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POST-DOCTORATE PROPOSAL

Title : Data analysis on aluminum combustion in a solid-propellant flame

Reference : **PDOC-DMPE-2024-01**
(to be recalled in all correspondence)

Start of contract: Octobre, 2nd, 2024	**Application deadline:** May, 2024

Duration: 12 months, possibly extendable to 24 months - Net yearly salary: about 25 k€ (medical insurance included)

Keywords

Rocket propulsion, solid propulsion, aluminum, combustion modeling, CFD, data analysis, laser diagnostics, laser-induced fluorescence imaging

Profile and skills required

A PhD degree in fluid dynamics and combustion or an associated field

Knowledge in numerical simulation and data analysis

Strong interest in combustion modelling and image processing. Ability to interact with researches from different scientific fields: combustion, CFD, spectroscopy and laser-induced fluorescence imaging, image processing…

More generally, open-mindedness in scientific studies. It is not necessary to have previous experience in all the fields to candidate, only a strong will to discover new tools and new theoretical aspects

Presentation of the post-doctoral project, context and objective

Context

For space applications, aluminum particles are included in propellant compositions in order to improve propulsive performance of solid rocket motors (SRM). Combustion of aluminum particles in a gas flow can trigger thermo-acoustic instabilities (ITHAC) resulting in pressure oscillations [1]. ITHAC is a complex phenomenon, which is not predicted accurately for SRM with the existing models. Aluminum particles burn as binary droplets (liquid aluminum and alumina cap) in a gaseous environment at high pressure and high temperature with relative flow velocity around several m/s.

Scientific project

Research work has been underway at ONERA since 2015, leading to the development of combustion models for a single aluminum droplet. Various numerical approaches have been developed: first, a 1D configuration with spherical symmetry for steady-state or unsteady calculations; second, a 2D configuration with axial symmetry and an alumina cap. The latter is realized by implementing detailed models for molecular transport and chemical kinetics [2] in the CEDRE code of ONERA. Model validation requires experimental data which are sparse in the literature. The planar laser-induced fluorescence (PLIF) imaging technique applied to Al atom (Al-PLIF) has been developed at ONERA since 2014 thanks to two PhD works [3][4]. It was used at ONERA with a combustion chamber for small solid-propellant samples, which can operate up to 15 bar with optical access. By this way, the combustion of aluminum droplets in the solid-propellant flame can be studied. The Al-PLIF technique gives access to instantaneous field of aluminum vapor around the droplet while it burns above the sample surface. Al-PLIF imaging was coupled with direct visualization for simultaneous analysis of droplet morphology and size. The high acquisition rate (5 to 10 kHz) enables droplet tracking and generates a large experimental database: a large number of images are acquired for each test under various conditions (solid-propellant compositions, operating pressures).

Missions

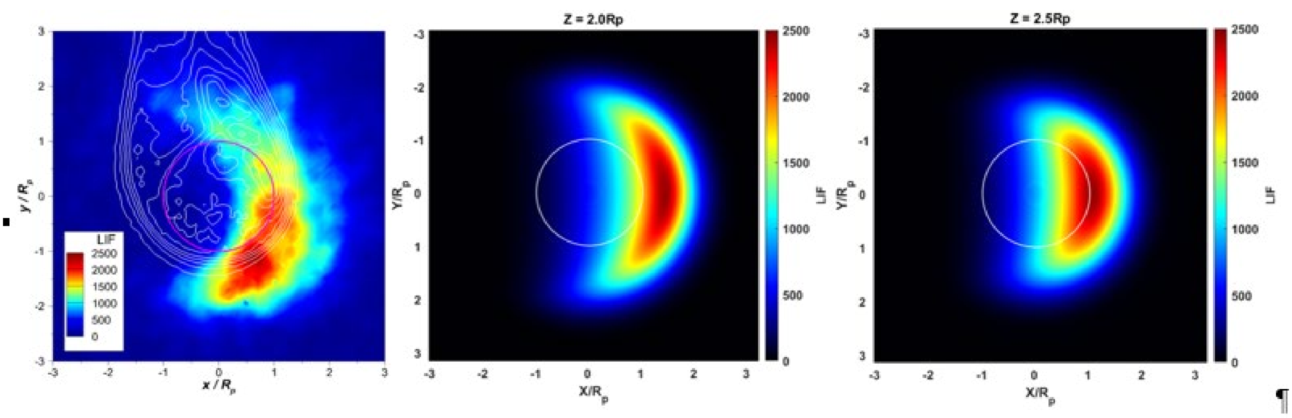
The postdoctoral work will focus on two areas.

On the one side, numerical simulations of single-droplet combustion will be performed for various droplet sizes for conditions representative of Al-PLIF tests. These calculations will provide a sensitivity analysis for key parameters such as the kinetic scheme, the gas composition, and the position of the alumina cap.

On the other side, Al-PLIF images will be simulated from fields of Al-atom concentration and temperature inside the laser probe volume [4]. These fields will be obtained from the single-droplet simulations performed in the first part of the work. The Al-LIF signal will be calculated using a specialized code developed by our previous PhD student. The LIF signal modeling is based on spectroscopic properties and collisional data to account for pressure effects [3]. The resulting synthetic PLIF images will be directly compared to the selected experimental images. Selection criteria for the studied cases are will be established regarding the morphology and size of the droplet from direct visualization as well as the spatial distribution of LIF signal intensity. The proposed approach has been demonstrated for a couple of examples and seems very promising. The comparison strategy needs to be realized together with parametric studies in order to consolidate the combustion simulation assumptions. The candidate will be in charge of data processing and analysis with the objective of making more systematic the comparison between simulated and measured images respecting morphological criteria and spatial correlations.

The candidate will be in charge of writing the corresponding peer-reviewed publications.

Experimental image	*Simulated images for two laser-sheet positions relative to the droplet.*



Experimental and simulated Al-PLIF images for an aluminum droplet. The simulation is based on computational results from a 1D combustion model with detailed kinetics. [4]

References:

[1] Orlandi O. et al., Aluminium droplets combustion and SRM instabilities, Acta Astronautica, 158, pp. 470-479, 2019.

[2] Muller M., Modélisation de la combustion de gouttes d'aluminium dans les conditions d'un moteur fusée à propergol solide, Thèse de doctorat, Sorbonne université, 2019.

[3] Vilmart G., Détection de vapeurs d'atomes métalliques par fluorescence induite par laser (LIF): application à la propulsion solide. Thèse de doctorat, Université Paris-Saclay, 2017.

[4] Chevalier P.-H. et al., Investigation of aluminum droplet combustion in solid propellant flames: Al-PLIF experiments and numerical simulation, AIAA Propulsion and Energy 2021 Forum.

External collaborations

CNES

Host laboratory at ONERA

Department: Multi-Physique pour l'Energétique

Location (ONERA centre): Palaiseau

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