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A canonical geometry to study wall filming and atomization in pre-filming coaxial swirl injectors

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Abstract

A coaxial twin counter-rotating air swirl prefilming injector with necessary optical access, is developed to visualize and quantify its internal fluid dynamics. This research injector consists of a simplex nozzle arranged at the center of two coaxial counter-rotating radial air flow swirlers, and two transparent coaxial tubes are attached, one each to the primary and secondary air swirl paths. Spray from the simplex nozzle is swirled by the primary air and impinges on the inner tube—the prefilmer, undergoes filming, and convects to the tube tip to form a liquid rim, which is sheared by the counter-rotating swirl into finer droplets. Stage-wise phase Doppler particle analyzer measurements indicate the final spray to be much finer than the simplex nozzle spray after undergoing the above processes. Time resolved laser induced fluorescence (TR-LIF) imaging techniques are applied to visualize the wall filming and primary atomization inside the injector. The simplex nozzle spray velocity under the influence of air swirl flow is measured using stereo-particle image velocimetry. The precessing vortex core from the primary swirl imparts a precessing motion to the simplex spray, which in turn induces a non-uniform filming on the prefilmer. The droplet impingement on the prefilmer leads to splashing and crater formation on the surface. The crater size distribution is obtained and compared to the droplet size of the injector spray before impingement. The film thickness variation on the prefilmer surface and the rim thickness are estimated from planar LIF experiments along with a long distance microscope. The thickness of the liquid rim is identified as a major factor in determining the final droplet size at the injector exit. These are correlated to SMD at the injector exit at different air flow rates.

Keywords: Prefilming coaxial swirl injector; Atomization; Wall filming; Film thickness; Laser induced fluorescence

1. Introduction

Aero engine combustors generally employ piloted prefilming airblast atomizers to achieve efficient atomization and uniform fuel air mixing. Lefebvre [1] reviewed spray characteristics of airblast atomizers and correlated different spray parameters. The major design focus on prefilming atomizers is to spread the liquid fuel to the thinnest possible sheet using a prefilming surface, and to atomize it into fine droplets by the aerodynamic forces generated from swirling air streams. The

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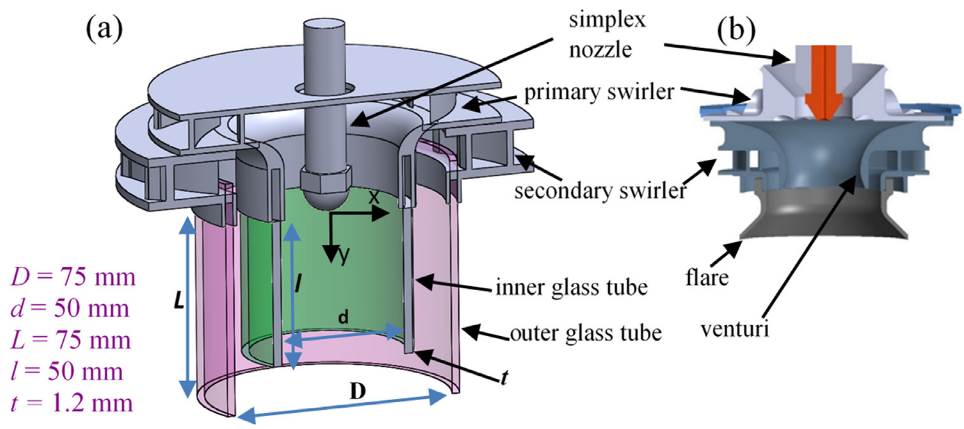

Fig. 1. Cut section of: a. the present injector, b. practical gas turbine injector [2].

swirl flow field in the injector generates a central toroidal recirculation zone (CTRZ), which helps in flame stabilization and fuel–air mixing [2].

Many previous studies on practical engine injectors are reported on the spray flow field at the injector exit under both reacting and non-reacting conditions [3–5]. However, this alone is insufficient to completely understand the injector fluid mechanics. This is mainly because, apart from the spray characteristics, the swirl flow field and the droplet dispersion inside the combustor are mainly controlled by the flow evolution inside the injector involving the interaction of the swirling air streams, spray-wall impingement [6], wall filming [7], ligament breakup, and secondary atomization [8–10]. So, it is important to study the two-phase flow evolution inside the injector and correlate the internal flow characteristics to the external spray characteristics.

This is challenging because of the need to access the complicated internal geometry for diagnostics. Investigations [6–11] to understand the internal flow field of the injector are reported on relatively simple configurations such as planar, non-swirling geometries. Indeed, correlations are recently developed to relate the thickness of the atomizing edge to the Sauter mean diameter (SMD) of the droplets and breakup frequency [12]. Braun et al. [10] have shown that the role of the atomizing edge is significant mainly when it is >100 μm. Even though this provides a good understanding on the mechanisms of prefilming airblast atomization, its applicability to practical injectors is limited because of the combined effects of the flow features mentioned earlier.

In contrast, we attempted to measure the flow field inside a practical injector that is quite complicated [13], as shown in Fig. 1. Figure 1b schematically shows the cut section of a swirl cup [2], the geometrical details and working of which can be found in [13]. We mainly faced difficulties in visualizing the film break-up at the venturi tip because of the lack of required optical access when the secondary swirl passage was present. Therefore, the present study is intended to investigate an injector geometry similar to practical injectors for the wall filming and atomization occurring inside. For this, a prefilming coaxial swirl injector is developed which has similar geometrical and flow features of the practical aero engine injector, and yet avoids the three-dimensional curvature effects of the venturi. Li and Soteriou [14] have investigated the details of the internal flow through high-fidelity numerical simulations of a similar geometry. Here, we adopt two transparent concentric circular air passages for the primary and secondary swirling streams (Fig. 1a) to clarify the flow processes involved, with sufficient resolution and minimal optical distortion.

In the present work, measurements are made at different stages of the above injector. Time-resolved laser-induced fluorescence (TR-LIF)-based imaging techniques are used to capture the overall flow field inside the injector and to characterize the unsteady injector dynamics. The size distribution of the pilot spray droplets, the liquid film thickness and the size of the craters formed by the spray impinging on the film are measured. The thickness of the liquid rim accumulating at the prefilmer tip is quantified. This is correlated with the SMD of the droplets formed from the ligaments shedding from the liquid rim, as a function of the air-to-liquid ratio (ALR).

The injector presented in this paper is a versatile modular research injector of its class, capable of allowing variations in the relative positions of the pilot spray and the tubes, and in the relative swirls of the air streams. The present work comprehensively connects the occurrences from the exit of the pilot spray to the full injector exit quantitatively, which can pave way for designs and detailed benchmarking of numerical simulations of practical injectors.