

Figure 1: the molecular tagging equipment at the microfluidics laboratory of ICA.

Expected skills

The student is enrolled in the final year of the master's degree or equivalent (engineering school) related to mechanical engineering, aerospace engineering or physics. A background in fluid dynamics and data computing would be appreciated. Expertise in optics and imagery data treatment would be an asset but this is not essential. The student must have a keen interest in numerical computing, a high level of scientific curiosity and the ability to work independently. Good oral and written communication skills will be appreciated.

Internship environment

The internship will take place at **Institut Clément Ader**, Toulouse. The supervisory team related to this internship is composed by members of the Metrology Identification Control and Monitoring (MICS) team, who have strong expertise in full-field measurements methods based on optics and digital images in a date assimilation approach, and the Mechanical Systems and Microsystems Modelling (MS2M) team, who have strong expertise in developing experimental optical tools and numerical models to investigate rarefied gas flows.

Duration: 5 months, starting date 1st of March 2024

Salary:

- 600 €/month
- Financial aid for mobility will be provided for students coming from abroad (1x plane ticket)

It is to notice that this trainee could lead to a PhD thesis (funding to be secured)

Supervisors

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Attachments to be provided with the application

- CV
- Cover letter
- Recommendation letter
- Master grades

Context

The behavior of gas flows is a critical element to determine the performance of a large variety of devices and processes, particularly in the age of miniaturization. As examples, we can mention space, biological and micro electro-mechanical systems that have attracted growing interest in recent years. To control and optimize these systems, flow and thermal characteristics are of great interest [1]. In particular, there is a need to precisely know the flow field of the gas in confined geometries, including the core as well as the near wall of the flow. To implement diagnostics on these systems and to post-process data in order to obtain multi-dimensional velocity fields is very challenging. There is still very limited experimental data about the detaSils of the micro-scale flow. Some works have reported microfluidic velocimetry techniques but they mainly deal with liquid flows [2]. For gas flow visualization, traditional techniques such as particle image velocimetry or laser doppler velocimetry are not well adapted since the seeding of the flow with particles may lead to inaccuracy and flow modification. As an alternative, molecular tagging approaches can offer significant advantages [3].

The **Molecular Tagging Velocimetry** (MTV) technique works on the laser induced fluorescence and phosphorescence principle (Fig.2): the displacement of vapor molecular tracer is measured by following the photon re-emission in the visible spectrum after laser excitation. Very few works have reported MTV diagnostics for internal gaseous flow on the microscale, especially at microscale [4]. The microfluidics team of ICA has been developing MTV in the scope of rarefied gas flows investigation since 2009. Rarefaction is a condition which is present in gas at low pressures or in micro-metric devices. A gas flow in rarefied conditions can experience local thermodynamic disequilibrium phenomena, such as velocity slip at the wall. Several theses have been performed in the microfluidics team [5-10], leading to the development of the technique and as results to retrieve 1D velocity profiles in a millimetric channel for gas flow in hydrodynamic regime or to obtain first local velocimetry results in rarefied gas flows (slip velocity measurements close to the wall). However, improvements are needed to obtain correct velocity fields in rarefied gas by measuring molecular displacement, especially in order to adapt the technique to 2D measurements. To our knowledge, other than the works realized at ICA, no other consistent work has been realized in the literature on confined gas flows, especially in the perspective of measuring rarefaction effects like velocity slip at the wall.

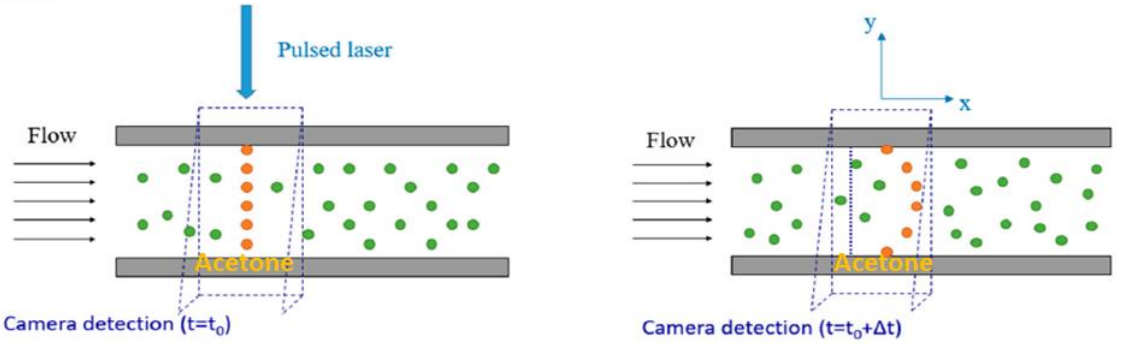

Figure 2. Basic principle of 1D-MTV by direct phosphorescence of acetone, for a gas flowing in a plane channel

Besides the implementation of the optical diagnostics, **data processing** is the second key element of the MTV technique in order to obtain accurate flow field velocity. Spatial cross correlation algorithm is the most widely-used velocity field algorithm but it relies on the (strong) hypothesis that the pattern can be tracked throughout the experiment. As a consequence, a novel approach based on digital imaging could be used to improve the already existing framework by improving the regularization of the reconstruction problem. The Metrology Identification Control and Monitoring (MICS) group has an expertise in model-based approach to full-field measurement methods which has been applied to the monitoring of experiments in 2D and 3D solid mechanics and is based on a physics-based data assimilation approach [11, 12]. Previous work has shown that experimental uncertainties on specific quantities of interest can be reduced by using such post-processing approaches and the benefits could be applied to the MTV in rarefied flows.

Objectives and job description

This work aims to identify and improve the limitations of the current MTV technique developed for 1D velocity field measurements in order to prepare 2D diagnostics. It will result in decreasing the current uncertainties related to existing 1D-MTV results, by improving the data treatment and analysis using prior knowledge regarding the flow and properties of the gas through extensive collaboration of microfluidics and imagery expertise.
This subject is strongly multi-disciplinary since it involves optical diagnostics, data processing and physics of rarefied gas flow. The work to be done during the internship can be divided into different parts:

- As a first step, preliminary work is necessary to handle the subject. The student will perform a literature survey regarding molecular tagging velocimetry with special attention to innovative and multidimensional tagging methods as well as processing algorithms. In addition, a dedicated study on existing results will be necessary to understand and assimilate the previous works performed in the laboratory.
- In a second phase, the work will focus on the data processing which is based on the reconstruction of the velocity profile via the advection-diffusion equation and imagery techniques. The student will develop a specific approach to be able to capture the velocity profile which needs to be developed specifically for rarefied flows.
- In a final phase, additional experimental work can be done on the tagging method. The goal is to define an optical grid able to provide a pattern that is bright and sharp enough for 2D measurements. For that it is necessary to identify the most suitable tagging molecule, to consider the design of an adapted microchannel and to develop an experimental setup to generate a laser grid pattern capable of measuring confined 2D gas flows for a millimetric system.

References

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