Atomization and Dispersion of a Liquid Jet

Experimental and Numerical approaches in applied agriculture

Francisco FELIS*[(1)(2)(3)], Fabien ANSELMET[(3)], Ariane VALLET[(1)], Séverine TOMAS[(2)], Muriel AMIELH[(3)]

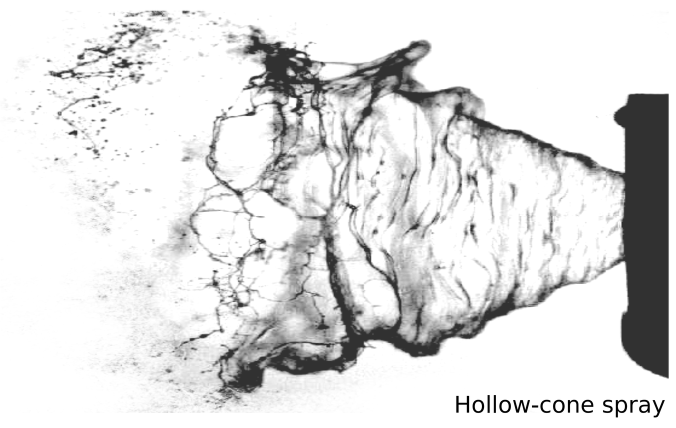
(1) IRSTEA Montpellier UMR ITAP - (2) IRSTEA Montpellier UMR G-EAU - 361 rue J.F. Breton, BP 5095, 34196 Montpellier Cedex 5, France

(3) Aix Marseille Université, CNRS, Centrale Marseille, IRPHE UMR 7342, 49 rue F. Joliot-Curie, 13384 Marseille Cedex 13, France

* Contact: francisco.felis-carrasco@centrale-marseille.fr

Abstract

To accurately predict the behavior of sprinkler irrigation or pesticide sprayer systems, a complete approach must be carried out. CFD (Computational Fluid Dynamics) simulations may reduce equipment testing cost, but model adjustment needs state-of-the-art experimental resources to compare with. This project aims to address the issue by setting-up and handling both experiment and simulation parts.



Hollow-cone spray

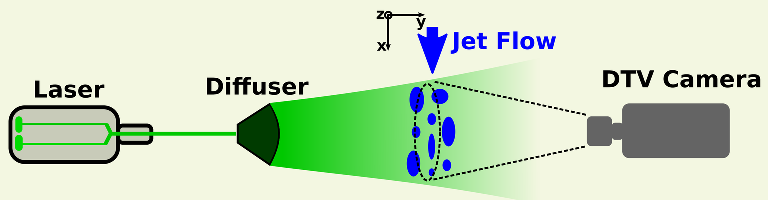
Scientific Challenges

- To build a simulation platform for multiphase flows under variable density pseudo-fluid formulation.
- To conceive and conduct experiments in order to characterize both liquid and gas phases and to estimate measurement errors.
- To construct and adjust several closure problems for modeled equations, giving a feedback to simulation cases.

Experiments

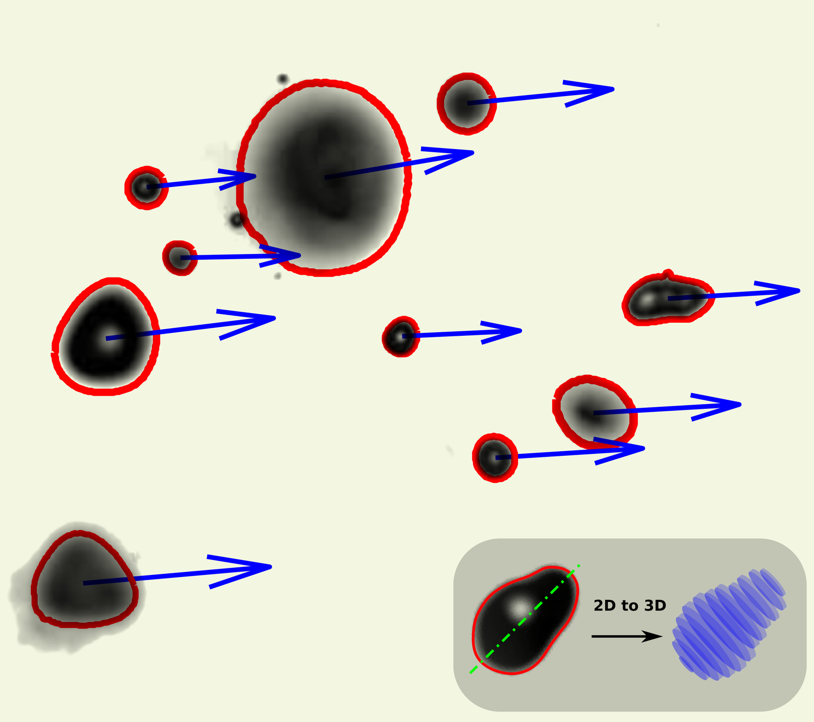
Experiments are based on optical techniques to gain access to both liquid and gas phases quantities in a liquid-jet or spray.

LDV (Laser Doppler Velocimetry) is used to measure the liquid core velocity when a continuous phase is present. In zones where the liquid is considered a disperse phase, DTV (Droplet Tracking Velocimetry) is used to measure droplet size and velocity.



Typical set-up for DTV measurements by shadowgraphy

Current development



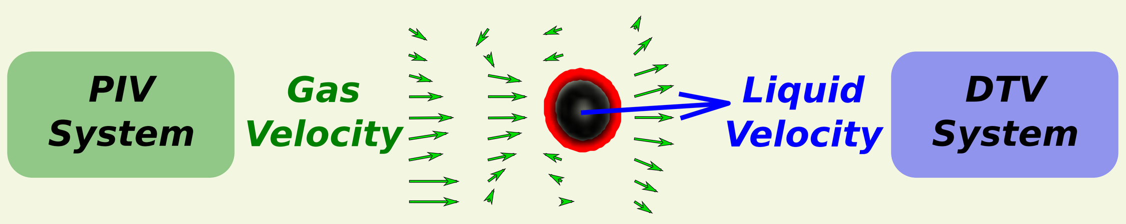
An In-house image processing algorithm was built to measure the liquid phase fields.

It detects every droplet via shadowgraphy and extracts the estimated volume and surface using a 3D reconstruction, assuming an axisymmetric flow.

The velocity field is then obtained using a point-to-point matching algorithm between two consecutive frames.

Future challenge

To fully compare experimental data with simulation cases, both phases quantities must be measured simultaneously. For this propose a PIV (Particle Image Velocimetry) system will be used along the DTV to gain access to the gas phase velocity field. Special care to the data post-processing is needed to visualize the liquid/gas interaction.



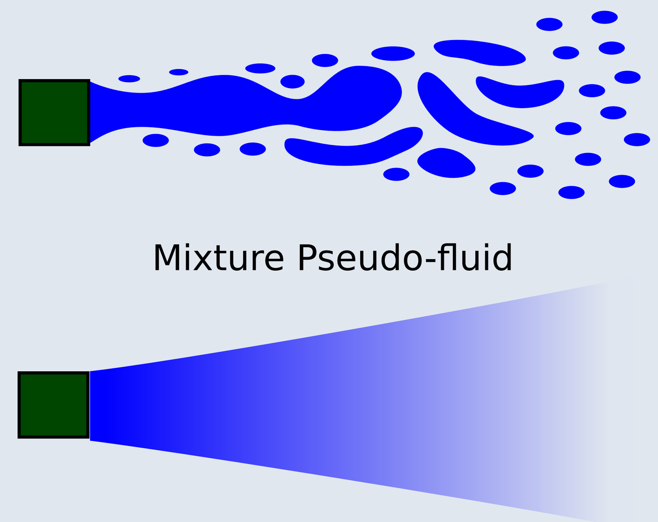
Liquid round jet fragmentation

Simulations

Instead of a separated air/water two-phase flow, a variable density ($\bar{\rho}$) pseudo-fluid is used to describe the mean liquid mass fraction ($\widetilde{Y}$), velocity ($\tilde{u}_i$) and interface area per unit volume (Σ).

$$\bar{\rho} = \overline{Y}\rho_l + \left(1-\overline{Y}\right)\rho_g \qquad \overline{Y} = \frac{\bar{\rho}\widetilde{Y}}{\rho_l}$$

where ρ_l and ρ_g are respectively the liquid



Current development

Momentum:

$$\frac{\partial \bar{\rho}\tilde{u}_i}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_i\tilde{u}_j}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial \bar{\tau}_{ij}}{\partial x_j} - \frac{\partial \bar{\rho}\widetilde{u_i''u_j''}}{\partial x_j}$$

Mass conservation:

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_i}{\partial x_i} = 0$$

Mass fraction transport:

$$\frac{\partial \bar{\rho}\widetilde{Y}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_i\widetilde{Y}}{\partial x_i} = -\frac{\partial \bar{\rho}\widetilde{u_i''Y''}}{\partial x_i}$$

Interface area per unit volume:

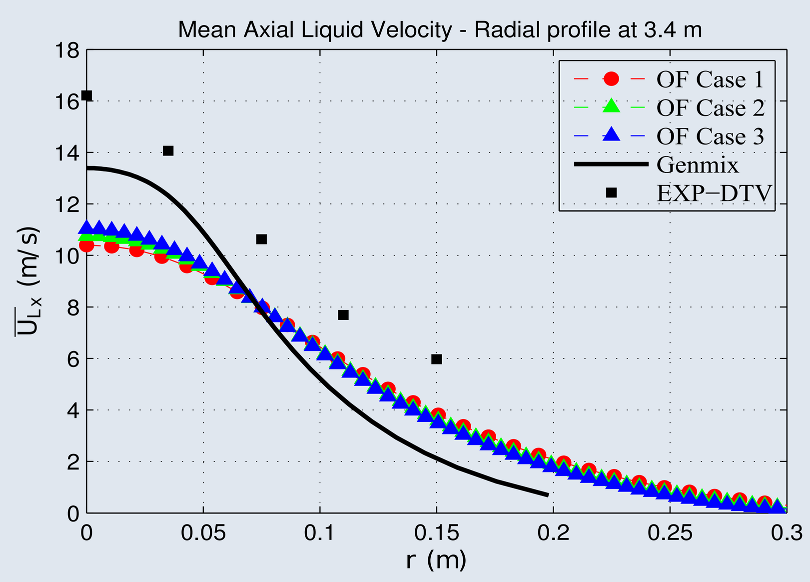
$$\frac{\partial \bar{\Sigma}}{\partial t} + \frac{\partial \tilde{u}_i\bar{\Sigma}}{\partial x_i} - \frac{\partial}{\partial x_i}\left(\frac{\nu_t}{\sigma_{\Sigma}}\frac{\partial \bar{\Sigma}}{\partial x_i}\right) = (A+a)\bar{\Sigma} - V_a\bar{\Sigma}^2$$

The modeled equations for this pseudo-fluid were implemented into a customized *OpenFOAM* transient solver.

Current development includes a basic variable density *k-ε* turbulence model and the liquid/air interface transport.

The main challenge is to expand and explore other turbulence models while keeping convergence in a reasonable computational time.

First results



When comparing the liquid velocity radial profile 3.4 m from the nozzle in a case study, it is clear that modifications or new models are needed to better describe this type of flow.

These first results were obtained using a variable density k-ε turbulence model in a 2-D axisymmetric case, using 3 mesh sizes.

Achievements and Perspectives

- Up to this stage, experiments provide information only from the liquid phase, given the multi-scale liquid fragmentation problem, one of the main challenges is to accurately implement a new set-up that may give access to both liquid and gas phases. These results will provide a complete database to compare future simulations with.
- Because of the variable-density pseudo-fluid formulation, not only the expansion to other turbulence models may be problematic, special care to numerical schemes and convergence criteria must be also taken into account when further code modifications will be introduced.

Acknowledgments

This Ph.D thesis is co-financed between *Becas-Chile* fellowship from the Chilean government and IRSTEA UMR ITAP and UMR G-EAU.