AIAA Journal
Vol. 47, No. 11, November 2009

Novel Technique for Measurements of Continuous Liquid Jet Core in an Atomizer

G. Charalampous,* Y. Hardalupas,† and A. M. K. P. Taylor‡
Imperial College London, London, England SW7 2BX, United Kingdom

DOI: 10.2514/1.40038

A novel optical method is proposed for the measurement of the length of the continuous liquid jet core in atomizers. Laser light is directed through the injecting nozzle to illuminate internally the liquid jet, which acts as an optical fiber transmitting the laser beam. The continuous core of the liquid jet is visualized by means of laser-induced fluorescence, generated by the addition of dye in the liquid. The instantaneous continuous length of the liquid jet is measured as the distance from the nozzle exit, where the emitted laser-induced fluorescence intensity from the liquid jet becomes negligibly small due to interruption of laser light transmission through the liquid jet following the liquid jet breakup. The method provides a nonintrusive measurement approach, promising improved measurements in dense sprays, where droplets obstruct the illumination and the imaging path of shadowgraphic techniques. Measurements in an air-blast atomizer showed that the continuous liquid length measured by the novel approach is systematically shorter than that measured by shadowgraphy. As such, existing empirical correlations for the breakup length, which have been mainly measured by shadowgraphy, may need to be revisited.

Nomenclature

D_G = inner diameter of the gaseous jet nozzle
D_L = inner diameter of liquid jet nozzle
D_0 = outer diameter of the liquid jet nozzle
L = breakup length
MR = gas to liquid momentum ratio
Re_L = liquid Reynolds number
U_G = cross section average gaseous velocity at the annulus
U_L = cross section average liquid velocity at the nozzle exit
We = Weber number at nozzle exit
ν_L = kinematic viscosity of the liquid
ρ_G = density of coaxial gas stream
ρ_L = density of central liquid jet
σ = surface tension

I. Introduction

THE process of coaxial air-blast atomization in combustion systems, such as rocket engines and gas turbines, is a complex phenomenon that has been investigated by many researchers, including [1–7]. Successful atomization of the liquid jet will provide sufficiently small droplet sizes, which can thoroughly evaporate and improve mixing between the liquid vapor and the surrounding gas, which is important for combustion applications.

The atomization process takes place in two regions, the primary and the secondary. In the primary breakup region, the shear forces at the gas–liquid interface are responsible for the breakup of the liquid jet into droplets and ligaments. The liquid jet usually remains continuous over several liquid jet diameters downstream of the nozzle exit depending on flow conditions, such as liquid and gas velocities, nozzle geometry, and the physical properties of the two fluids. Downstream of the primary breakup, the secondary atomization region follows, during which further atomization of droplets and ligaments occurs due to deformation by the surrounding gas stream [8].

The process of atomization itself can be characterized by a number of factors among which is the length of the continuous core of the liquid jet, which is also known as breakup length. The length of the continuous liquid jet core determines the extent of the primary atomization region and is very important for the performance of atomizing nozzles and for the development of computational models of the atomization process. However, it is usually difficult to probe into this region due to the formation of a dense cloud of droplets and ligaments around the central liquid jet. Currently, most methods used for the quantification of the continuous length are either intrusive [9,10] or photographic [6,11]. Both have limitations. The former method affects the atomization process due to the presence of a physical probe in the flow. In the latter, which is the most commonly used, the spray is illuminated by background lighting provided by a lamp or a laser, and shadowgraphs of the breakup region are recorded. However, the shadowgraphic images of the continuous liquid core are hindered by the presence of the products of atomization (ligaments and droplets), which can lead to erroneous measurements of the length of the continuous liquid jet core. Yet, most empirical correlations for the breakup length are based on shadowgraphic measurements, which generates doubts on their accuracy. More recent methods for investigating the structure of sprays that could be used to evaluate the continuous length of sprays are x-ray absorption [12–14], which is based on the measurement of the attenuation of x-ray beams passing through the investigated spray and ballistic imaging [15–17] where the investigated spray is back illuminated by a very short laser pulse (pulse duration on the order of femtosecond), and only the photons that pass through the spray without being scattered by the spray liquid are imaged. However, both these methods are very expensive to implement and require highly specialized equipment.

In this paper, we describe a novel optical technique for the measurement of the breakup length of liquid jets, which is based on the illumination of the liquid jet from within the injecting nozzle. In this case, the liquid jet acts as an optical fiber, with the propagation of light interrupted at the breakup region. A fluorescing dye added to the atomizing liquid is excited by the propagating laser beam and, as a result, the volume of the continuous portion of the liquid jet fluoresces. The novel technique was used to measure the breakup length of the liquid jet in a coaxial air-blast atomizer. The breakup length was also measured simultaneously by means of conventional shadowgraphy. Comparison is made between the two techniques and

---

Presented as Paper 1337 at the 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 8–11 January 2007; received 25 July 2008; revision received 15 May 2009; accepted for publication 7 July 2009.

*Research Assistant, Department of Mechanical Engineering; georgios.charalampous@imperial.ac.uk.

†Professor, Department of Mechanical Engineering; y.hardalupas@imperial.ac.uk. Associate Fellow AIAA.

‡Professor, Department of Mechanical Engineering; a.m.taylor@imperial.ac.uk.