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► **To cite this version:**

Victor Chéron, Jorge César Brändle de Motta, Jean-Bernard Blaisot, Thibaut Ménard. Morphological characterization of 3D spray droplets. 11th International Conference on Multiphase Flow, Apr 2023, Kobe, Japan. hal-04511673

HAL Id: hal-04511673

<https://hal.science/hal-04511673>

Submitted on 20 Mar 2024

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Morphological characterization of 3D spray droplets

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Keywords: Spray characterization, droplets, shape parameters

Abstract

The characterization of sprays is required to describe many natural and industrial processes. Additionally to the characteristic lengths, many authors propose to analyze the morphology of the droplets in spray through shape parameters based on 2D projections. Following a previous study, we introduce four complementary 3D shape parameters which are applied to the analysis of two numerical droplets databases within this work.

Introduction

Atomization of a liquid bulk is a common process in nature and industrial applications. The characterization of the resulting spray is necessary to control this process and understand the involving phenomena (mixing, evaporation, etc.). A generally used quantity in spray analysis is the Sauter Mean Diameter, that is often used for heat and mass transfer (Levebvre 2017). The size distribution function provides more details such as the polydispersion, and often represents a footprint of the underlying atomization mechanism. These two quantities are computed considering that each droplet is described by only one length, i.e. the diameter. In other words, the ideal case of spherical droplets is considered in such cases. In order to go further in the quantitative description of the droplets, shape parameters can be introduced.

In the atomization and sprays literature, many authors have worked on the shape parameters based on two-dimensional projection of the droplets (Blaisot & Yon 2005; Ghaemi et al. 2009). This constraint of projection is due to the fact that sprays are often analyzed from experimental facilities where the images are obtained by shadowgraphy or backlight imaging. In (Ghaemi et al. 2009) many 2D parameters are given to classify the liquid structures as spherical droplets, deformed droplets, or ligaments.

With the enhancement of the quality of direct numerical simulations of atomization and the access to 3D shape of droplets in experiments (e.g. (Masuk et al. 2019) for shape characterization of bubbles) the extension of these parameters for 3D is possible. Recently, our group highlighted the link between the 2D shape parameters and their equivalent in 3D (Chéron et al. 2022). For this purpose, we use ideal spheroids and 3D droplets obtained by numerical simulations. In order to extend this work, the authors discuss in the present communication how the shape characterization can be done using these 3D parameters.

Numerical Methods

The spray droplets analyzed in this work are obtained by direct numerical simulations. The incompressible Navier-Stokes solver ARCHER is used. The interface is described with the coupled Level-Set Volume of Fluid approach, allowing the access to an accurate description of the droplets shape¹.

Two databases are used for the description. The first database consists of the simulation of numerous isolated droplets under turbulent conditions (Chéron et al. 2019, 2022). These droplets are characteristic of slightly deformed droplets. A second database is based on an airblast atomizer simulation (Mukundan et al. 2021; Chéron et al. 2022). This database contains large deformed droplets subject to break up, with major deformations along the streamwise direction.

Shape parameters

In the present communication we focus on four shape parameters, defined in this section, which have been chosen after some analysis and discussion, see (Chéron et al. 2022) for details.

Aspect ratio. This parameter is based on two lengths, defined from the contour or the interface of the droplet considered. The definition of these two lengths differs in the literature. Here, we consider the maximal and minimal distance from the interface to the center of mass, a and b respectively. The aspect ratio parameter reads:

$$\alpha = \frac{b}{a} \quad (1)$$

Uniformity. The uniformity uses the same two lengths, a and b , and includes the volume-based-equivalent radius $R =$

¹See hal.archives-ouvertes.fr/ARCHER for all solver's references.

$\sqrt[3]{\frac{3V}{4\pi}}$, where V is the volume of the droplet. The uniformity parameter reads:

$$\eta = \frac{a - b}{R} \quad (2)$$

Irregularity. This parameter considers the volume-based-equivalent radius R and the total area of the interface, S . The irregularity reads:

$$\iota = \frac{4\pi R^2}{S} \quad (3)$$

Symmetric difference shape parameter. Finally, the symmetric difference shape (SDS) parameter considers the symmetric difference between the droplet, \mathcal{D} ; and the equivalent sphere based on the volume-based-equivalent radius R and centered at the center of mass of the droplet, \mathcal{S} . The SDS parameter reads:

$$\psi = \frac{V_{\mathcal{D} \cup \mathcal{S}} - V_{\mathcal{D} \cap \mathcal{S}}}{V_{\mathcal{D}}} \quad (4)$$

Results and Discussion

Except for ideal cases (e.g. sphere, spheroid), for which shapes can be characterized by few parameters, in real life the number of parameters needed is not known. The more complex is the shape, the more parameters are required. Thus, it is necessary to combine several shape parameters to provide a thorough description of droplets in spray. For this reason we present in the figure 1 a chart where the value of the four shape parameters for each droplet of the database is showed. As reference, we plot also the relation of the ideal case of spheroids (oblate and prolate). These relations are derived in (Chéron *et al.* 2022) and can be seen as an indicator of how far the droplets are from the spheroidal case.

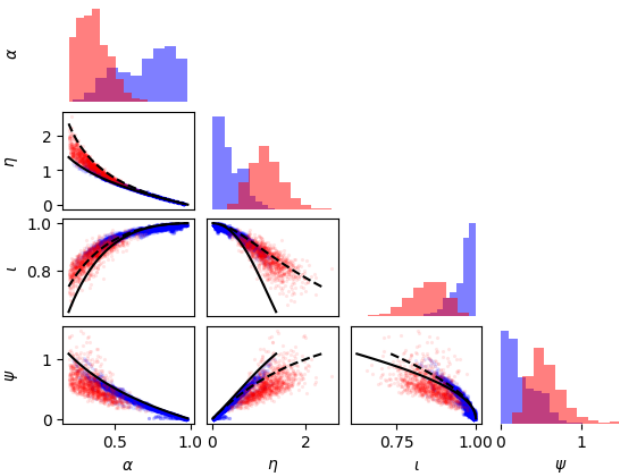


Figure 1: Distribution of droplets for the different shape parameters. Blue for turbulent database and red for the airblast database. The lines are for oblate and prolate spheroids.

We observe that the droplets generated from the airblast database exhibit larger deformation. Additionally, the larger

is the deformation of the droplets, the further they are from the ideal spheroidal case. For these strongly deformed droplets, each of the parameters gives different information.

Conclusion

The present work provides an insight into the usefulness of different shape parameters to classify the droplets and liquid structures in different families. The use of additional databases, from different numerical setups and, when possible, from experiments, is necessary to enhance the understanding of these parameters. Finally, the analysis of 2D shadowgraphy images can be enhanced by the understanding of the relation between 2D and 3D parameters.

Acknowledgments

This work was granted access to the HPC resources of IDRIS, TGCC and CINES under the allocation A0112B1010 made by GENCI (Grand Equipement National de Calcul Intensif) and the CRIANN (Centre Régional Informatique et d'Applications Numériques de Normandie) under the scientific project N. 201 704. This work was supported by a grant overseen by the French National Research Agency (ANR-20-CE46-0002), and the Normandy region, AMCAS project.

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