PROPOSITION DE POST-DOCTORAT

Intitulé : Development of a Synthetic Image Generation Tool for Light Propagation in Turbid Media

Référence : **PDOC-DMPE-2025-03**	
Début du contrat : 01/01/2026	**Date limite de candidature :**
Durée : 12 mois, éventuellement renouvelable une fois -	
Mots clés: Ray-tracing tool, radiative solver, multi-scattering, image generation, Background Oriented Schlieren (BOS)	

Profil et compétences recherchées

PhD in CFD. Knowledge of two-phase flows, light scattering by particles, radiative transfer, Monte Carlo methods, and/or optical imaging are valuable assets for this position.

Présentation du projet post-doctoral, contexte et objectif

Context:

The **experimental analysis of spray liquid distribution and vaporization** plays a crucial role in enhancing the efficiency of industrial processes across diverse applications: fire suppression, food and drug production, agricultural irrigation, cooling in electronic systems, nuclear core management… In combustion systems, particularly, efficient mixing and rapid evaporation of injected liquid fuel lead to higher volumetric heat release rates, easier ignition, an extended burning range, and reduced exhaust emissions such as CO2, soot, and NOx. Therefore, progress in the experimental characterization of two-phase mixtures can yield significant benefits for optimizing many industrial processes. The characterization of mixing in a multiphase system involves analyzing both the local distribution of each phase within a given volume and the local distribution of various species within each phase. In a particle-laden flow, these are typically quantified by 1) **the liquid volume fraction α_l** and 2) the **mass fraction of its vapor phase Y_F,** respectively.

To support the development of **Background-Oriented Schlieren (BOS) as a new alternative that could characterize simultaneously α_l and Y_F without the need for lasers or intricate optics**, this project aims to concurrently **develop a ray tracing tool capable of simulating synthetic images of this "two-phase" BOS**. The literature highlights the importance of such tool in supporting the development of optical diagnostics. Since these diagnostics rely on multiple assumptions regarding the flow characteristics and the received signal, it is crucial to verify these assumptions and rigorously assess the validity, accuracy, and precision of the measurements. In particular, the multi-scattering effects induced by the liquid phase must be addressed either downstream the measurements through optical setup adjustments or upstream via post-processing techniques.

A recently developed open-source software has been tailored for monophasic variable density environments. This software uses a ray tracing algorithm to simulate synthetic BOS images from an optical setup and a density field. These images are instrumental in optimizing experimental design for an effective post-processing by image analysis tools, preventing experimental artifacts and analyzing bias errors and uncertainties related to an experimental setup. For light propagation through scattering media, the Multi-Scattering software developed by Lund University is noteworthy. This software conducts Monte Carlo simulations of photon transport through scattering media, which is divided into voxels with uniform dimensions, each characterized by its optical properties. Beyond predicting the transmitted light intensity profiles captured by the camera, the software can model image formation by incorporating a virtual collecting lens and detection matrix.

Objective:

In order to develop a similar tool for 'two-phase' BOS, this post-doctoral proposition aims to integrate the pixel-wise ray-tracing algorithm for light deflection calculation into the radiative solver ASTRE, both developed at ONERA. Also, the ASTRE solver will be enhanced to simulate light propagation through a scattering medium and ultimately render images corresponding to a given optical setup. Hence, from a numerical variable density and turbid media, ASTRE will be able **to generate the image of the dot pattern from a given optical configuration, considering the deflection and the extinction of the light rays**. In addition to synthesizing BOS image generation and the Multi-Scattering software mentioned above, ASTRE will offer two key advantages compared to these tools: 1) it will support unstructured meshes, and 2) it will enable coupling with a two-phase CFD solver to produce sequences of instantaneous BOS images.

Work description:

Although ONERA already has an in-house ray-tracing code for simulating ray deviation through a medium with density gradients using a CUDA framework, this code has several limitations: it does not support unstructured meshes (working only with Cartesian and regular meshes), does not account for propagation through optical elements (lenses, apertures, etc.), and does not render BOS background images. **Therefore, in addition to incorporating ray deflection into the ASTRE radiative solver, the first task will also involve integrating these features**. The BOS images generated by ASTRE will then be validated against those produced by the PIV/BOS synthetic image generation tool in the case of a vertical laminar heated jet, which has the advantages of being fully three-dimensional and having a well-defined analytical solution, and more complex density field taken from a DNS of a buoyancy driven turbulence, downloaded from the Johns Hopkins University Turbulence Database (JHU-TDB).

The second task will involve using the radiative solver ASTRE and develop it to simulate light propagation through gas-droplet flows for a given optical setup (including optics and light sources) to generate the resulting image on the camera sensor. Specifically, these images should include profiles of the transmitted light and the contributions of individual scattering orders to the total transmission. While the Multi-Scattering software developed by Lund University is designed to simulate light propagation through a wide range of particulate and tissue-like media, the scope of this project will be limited to gas-droplet flows. The images produced by ASTRE will first be validated against the open-access experimental and simulation database provided by Lund University, which reproduces a cubic glass cuvette containing a homogeneous aqueous dispersion of scattering microspheres of known size and concentration. This database includes particles with diameters $d_p = 0.5, 2$ and 5 μm and optical depths ranging from optical depth OD = 2 to 17.5. Once ASTRE is validated for homogeneous and monodisperse turbid media, the next step will involve extending the simulations to more realistic cases **involving heterogeneous and polydisperse media**.

Finally, **the last task will be to compare experimental BOS images of a hollow-cone evaporative spray injection**—where light deflection and scattering are intricately intertwined—with the images generated by ASTRE from the numerical simulation.

Collaborations extérieures

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