Volume estimation on ombroscopy images using deep learning and high fidelity simulations

Granger Florian[1,3], Airiau Magdeleine[1,3], Devillers Robin[1],

Dorey Luc-Henry[1], Zuzio Davide[2], Estivalezes Jean-Luc[2]

[1]DMPE, ONERA, Université Paris Saclay, F-91123 - Palaiseau, France

[2]DMPE, ONERA, Université Toulouse, F-31055 - Toulouse, France

[3]CNES - Transport Spatial - Etablissement de Daumesnil, F-75612, Paris Cedex, France

florian.granger@onera.fr

Keywords: Deep learning, high fidelity simulations, volume estimation, two-phase flows, assisted atomization

Topics: TESTING, PROPHY, **Status**: Student, **Type**: Oral

Abstract

Liquid Rocket Engines (LRE) have a better efficiency than solid rocket engines by using oxygen associated with high specific impulse fuel such as hydrogen or methane. LRE combustion chambers involve coaxial injectors designed to efficiently mix the high mass flow rates of fuel and oxidizer. Both oxygen and hydrogen are stored in a liquid form. When sufficiently low temperature and pressure conditions are encountered in the chamber, in particular during engine ignition, the oxygen is injected as a liquid phase, while the fuel is injected in the gaseous form. In the combustion chamber, the fluids are mixed by an assisted atomization process that directly affects combustion efficiency and plays a crucial role in combustion instabilities [1]. Despite the large number of dedicated studies, the prediction of the atomization outcome in terms of droplets size and velocity is still a challenging task. Spray granulometry is currently characterized experimentally via laser measurements [2] or image analysis [3], but both face limitations and uncertainties. Laser measurements only probe a small portion of the spray while ombroscopy imaging gives access to the full spray length but with limitations induced by the depth of field and image projection. The visualized droplets on the image are 2D projections of the real 3D liquid structure: equivalent diameters or characteristic lengths estimated in 2D are hard to convert into 3D data such as accurate volume values, even more with the additional uncertainty due to blurred droplets. While stereo depth estimation is an old computer vision task [4], monocular depth estimation and/or volume reconstruction was performing poorly until recent deep learning advances [5].

The goal of this work is to improve the volume estimation of liquid structures on monocular experimental spray images by taking advantage of existing simulation data. Projections of liquid structures are performed from Computational Fluid Dynamics (CFD) results to generate the ground truth data used for training and testing of the neural network. Indeed, Hoarau et al. [6] demonstrated the capabilities of DNS two-phase simulation to capture the most relevant scales of a LRE coaxial atomization in realistic conditions [7]. These numerical results can be investigated in depth [8] to obtain an accurate description of the liquid instantaneous and local topology, creating a database of more than 6 million liquid structures. The study proposes testing the method on a sample of this database with increasing complexity projections, from simple liquid/gas interface visualizations to realistic ray-tracing renderings.

This paper shows an interest in high-fidelity simulations for creating a training database for classification neuronal networks. Its application to experimental images allows to produce new types of measurements useful for the characterization of flows encountered in liquid rocket engines and could be extended to other quantities of interest than volume (surface, sphericity).

References

[1] N. Rutard, L. H. Dorey, C. Le Touze, M. Théron, and S. Ducruix. Numerical study of acoustic radiation effects on air-assisted jets. In *EUCASS*, 2017.

[2] N. Fdida, L. Vingert, Y. Mauriot, L. H. Dorey, and M. Théron. Comparison of LOX / Methane and LOX / Hydrogen cryogenic spray combustion with simultaneous optical diagnostics. *Eucass 2019*, pages 2–11, 2019.

[3] P. Marmottant and E. Villermaux. On spray formation. *Journal of Fluid Mechanics*, 498(498):73–111, 2004.

[4] S. T. Barnard and M. A. Fischler. Computational Stereo. *ACM Computing Surveys (CSUR)*, 14(4):553–572, 1982.

[5] H. Fu, M. Gong, C. Wang, K. Batmanghelich, D. Tao, Ligm Umr, and Esiee Paris. Deep ordinal regression network for monocular depth estimation. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 2002–2011, 2018.

[6] J. C. Hoarau, F. Granger, L. H. Dorey, D. Zuzio, and J. L. Estivalèzes. DNS of a coaxial atomization in fiber regime. *International Journal of Multiphase Flow*, 2023.

[7] A. Ficuciello, J. B. Blaisot, C. Richard, and F. Baillot. Investigation of air-assisted sprays submitted to high frequency transverse acoustic fields: Droplet clustering. *Physics of Fluids*, 29(6):1–17, 2017.

[8] M. Averseng. *Contribution à la modélisation de l'atomisation assistée par analyse de simulations haute fidélité*. PhD thesis, Toulouse University, 2022.