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Effect of Mass-Velocity on Liquid Jet Atomization in Mach 1 Gasflow

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EFFECT OF MASS-VELOCITY ON LIQUID JET ATOMIZATION IN MACH 1 GASFLOW

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SUMMARY

Interacting two-phase flow in four differently sized pneumatic two-fluid atomizers was investigated to determine the effect of gas mass-velocity on the Sauter mean diameter of sprays produced by small diameter liquid jets breaking up in high velocity gasflow. Tests were conducted primarily in the acceleration-wave regime for liquid jet atomization, where it was found that the loss of droplets due to vaporization had a marked effect on drop size measurements. A scattered-light scanner, developed at NASA Lewis Research Center was used to measure the Sauter mean diameter, D_{32}, which was correlated with nitrogen gas mass-velocity to give the following expression:

$$D_{32}^{-1} = 11.7(\rho_n/V_n)^{1.33}$$

The exponent 1.33 for the gas mass-velocity is identical to that predicted by atomization theory for liquid jet breakup in the acceleration-wave regime.

INTRODUCTION

When liquid fuels are injected into gas turbine or rocket combustors they are rapidly atomized into clouds of vaporizing droplets that quickly ignite and burn. To accurately describe the fuel-spray combustion process, detailed knowledge of fuel spray formation is required and characteristic dropsize measurements are needed at the point of initial spray formation near the atomizer orifice. Also, to better understand how liquid fuels are atomized, mathematical expressions are needed that adequately describe processes such as two-fluid atomization in which various liquid and gas combinations may be used to produce the sprays. To do this, the effects of liquid and gas properties on spray dropsize must be determined. Numerous investigators have reported experimental results that correlate spray characteristic dropsize with relative velocity, i.e., gas velocity relative to liquid-surface velocity and also with liquid properties as given in references 1 to 5. Some of the correlations agree very well with atomization theory whereas others differ considerably. This could be attributed to the fact that measurement techniques and instrumentation have not yet been sufficiently developed or standardized to such an extent that good agreement might be expected. Experimental studies are needed that will produce correlations of characteristic dropsize measurements with dimensionless force ratios such as the Reynolds and Weber numbers. Such correlations are very useful in calibrating fuel nozzles for jet engines. This can be accomplished by first making dropsize measurements of water sprays produced with the fuel nozzle and then using the correlation to correct for the effects of liquid density, viscosity, and surface tension on the dropsize that would be produced with the nozzle using a fuel such as a Jet-A.

From a study reported in reference 6, it was found that the effect of droplet vaporization on spray samples could be minimized by taking the sample at a distance of only 2.2 cm downstream of the atomizer orifice. This technique gave the best agreement between theoretical and experimental effects of nitrogen gas flowrate on Sauter mean, D_{32}, volume-linear mean, D_{31}, and volume median, $D_{v.5}$, drop sizes. Therefore, in the present study, the characteristic drop diameters were measured at a sampling distance of 2.2 cm downstream of the nozzle orifice, with a scattered-light scanning dropsize measuring instrument previously developed at the NASA Lewis Research Center.

Prior to this study, an investigation was made with two-fluid atomizers and good agreement of experimental results with atomization theory was obtained as discussed in reference 6. It was found that the Sauter mean drop diameter, D_{32}, could be correlated with nitrogen gas flowrate, W_n, raised to the -1.33 power, which agrees well with atomization theory for liquid jet breakup in high-velocity gasflow. As a continuation of that study, the present investigation was initiated to extend experimental conditions to include a variation in the nozzle orifice diameter. By using four differently sized atomizers, it was possible to investigate the effects of nitrogen gas mass-velocity, $\rho_g V_g$, on the characteristic drop size, D_c, of the sprays. Values of $\rho_g V_g$ were calculated from nitrogen gas weight flow per unit area, W_n/A_o, and values of A_o for the four different nozzle orifices varied from 0.0804 to 0.246 cm^2.

NOMENCLATURE

A area

D_i diameter of ith drop, cm

D_{32} Sauter mean diameter, $\Sigma_i nD_i^3/\Sigma_i nD_i^2$, cm

n number of droplets

W weight flow of fluid, g/sec

$\bar{x}$ axial downstream spray sampling distance, cm

ρ density of fluid

Subscripts

g gas

n nitrogen

o atomizer orifice

APPARATUS AND PROCEDURE

The pneumatic two-fluid atomizer was mounted in the test section as shown in figure 1 and a diagram of the atomizer is shown in figure 2. The spatial resolution of the scattered-light scanner is 2.86 cm and corresponds to the laser beam diameter. A sufficient volume of each spray was sampled to minimize spray pattern effects when measuring characteristic mean drop diameters for the entire spray. Effects of the drop size distribution function on scattered-light scanner measurements is discussed in detail (ref. 7). It was found (ref. 7) that the irradiance distribution is only weakly related to the particle diameter distribution function. Therefore, the irradiance distribution was used to determine characteristic drop diameters and changes in the drop size distribution function were assumed to have a negligible effect on drop size measurements. Reproducibility tests gave experimental measurements of drop size that agreed within ±5 percent. Five sets of monosized polystyrene spheres having diameters of 8, 12, 25, 50, and 100 μm, were used to calibrate the scattered-light scanner. A more complete description of the scattered light scanner, the mean drop diameter range, and the method of determining mean or median particle diameter can be found in references 7 and 8. The sprays contained a relative high number density of very small droplets since they were sampled very close to the atomizer orifice. As a result, the light scattering measurements were corrected for multiple scattering as described in reference 9 concerning high number density sprays, and for Mie scattering at small droplet diameters, i.e., <10 μm.

EXPERIMENTAL RESULTS

As shown in figure 1, the entire spray was sampled at an axial distance of $\bar{x}$ = 2.2 cm downstream of the atomizer orifice. Values of the Sauter mean diameter, D_{32}, are plotted against nitrogen flowrate per unit orifice area as shown in figure 3 and the following expression is obtained:

$$D_{32}^{-1} = 11.7(W_n/A_o)^{1.33}$$

which may be rewritten as $D_{32}^{-1} = 11.7(\rho_n V_n)^{1.33}$ in terms of mass velocity, ρV.

The exponent 1.33 for W_n/A_o agrees very well with atomization theory for liquid-jet breakup in the acceleration-wave regime. This agreement of experimental data with theory was attributed to the fact that measurements obtained at $\bar{x}$ = 2.2 cm are less affected by vaporization and dispersion of the very small droplets as compared with measurements made farther downstream of the atomizer orifice. Values of the exponent, n, obtained in other experimental studies are shown in table 1 for comparison with atomization theory for liquid jet breakup (ref. 10).

It is difficult to compare results obtained by the various investigators since a wide variety of techniques and instruments were used to measure dropsize. The imaging and light scattering techniques of references 2 and 3 tend to give spatial instead of the flux type of dropsize distributions which were obtained in references 1 and 4 by collecting wax spheres formed in high velocity airflow. Measurement techniques and instrumentation have not yet been sufficiently developed or standardized to such an extent that good agreement might be expected among different investigators.

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Table 1 Velocity Exponent, n, for Acceleration-Wave Breakup of Liquid Jets: $D_m^{-1} \sim V_g^n$

Source	Exponent, n
Theory[b]	1.33
Present study, $\bar{x}$ = 2.2 cm	1.33
Weiss and Worsham[c]	[a]1.33
Wolfe and Andersen[d]	1.33
Kim and Marshall[e]	[a]1.14
Nukiyama and Tanasawa[f], $\bar{x}$ = 5 to 25 cm	1.0
Lorenzetto and Lefebvre[g]	1.0

[a]Drop-size data for wax spheres.
[b]Ref. 10.
[c]Ref. 4.
[d]Ref. 5.
[e]Ref. 1.
[f]Ref. 3.
[g]Ref. 2.

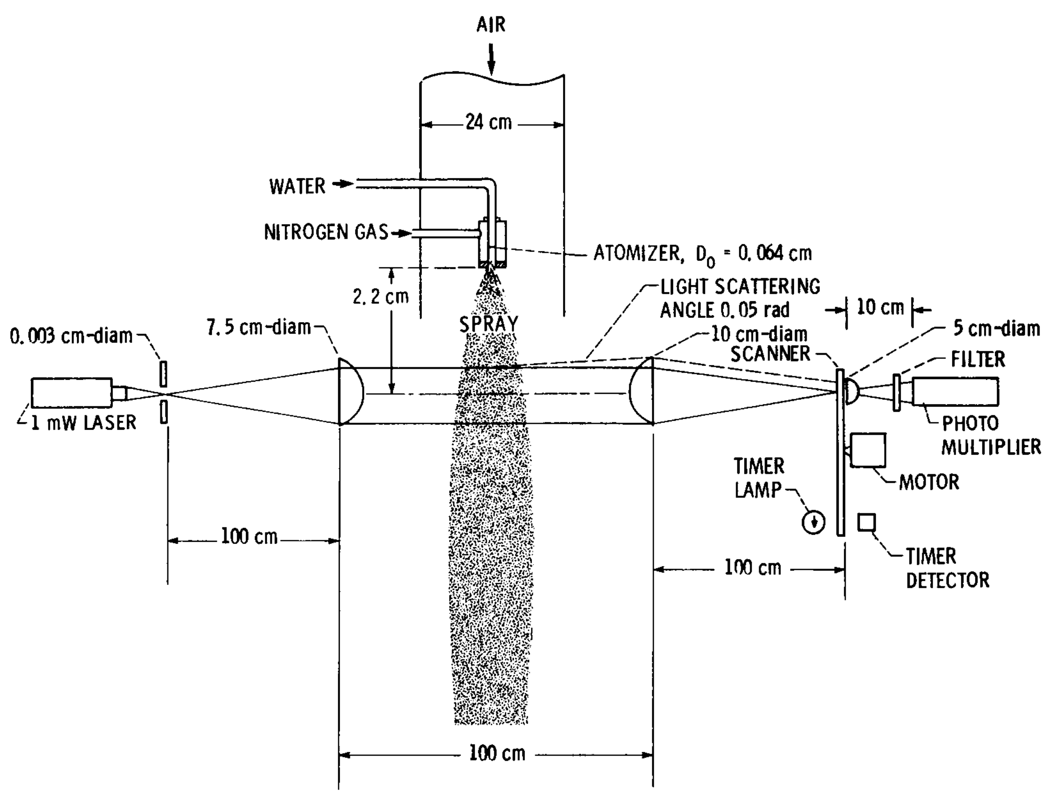

FIGURE 1. - ATMOSPHERIC PRESSURE TEST SECTION AND OPTICAL PATH OF SCATTERED-LIGHT SOURCES.

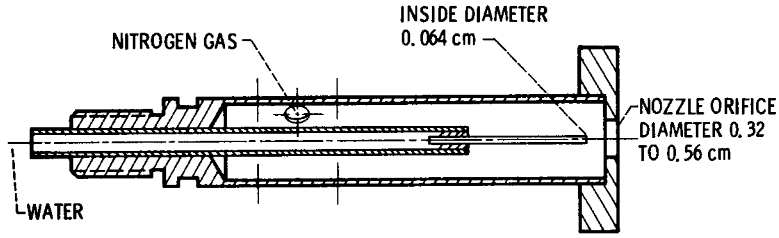

FIGURE 2. - DIAGRAM OF PNEUMATIC TWO-FLUID ATOMIZER.

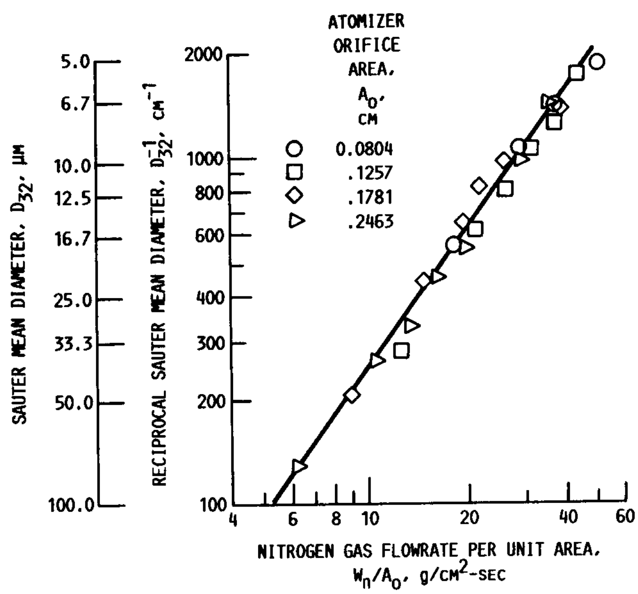

FIGURE 3. - CORRELATION OF D_{32} WITH W_n/A_0.

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