Direct numerical simulation of conical swirled jet primary break-up

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Introduction

The process of liquid jet primary break-up has been the subject of massive investigation over the years, although it is still an open subject of research due to the inherent difficulties both in the experimental analysis and in the theoretical description.

Swirl injectors have been widely adopted for modern gas-turbine engine combustors [1]. In this category of injectors, a liquid lamella is formed in the nozzle discharge hole, generating a liquid cone as it exits the nozzle that undergoes the primary break-up yielding drops and liquid ligaments [2-4].

Different models had been developed to describe the break-up mechanisms for conical jets, which are different from plain jets, although the experimental validation is still missing due to the intrinsic inadequacy of the available experimental techniques to penetrate the dense region where this phenomenon takes place. Among others, the models of Squire [5] and the following analysis of Clark and Dombrosky [6] taking into account the Kelvin-Helmholtz instability of liquid sheets under the influence of surface tension and liquid viscosity are worth to be mentioned. Senecal at al. [7] pointed out some limitations of those models and proposed a model, similar to that developed by Li et al. [8, 9], showing the different role of long and short wavelength disturbances to induce the lamella break-up.

Possible effect of turbulence in the liquid lamella has been considered by Tonini et al. [10].

In absence of experimental data, Direct Numerical Simulations (DNS) is a tool capable to provide information on the lamella evolution as it exits from the nozzle and the primary break-up characteristics.

This work aims to compare the results from the Direct Numerical Simulations using the in-house multiphase Free Surface 3D code (FS3D) [11] with those obtained from atomisation models available in the open literature.

Numerical tools

The liquid lamella exiting a pressure swirl atomizer for aeronautical applications is numerically modeled using the FS3D CFD code, developed by the Institute of Aerospace and Thermodynamics (ITLR) of the University of Stuttgart. The model solves the incompressible Navier-Stokes equations for multi-phase flows, based on the volume of fluid (VOF) method [12]. Refer to [11] for a detailed description of the FS3D characteristics.

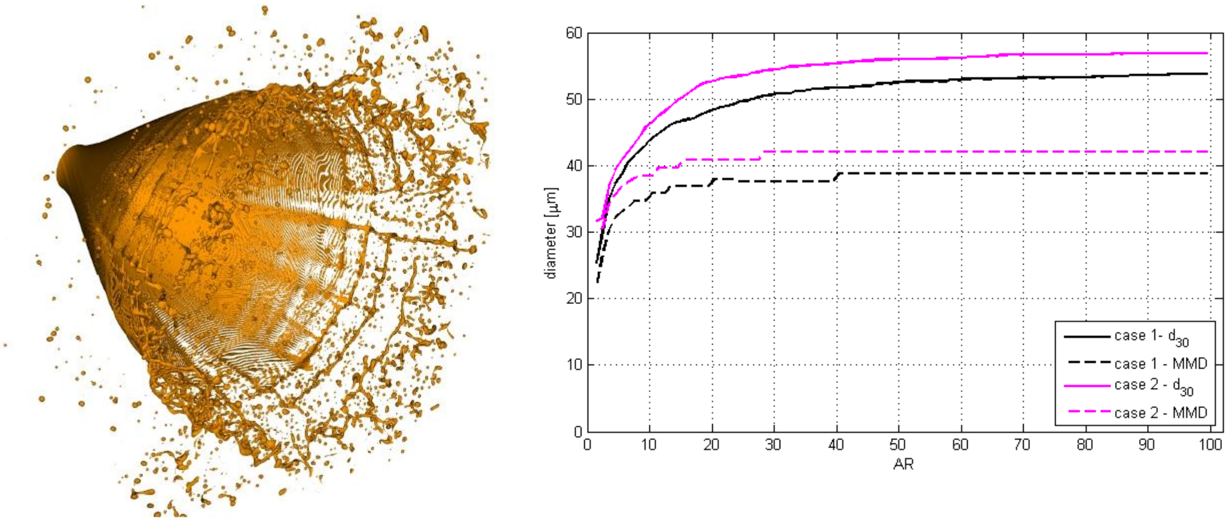
A numerical grid with 302 millions of cells, ensuring a Kolmogorov factor *KF* equal to 8.19, was used. The inlet velocity profiles of the annular jet have been extracted from previous VOF simulation of the internal flow of the atomizer, corresponding to the take-off (50%) engine operating conditions [13]. The fuel characteristics are those of JET-A1.

The characteristics of all the formed liquid ligaments and drops were extracted from the DNS results in terms of volume, shape, velocity and position. These information were compared with the outcomes from the above mentioned atomisation models for conical swirled jets.

Results and Discussion

Figure 1 shows a sample of the liquid lamella break-up as simulated by FS3D, enlightening the peculiarities of the liquid structures. The estimated values of break-up length, the corresponding liquid film thickness, the ligament and droplet size after the primary break-up have been compared with the analytical model of Senecal et al. [7]. The effects of aerodynamic forces, liquid turbulence and swirl motion on the spray formation have been evidenced and discussed.

The results from the numerical simulations evidence that only a small amount, less than 10%, of the liquid ligaments has a shape close to a sphere and very highly deformed ligaments are instead the most frequent ones, as shown in Fig. 2 for the two test cases reported in Table 1. This has an evident effect on the subsequent secondary atomisation that may not be caught by the commonly used secondary break-up models, which usually assume spherical or spheroidal drop shapes.



(a) (b)

Fig. 1 (a) Conical swirled jet at 0.3 ms after start of injection. Test case #1 of Table 1. (b) *d30* and *MMD* evaluated considering different threshold of aspect ratio $AR=L_{max}/L_{min}$, for the two test cases of Table 1, where L_{max} and L_{min} are the maximum and minimum ligament dimensions, respectively.

Table 1 Investigated operating conditions and computational grid characteristics.

Test case	-	$\dot{m}_l \times 10^3$ [kg/s]	ρ_g [kg/m^3]	$2h$ [μm]	*KF*	$n_{cell} \times 10^8$
# 1	Take off 50%	2.8	13.3	100.4	8.4	3.03
# 2	Approach 30%	3.0	6.8	94.6	8.6	5.37

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