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Airblast spray in crossflow – Structure, trajectory and droplet sizing

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ABSTRACT

This study reports results of an experimental investigation of airblast spray of water and ethanol in crossflow. Laser shadowgraphy and Particle/Droplet Imaging Analysis (PDIA) are used to derive spray trajectory and drop size information while Particle Tracking Velocimetry (PTV) is used to measure droplet velocities. A new phenomenon of spray bifurcation is observed for low Gas to Liquid Ratio (GLR) cases. The reasons for the spatial bifurcation can be attributed to a combination of reasons. These are (a) presence of large ligaments and droplets in the near-nozzle region for low GLRs (b) secondary breakup experienced by ligaments/droplets leading to formation of a large number of small droplets, and (c) the crossflow causing differential dispersion of the small and large droplets. A novel correlation for spray trajectory is proposed incorporating the momentum ratio and liquid surface tension. This correlation is shown to be effective in predicting the non-linear spray trajectory over a large range of conditions for not only water but ethanol and Jet-A also. It is observed that the larger droplets penetrate further into the crossflow, in the direction of injection. Thus, with increase in height of the measurement location from the injection plane, the droplet Sauter Mean Diameter (SMD) is found to increase. Moreover, as the droplets travel downstream in the crossflow direction, the droplet SMD is observed to decrease. The effect of drag is assessed by comparing velocity of different sizes of droplets at various locations. Smaller droplets are entrained into the crossflow at much lower elevations, whereas larger droplets tend to penetrate further into the crossflow.

Introduction

Spray in crossflow configuration finds its application in a variety of natural as well as engineering processes. Many engineering devices use crossflow configuration for fuel injection, primarily in gas turbine combustors, afterburners, ramjets and scramjets. Fuel is generally injected as a liquid or gaseous jet. There are several studies on liquid jet and gas jets in crossflow (Wu et al., 1997; Becker and Hassa, 2002; Ng et al., 2008; Aalburg et al., 2005; Tam et al., 2005; Lubarsky et al., 2010; Smith and Mungal, 1998; Haven and Kurosaka, 1997). However, there are very few studies on spray in crossflow. The earliest works on spray in crossflow are focused on agricultural applications, particularly spraying of pesticide and insecticide in an agricultural farm (Ghosh and Hunt, 1998; Philips and Miller, 1999; Philips et al., 2000). These investigations typically had a large test section spanning a few meters, large spray momentum, larger droplets and small crossflow velocities, not relevant to gas turbine conditions. Ghosh and Hunt (1998) have mostly presented theoretical derivations with little experimental corroboration. They have studied injection of droplets into the crossflow but have not examined the role of airblast gas on injection and dispersion.

The work of Leong et al. (2000, 2001) appears to be the most comprehensive set of experiments conducted on a spray in crossflow configuration and is the first work focused on gas turbine applications. They have carried out studies on airblast spray in crossflow under atmospheric and high pressure ambient conditions. The spray structure has been imaged for various flow conditions and a trajectory equation has been derived based on the experimental results. In their experiments, they have used very low momentum ratios falling within a narrow range (0.5–5.58). Moreover, they have used only Jet-A. Li et al. (2010a, 2010b) have studied the spray painting process using a viscoelastic liquid and also water in an airblast spray subjected to a crossflow. They have utilized Mie scattering images to estimate equations for the centerline trajectory. However, they have not conducted any drop-sizing measurements in their work. Bai et al. (2009) and Zhang et al. (2013a, 2013b) have done experimental studies utilizing centrifugal, hollow cone and impinging pressure swirl injectors respectively. They have focused on a plane transverse to the crossflow and

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utilized PIV technique to visualize the flow field. These authors have reported the presence of counter rotating vortex pairs in the transverse plane. They have also used a Malvern instrument to obtain line-averaged particle size at various locations. More recently, Surya Prakash et al. (2014) have reported experimental results on pressure-swirl spray in crossflow. They have identified and reported the various regimes of breakup and their dependence on Weber number and swirl number.

To summarize, there exists a need to study the structure and trajectory for a spray in crossflow in detail and assess the various parameters affecting the trajectory for a wider range of liquid and crossflow air flows. There is also a need to account for liquid properties in the trajectory equation so that the equation can be used for different liquids. The present work attempts to address these issues by focusing on the study of spray structure from an airblast injector in the presence of a crossflow to derive understanding of the structure and dispersion of the liquid. Specifically, experiments with water and ethanol (selected due to a large difference in its surface tension as compared to water) are conducted, and the next few sections describe the experimental setup, techniques used, spray trajectory, droplet size measurements and discussion of the results.

Experimental setup and imaging techniques

Experimental setup

A schematic of the experimental facility is shown in Fig. 1, while the schematic for optical diagnostics is shown in Fig. 2. The experimental rig consists of a diffuser, a settling chamber and a convergent section, which finally guides the incoming air into the test section. The settling chamber has the largest cross section in the flow line and is provided with appropriate flow conditioning elements to remove non uniformity, filter large scale turbulence and straighten the flow. The converging section is designed following the guidelines of Mehta and Bradshaw (1979) and Brassard and Ferchichi (2005). The velocity profile and turbulence levels are characterized using a hot wire anemometer at the exit of the converging section. The velocity profile is found to be fairly uniform with the velocity values varying within 2.5% of the mean. The turbulence intensity (u'_{rms}/U) is also found to be lower than 3.2% for all the measured locations. The velocity and turbulence intensity values at various points at the test section entrance are shown in Fig. 3. The test section is a rectangular duct of height 50 mm, width 54 mm and length 250 mm, provided with optical access. As per

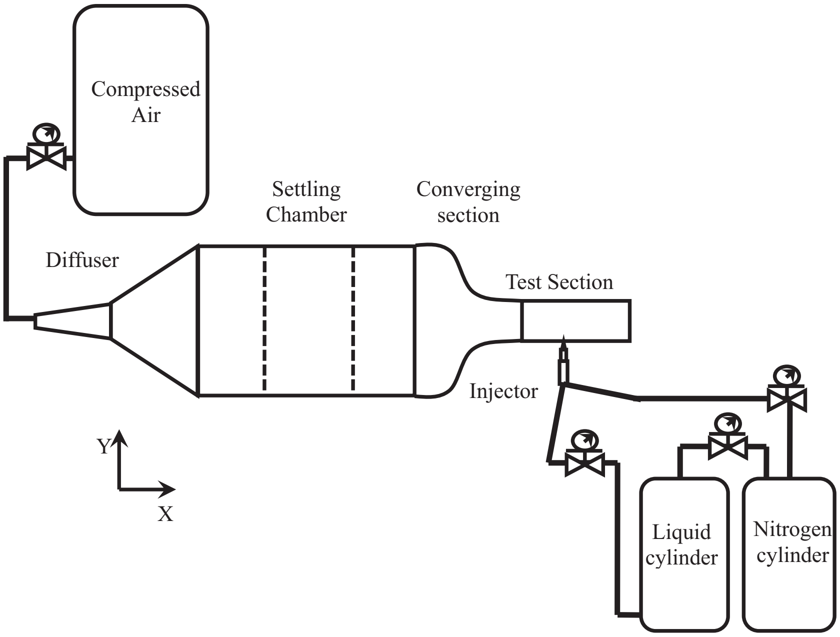

Fig. 1. Schematic of experimental facility.

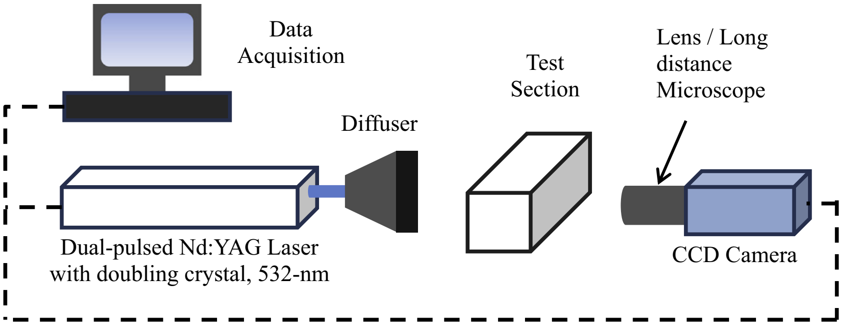

Fig. 2. Schematic of PDIA/PTV techniques.