EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:
https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report")*,
- even for experiments whose scientific area is different form the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round - **5th March**
- 10th September Proposal Round - **13th September**

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title: Liquid core dynamics and statistical analysis in atomization via synchrotron high-speed radiography**	**Experiment number**: ME-1585
Beamline: ID19	**Date of experiment**: from: 17/09/2021 to: 20/09/2021	**Date of report**: 16/05/2023
Shifts: 9	**Local contact(s)**: Alexander Rack	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

- **Nathanaël Machicoane (CNRS – main proposer)**
  Environmental and Industrial Flows Laboratory (LEGI, UMR5519)
- **Oliver Tolfts (PhD student GINP)**
  Environmental and Industrial Flows Laboratory (LEGI, UMR5519)
- **Guillaume Deplus (Master student UGA)**
  Environmental and Industrial Flows Laboratory (LEGI, UMR5519)
- **Carlos Perez-Fernandez (Master student UGA)**
  Environmental and Industrial Flows Laboratory (LEGI, UMR5519)

Report:

Objective

This project aims at characterizing the dense two-phase flow exhibited in coaxial two-fluid atomization at high gas velocities. The liquid jet destabilization and fragmentation are uniquely captured by **high-speed radiography**, and particular attention is devoted to the role of liquid flow rate increase and of gas swirl addition (angular momentum in the gas jet) in the spray formation process. Two main goals are targeted:
- Characterize the morphology and the regime of fragmentation of the liquid jet, at least qualitatively.
- Obtain quantitative information about the liquid jet dynamics and the liquid mass distributions.

To this end, 9 shifts were required: 1 to set up the flow loop of the atomizer, 1 to set and optimize the beam and acquisition parameters, 1 to image the flow inside of the atomizer, and the remaining 6 shifts were devoted to acquiring data at various operating conditions and in various locations of the spray. Qualitative **regime maps** were successfully obtained, and some **fully quantitative information on the jet dynamics** is already secured.

Sample details

The sample is a water jet with an exit diameter of 2 mm, destabilized and fragmented by a high-speed air jet. Due to the large difference in absorption coefficients, only water is measured. The beam slits are adjusted to have a fairly homogenous beam over the measurement regions and reach a field of view of around 8x6 mm². The beam traverses the sample and is absorbed by a scintillator that reemits in visible lights, which is captured by a Photron SAZ1 camera (see Fig. 1). A fast shutter is implemented, synchronized with the camera, to allow for 1 second of acquisition. Beyond that time, the scintillator suffers mechanical failure due to the heat load, as high energy is required to reach exposure times of 2.5 µs. Longer exposure time would result in large motion blurs. The field-of-view of view can be further reduced, effectively cropping the images, to increase the sampling rate up to 100 kHz. The pixel size is fixed at 6.7 µm for the whole measurement series.

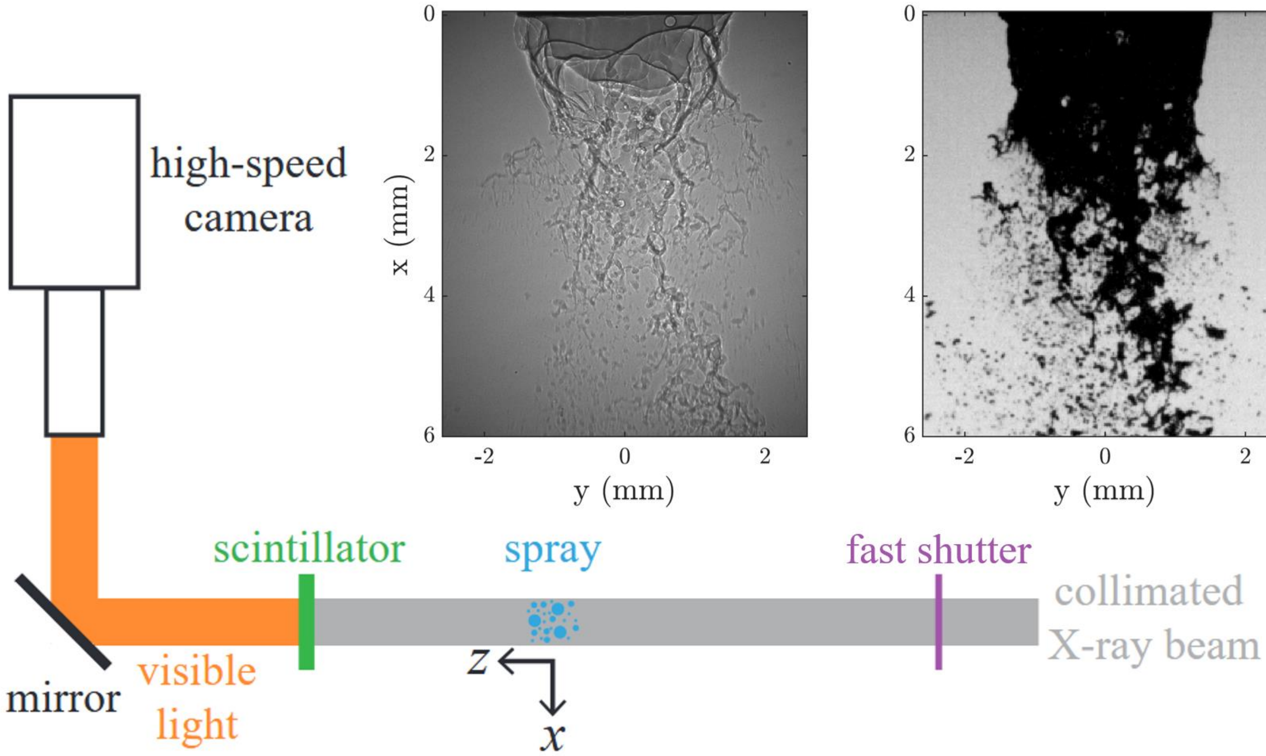


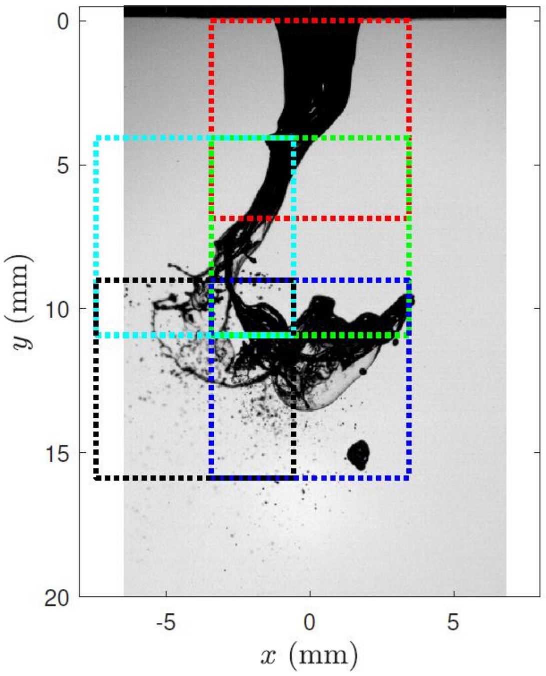
Figure 1. *Schematics of the high-speed X-ray radiography at ESRF, with a resulting radiograph, that is compared to what is obtained at the same operating condition using visible light. The many overlapping interfaces seen on the left translate into an obscured region where no measurement is possible.*

Experimental set-up and measurements conducted

Much care was taken to prevent droplet presence and moisture in the hutch, even at extreme atomization conditions, as illustrated by Fig. 2. This was successful and the humidity did not increase throughout the 9 shifts. Building air supply was used for a large portion of the conditions undertaken, while the most extreme gas velocities (up to Mach 0.95) were attained using nitrogen gas cylinders provided by ESRF.

Figure 2. *Screenshot of the tweet from ESRF communication service. The left picture shows the spray with O. Tolfts, N. Machicoane, and A. Rack (left to right) during set-up. The right picture highlights the spray collection system (green pool and grids) that prevents droplet recirculations and splashing. The nozzle is held by a 3-axis translation stage with an aluminium frame to allow for measurements at various locations of the spray development region by moving the atomizer with respect to the (fixed) beam. The emergency stop of the translation stage was placed outside the hutch. Air and water tubings were managed to prevent bending and pulling during translations.*

The set-up, while cumbersome, was successfully installed and implemented in the hutch and all planned operating conditions were captured. 102 conditions were captured (despite data throughput issues and beam



being down for half a shift), corresponding to 204 movies at various locations along the spray near-field as illustrated in Fig 3.

Figure 3. *Snapshot from the near-field of coaxial two-fluid atomization captured by back-lit visible light imaging over a large field of view, at a low gas and liquid velocities displaying a long liquid core and highlighting the flapping instability and bag-breakup. The dashed lines correspond to the different locations that were explored for this condition at ESRF, using higher spatial and temporal resolution to study the underlying physical phenomena of the break-up process. Conditions with higher gas-to-liquid dynamic pressure ratio exhibit smaller liquid core and required less locations to be captured (one window at the exit of the nozzle was sufficient for the most intense atomization condition, while the case used here required 7 windows).*

Preliminary quantitative results and difficulties

Beyond the immense gain brought by the qualitative observations of the high-speed X-ray radiography images, we tried to develop a method to retrieve the Equivalent Path Length (EPL), representing the total amount of liquid that the beam encounter along its path (i.e. liquid mass distribution integrated along the beam direction). Large spatial and temporal variation of the recorded intensity were the main challenges and sources of experimental uncertainties in this venture. Using the program developed by Dr. A. Rack, ANKA Phase, we were nonetheless successful at recovery the EPL for the bulk of the liquid jet, i.e. the liquid core, and were able to study its morphology and define regimes based on quantitative indicators (statistical distributions of its center of mass, power spectra and residence times to study the temporal dynamics) as displayed in Fig. 4.

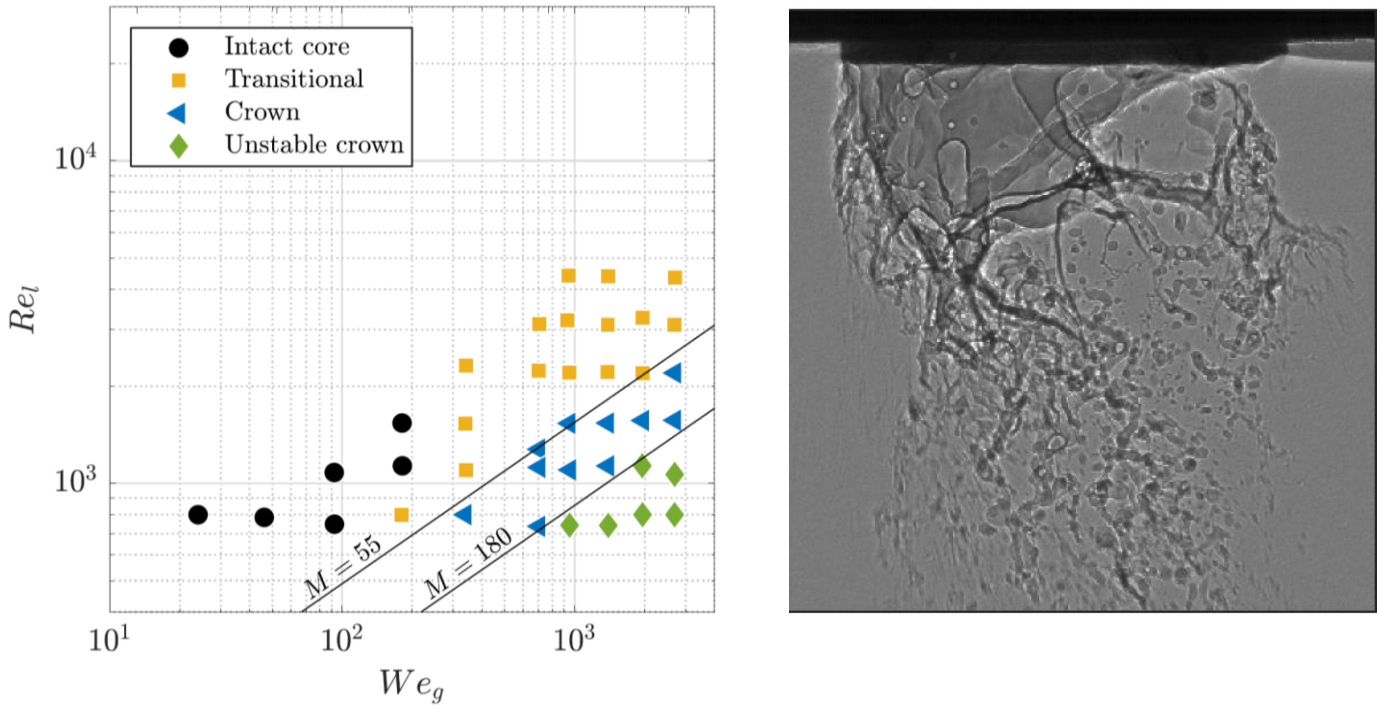


Figure 4. *Regime map of the morphologies of the liquid core uncovered in this study. The tight sampling of the parameter space highlighted a transitional regime, as well as unstable crown (right panel) attained in the absence of swirl when the gas-to-liquid dynamic pressure (or kinetic energy) ratio M is very high (low liquid and high gas injection velocities here). Two transitions between the reported regimes can be explained in terms of simple kinetic energy balance between both phases since they are separated by iso-M lines.*

Summary

The experimental session at ESRF was greatly successful. A large quantity of data was capture, covering a large parameter space that allowed to define finely transition among uncovered regimes. The role of the liquid Reynolds number and liquid turbulence in coaxial atomization will become much clearer thanks to this study. The results were already presented and well received by the community at the following international conference: N. Machicoane, O. Tolfts, A. Rack, 11th International Conference on Multiphase Flow, Kobe, Spray formation in two-fluid coaxial atomization with high-speed gas, from April 2 to 7, 2023. A publication is also in preparation for an international peer-reviewed journal. Future work would ideally tackle the role of gas turbulence is spray formation, which could explain the discrepancy between various works in the literature, since this parameter is often overlooked and not reported. The PI recently received funding by ANR to study this phenomenon (ANR JCJC FragTurb, 2023-2027).

Numerous difficulties were encounter and at least partially overcome, for this experiment. Beyond the difficulty mentioned earlier concerning intensity variations that makes quantitative results extraction harder, the amount of data and the associated processing time posed challenges already. However, a framework was implemented, and can now be built upon for future analysis on this data and future data to be collected. A list of improvements for future beamtime measurements was compiled, such as implementing synchronization between acquisitions and electron cycles in the ring, designing a calibration object to be placed at all times on the side of the field of view to drastically simplify analyses and increase measurement accuracy, and including the beam polychromatic nature in the analyses.