UC Irvine
UC Irvine Previously Published Works

Title

The Effect of Ambient Pressure on the Spray Characteristics of a Twin-Fluid Atomizer

Permalink

https://escholarship.org/uc/item/0dw9z99w

Authors

Drennan, SA
Sowa, WA
Samuelsen, GS

Publication Date

1990-06-11

DOI

10.1115/90-gt-393

Peer reviewed

90-GT-393

The Effect of Ambient Pressure on the Spray Characteristics of a Twin-Fluid Atomizer

S. A. DRENNAN
W. A. SOWA
G. S. SAMUELSEN[1]

UCI Combustion Laboratory
Institute of Combustion and Propulsion Science and Technology
University of California
Irvine, California 92717

ABSTRACT

A combined simplex/air-assist atomizer with swirl is
characterized in an isothermal high pressure spray
characterization chamber, with optical access, under various
ambient pressures. A single-component, phase Doppler laser
interferometer is used to obtain spatially resolved droplet size
and velocity information. Data are obtained at atmospheric
pressure as well as 3 and 6 atmospheres for conditions of
constant fuel and atomizing air flow rates. Two different nozzle
air flow rates and, hence, two different air-to-liquid ratios are
considered. Increasing ambient pressure decreases the air-to-
liquid momentum ratio and thereby decreases droplet mean
axial velocity and increases the droplet size. The response of a
spray to increasing ambient pressure is sensitive to the
parameters which are held constant while increasing ambient
pressure. The appropriate scaling parameters for the
extrapolation of atmospheric testing data to high ambient
pressures are likely geometry specific, and will require data of
the type reported here.

INTRODUCTION

The spray behavior of an atomizer has a direct effect on
combustor performance. As a result, the interest in fuel
atomization spans more than four decades of inquiry. As
diagnostics have evolved from photography to laser based
instruments, the detail of scrutiny has increased. Noteworthy is
that the vast majority of studies have been at atmospheric
pressure (e.g., Rizkalla and Lefebvre, 1975; Mao, Wang, and
Chigier, 1986).

In contrast, few atomizer studies have been conducted at
the high ambient pressures that more closely resemble actual
gas turbine environments. Of these, two characteristics stand
out. First, most have utilized laser diffraction to establish the
spatial mean drop size and drop size distribution along the line-
of-sight of a laser beam (e.g., Rizk and Lefebvre, 1983; Wang
and Lefebvre, 1987). Second, the studies have adopted as test
articles either research air-assist or pressure-swirl atomizers,
not combinations of both, and the nozzle features have been
kept relatively simple to facilitate interpretation. As a result,
the data have provided valuable insights into the effect of
elevated pressure on spray behavior. For air-blast atomization,
as an example, the study of Rizk and Lefebvre (1984) has
shown a logarithmic decrease in dropsize with increasing
ambient air pressure for constant air-to-liquid ratio (ALR)
and/or constant relative velocity (U_R) between the atomizing
air and liquid. For pressure-swirl atomization, decreasing
dropsize and spray cone angle has been associated with
increasing ambient pressure (Dodge and Biaglow, 1986; Wang
and Lefebvre, 1987).

While the laser diffraction technique provides a
convenient and easily interpreted reporting of drop size and
distribution for a spray, it does not reveal spatially-resolved
information on droplet size and droplet velocities. A relatively
new diagnostic, the phase Doppler interferometer, provides a
spatially-resolved flux measurement and, while more complex
than laser diffraction, provides both droplet size and velocity
information. And while both twin-fluid and pressure-swirl
atomizers are important in spray systems, the behavior of a
combined simplex/twin-fluid atomizer at elevated pressure has
yet to be addressed.

The objective of the present study is to (1) address the
effect of ambient pressure on the performance of an atomizer
that combines both the features of a simplex atomizer and a
twin-fluid atomizer, and (2) utilize phase Doppler
interferometry for the purpose of revealing the effect of
ambient pressure on the detailed structure of the spray field.

One of the principal contributions of the present study is
the provision of spatially resolved droplet size and droplet
velocity information. The benefits of phase Doppler results are
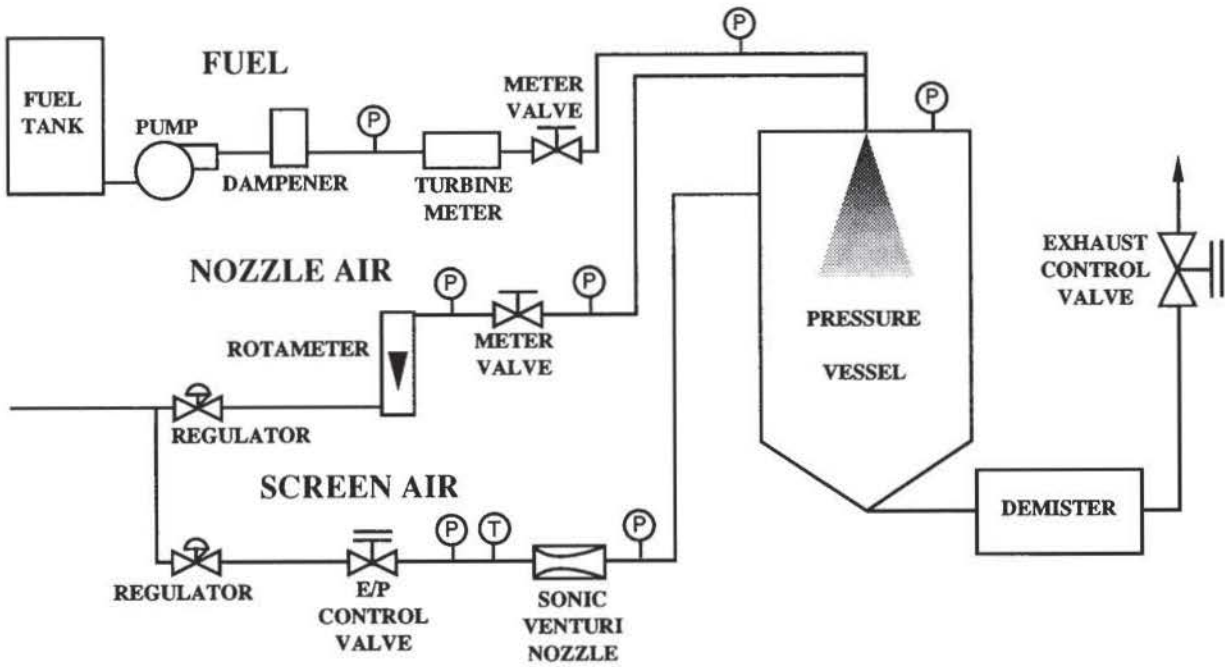
[1]Corresponding Author

FIGURE 1: High Pressure Spray Flow Diagram.

(1) the provision of velocity data, (2) the quantification of the extent of velocity change with increasing ambient pressure, and (3) the effect of the ambient pressure on the structure of both the droplet size and droplet velocity fields. Such data should prove useful in the development and validation of computer models purposed for gas turbine applications.

EXPERIMENTAL

The experimental systems used for the current study encompass three fluid circuits, a high pressure characterization chamber with optical access, an exhaust system, and a select diagnostic (Figure 1). A description of these components are provided in this section as well as a delineation of the test conditions.

Fluid Circuits

Two air circuits, nozzle and screen air, are provided. The screen air circuit consists of a regulator set at 0.79 MPa to provide course air regulation. An electro-pneumatic control valve is then used to provide fine regulation of the pressure upstream of a sonic venturi nozzle. The air pressure and temperature are monitored immediately upstream of the sonic venturi nozzle in order to determine air density, and thus flowrate, in addition to monitoring the pressure immediately downstream of the sonic venturi nozzle to verify a choked operating condition (in accordance with ASME/ANSI MFC-7M--1987). Screen air is introduced into the chamber at a flowrate sufficient to prohibit the accumulation of aerosol up into the measurement volume. The screen air is then supplied to the chamber, forced through a flow straightening section, and discharged into the chamber.

The nozzle air circuit used in this study consists of a regulator set at 0.96 MPa which supplies air to a rotameter and flowrate is varied with the use of a fine meter valve located downstream of the rotameter. The nozzle air is then supplied to the top of the nozzle tube and introduced to the nozzle.

The liquid system consists of a 18.9 liter fuel tank which supplies liquid to a remotely controlled meter pump into a precision turbine meter. A pulsation dampener is used to remove pressure fluctuations caused by the meter pump. A small meter valve is used to maintain a constant pressure in the liquid system such that the pulsation dampener is effective over the wide ambient pressure operating range of the chamber.

Chamber

The overall spray chamber dimensions shown in Figure 2 are 38.1 cm I.D., 121.9 cm long cylinder welded to an exit cone. The nozzle air and fuel are introduced into the spray chamber through a 50.8 mm O.D. stainless steel nozzle tube. The Z-traverse is obtained by axial movement up and down of the nozzle tube through a series of threaded shafts, bearing blocks and a gearing assembly, not shown. The X-Y traverse capability is achieved by a traverse table which translated the entire spray chamber, also not shown. An axial seal block is used to maintain pressure integrity around the nozzle tube while allowing Z-traverse capability. A cylindrical nozzle chamber, 15.2 cm dia. and 25.4 cm long, is attached to the end of the nozzle tube onto which the atomizer was mounted. The screen air is injected into the spray chamber through two diametrically opposed orifices and then passed through a flow straightening section which consists of fine mesh screen, followed by 10.2 cm of honeycomb, and another layer of screen.
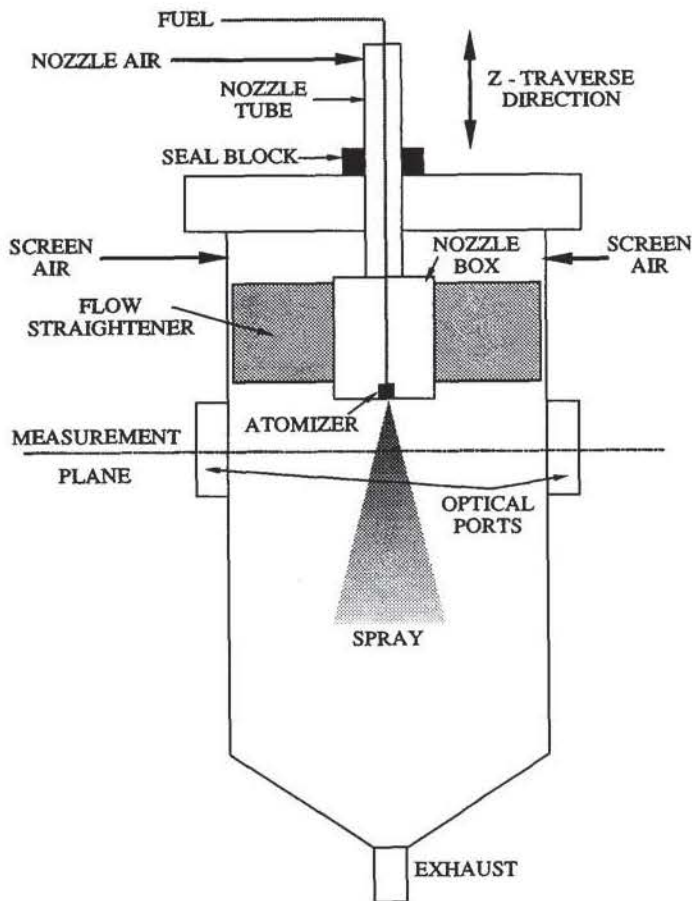
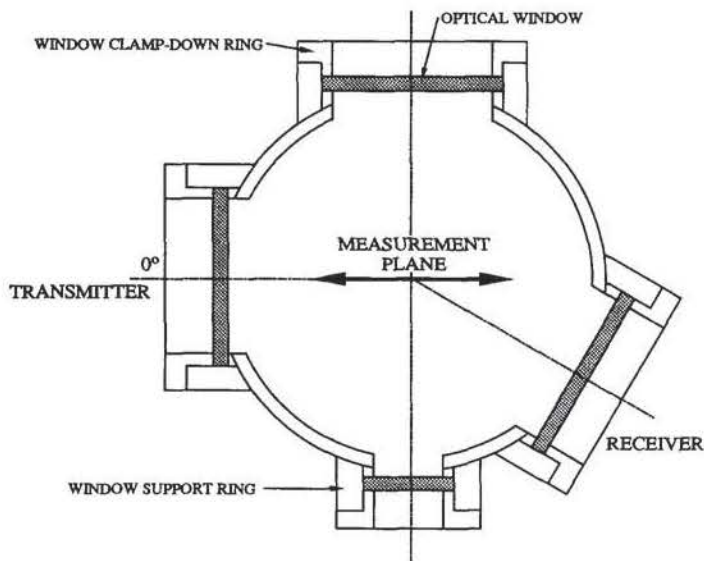FIGURE 2: High Pressure Spray Chamber.

FIGURE 3: Optical Port Arrangement.

A diagram of the optical port arrangement of the spray chamber shown in Figure 3 illustrates the transmitter window at 0° and the receiver window at 150°, measured counter-clockwise, both of which were 31.75 mm thick, 16.5 cm diameter Pyrex windows. At 90° was a small window, 12.7 mm thick, 8.9 cm diameter Pyrex, directly in line with a large access port with an oblong Plexiglass window at 270° for line-of-sight diagnostics and flow visualization studies. This large oblong port also provides access into the interior of the spray chamber for equipment modifications. The measurement plane for the current study is illustrated in this figure where the negative values of X are on the transmitter window side of the chamber.

Atomizer

The atomizer used in this study, shown as Figure 4, was developed specifically as an air-assisted research atomizer by Parker Hannifin with a high degree of reproducibility for inter-laboratory comparison of data. Referred to as the Research Simplex Atomizer (RSA), liquid is passed through a small pressure atomizing orifice at a specified flowrate and then brought into contact with a concentric swirling air stream. The air stream is passed through a swirl vane insert and converged at a 45° angle towards the centerline of the liquid orifice. The liquid jet, partially atomized by the fuel orifice, is then contacted by the swirling nozzle air as both fluids exit the atomizer.

Exhaust System

The exhaust system consists of a line separator which removed entrained droplets to prevent damaging the exhaust valve and to store liquid that was not evaporated during the testing period. Finally, the system pressure is maintained with an electro-pneumatic exhaust control valve.

Diagnostic

The capabilities of the phase Doppler, and direct comparisons of phase Doppler (PD) to laser diffraction, have been addressed through previous studies at atmospheric pressure. As one example, McDonell, Wood, and Samuelsen (1986) used the instrument to characterize the spray field of a twin-fluid gas turbine atomizer for both non-reacting and reacting flow conditions. In addition to demonstrating the potential of phase Doppler in these complex two-phase flow environments, a direct comparison of phase Doppler to laser diffraction was established by transforming the temporal measurement of the phase Doppler into the spatial measurement of the laser diffraction, and integrating the PD results along the measurement path of the laser diffraction. The results were favorably comparable. Mao, Wang, and Chigier (1986) conducted as well a direct comparison of phase Doppler with laser diffraction.

The instrument used in the present study to obtain spatially resolved dropsize and velocity measurements was a single-component phase Doppler spray analyzer (Aerometrics Model 2100) in conjunction with a UCI Combustion Laboratory breadboarded transmitter system. The phase Doppler was operated with a 500 mm focal length transmitting and receiving lenses. A transmitting beam of 514.5 nm wavelength was produced from a Lexel 250 mW Ar Ion laser.
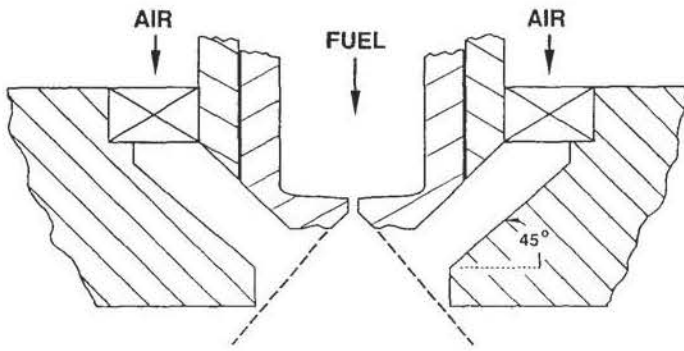
FIGURE 4: Research Simplex Atomizer Geometry and its Flow Paths.

The effects of increased air density and thick optical windows on phase Doppler measurements were assessed by determining the amount of beam stearing induced on a laser beam shining through the chamber windows onto a far wall. The amount of beam stearing was determined to be negligible.

Test Conditions

To maintain a constant U_R at constant ALR, the total mass flowrates of the liquid and air must be increased as the ambient pressure is increased due to the increasing density of the atomizing air. Thus, much of the data acquired to date and reported in the literature on the effects of ambient pressure on twin-fluid atomization have been obtained over a wide range of mass flowrates. This approach is well suited for the atomizers evaluated to date since their straightforward geometry and lack of swirling air allow for a relatively unambiguous determination of the relative velocity.

For the atomizer used in the present study, this approach is not suitable. In particular, the liquid emerges from the simplex liquid orifice in a hollow-cone liquid sheet (Figure 4) and subsequently encounters swirling atomizing air at an angle of approximately 45° relative to the centerline of the atomizer. As a result, the relative velocity between the two fluids is ambiguous. Thus, it was decided to maintain both the fuel and atomizing air flow rates constant at each of the three ambient pressure conditions considered. Experiments were conducted in this manner for two nozzle air flow rates (i.e., two air-to-liquid ratios).

The test conditions were selected from the standard test matrix developed for the RSA atomizer for interlaboratory testing and comparisons utilizing both the phase Doppler and laser diffraction instruments. The liquid selected is the standard for this matrix, Mil-C-7024 Type II calibration fluid. A baseline condition of this test matrix was chosen for one of the two test points, while a two-fold increase in atomizing air flow was selected as the second. These conditions correspond to a fuel flow rate of 0.616 g/s (4.88 lb/hr) and air flow rates of 0.605 g/s (4.79 lb/hr) and 1.29 g/s (10.22 lb/hr) producing ALR's of 0.98 and 2.09, respectively. Ambient pressures were selected to be 1, 3, and 6 atmospheres.
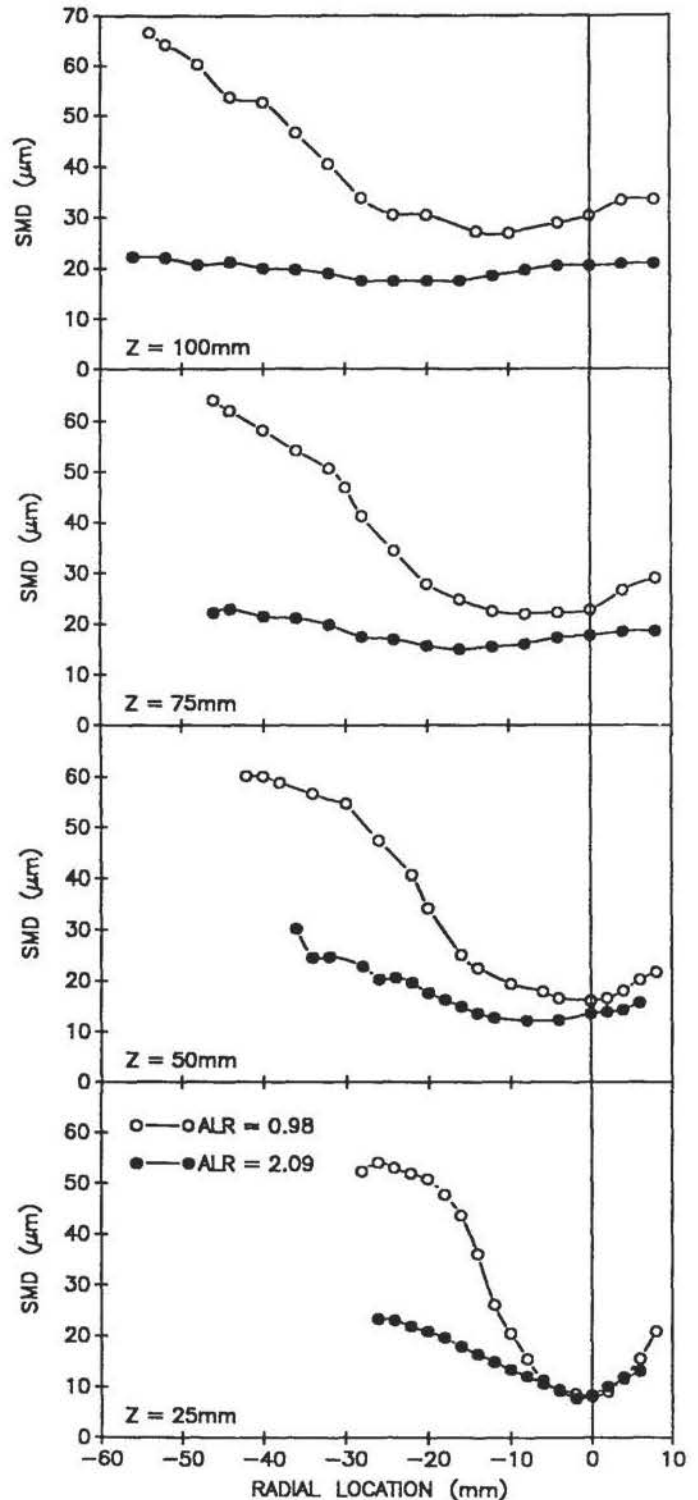

FIGURE 5 a) Local Variation in Droplet SMD at One Atmosphere.

4

FIGURE 5 b) Local Variation in Droplet Mean Axial Velocity at One Atomosphere.

At each of four axial locations downstream of the atomizer exit (25 mm, 50 mm, 75 mm, and 100 mm), radial profiles were acquired of droplet size and droplet velocity. The radial profiles included data from a few points beyond the centerline as a check on symmetry.

RESULTS AND DISCUSSION

Atmospheric Pressure

To establish the general structure of the spray, data are first presented for the atmospheric pressure condition. Characterization of the nozzle at atmospheric pressure produces a hollow-cone spray structure. This is shown in Figures 5a and 5b where both the droplet size (presented as Sauter mean diameter, SMD) and axial velocity of the droplets reveal a minimum at the aerodynamic centerline.

The results for the higher ALR case reveal the impact of the increased air momentum. First, the droplet SMD's are appreciably lower. Second, the axial velocities of the droplets are substantially higher, and the strong, off-center peak of the droplet velocity remains evident even at $Z = 100$ mm.

The structure of the spray at atmospheric pressure as established by phase Doppler interferometry in Figure 5 is consistent with the results obtained with another Research Simplex Atomizer by Mao, Wang, and Chigier (1986) with water and kerosine as the test liquids, and corresponds with the results obtained with a pressure swirl atomizer by Dodge, Rhodes, and Reitz (1987) using Mil-C-7024 Type II calibration fluid as the liquid.

Note that the data of Figure 5 show an asymmetry, albeit small, about the projection of the geometric centerline. Based on testing outside the chamber, the aerodynamic centerline of the spray is consistently found to be symmetrical about the geometric centerline. The displacement in the present case is associated with the challenge in assuring precise alignment of the atomizer in the relatively complex pressure vessel.

Elevated Ambient Pressure

An increase in ambient pressure from 1 to 6 atmospheres at constant ALR (Figures 6 and 7) reveals an appreciable increase in droplet SMD and a significant decrease in the droplet mean axial velocity. The effect of ambient pressure on the mean axial velocity is most prevalent for the low ALR case where the high droplet velocity core is essentially suppressed at the 6 atm ambient pressure.

These results are explained by considering the effect of increasing ambient pressure at constant nozzle air and liquid flowrates. In particular, an increase in ambient pressure increases the density of the atomizing air. As a result, the velocity of the atomizing air must decrease at constant air flow rate while the air density increases. The fuel velocity remains essentially unchanged due to its incompressibility. Thus, the relative velocity between the nozzle air and fuel decreases with increasing ambient pressure. The relative momentum ratio, representing a measure of the magnitude of the destructive force upon the liquid, decreases by the square of the velocity reduction. For the conditions of this study, both the atomization quality and the penetration strength of the droplets are degraded with increases in ambient pressure.
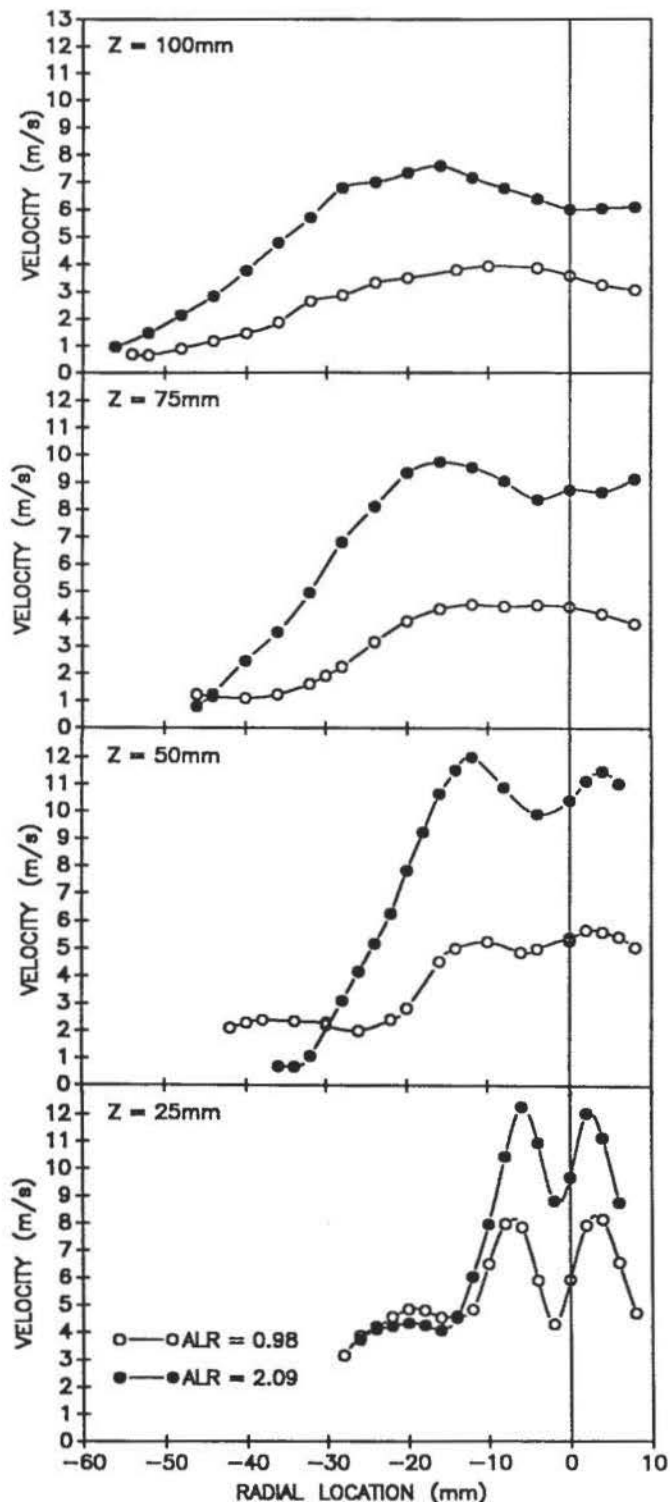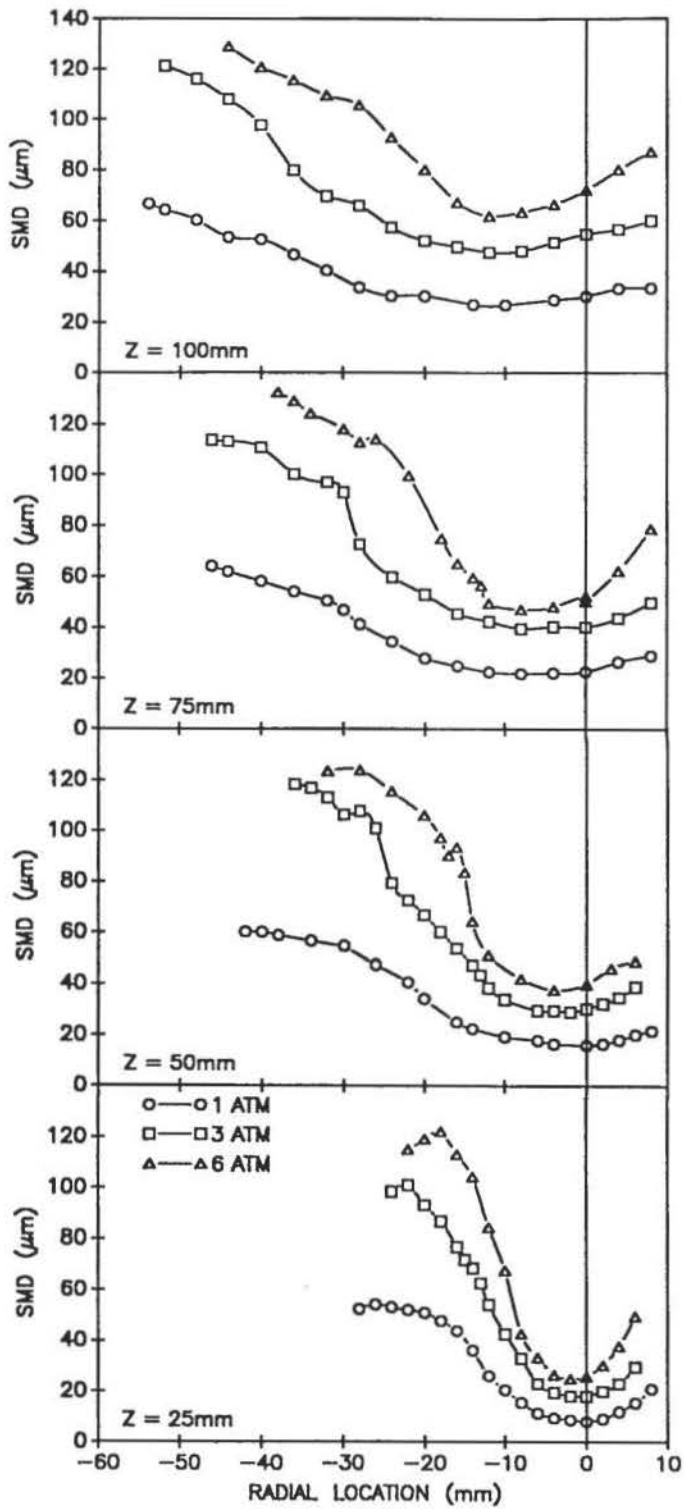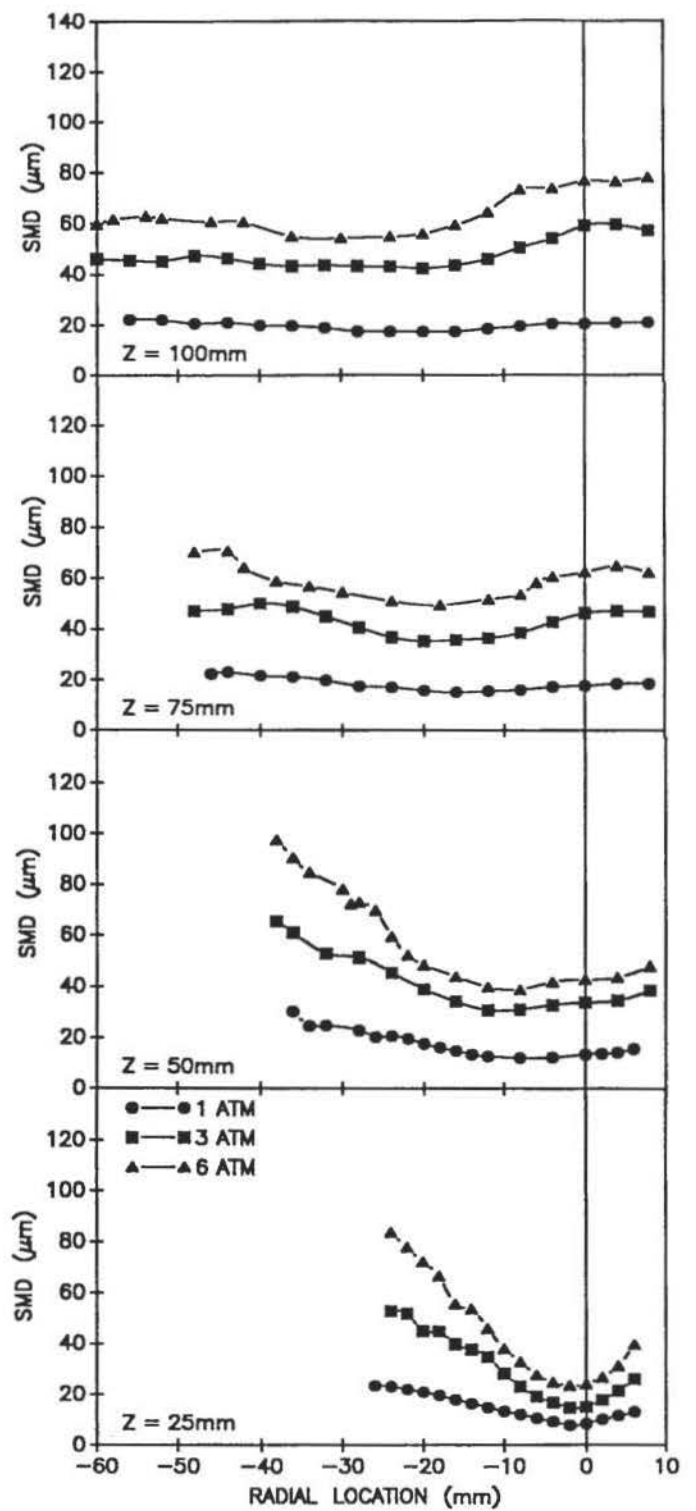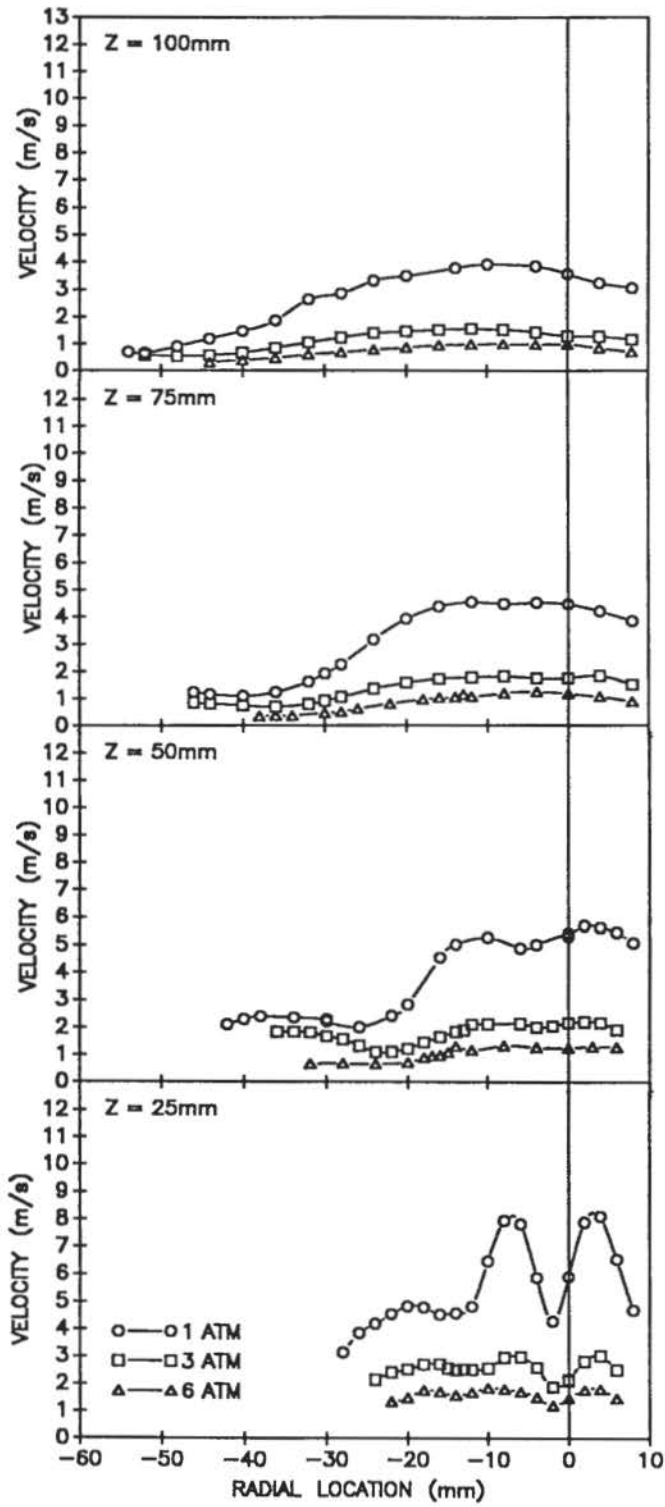
5

FIGURE 6: Effect of Ambient Pressure on Local Droplet SMD.
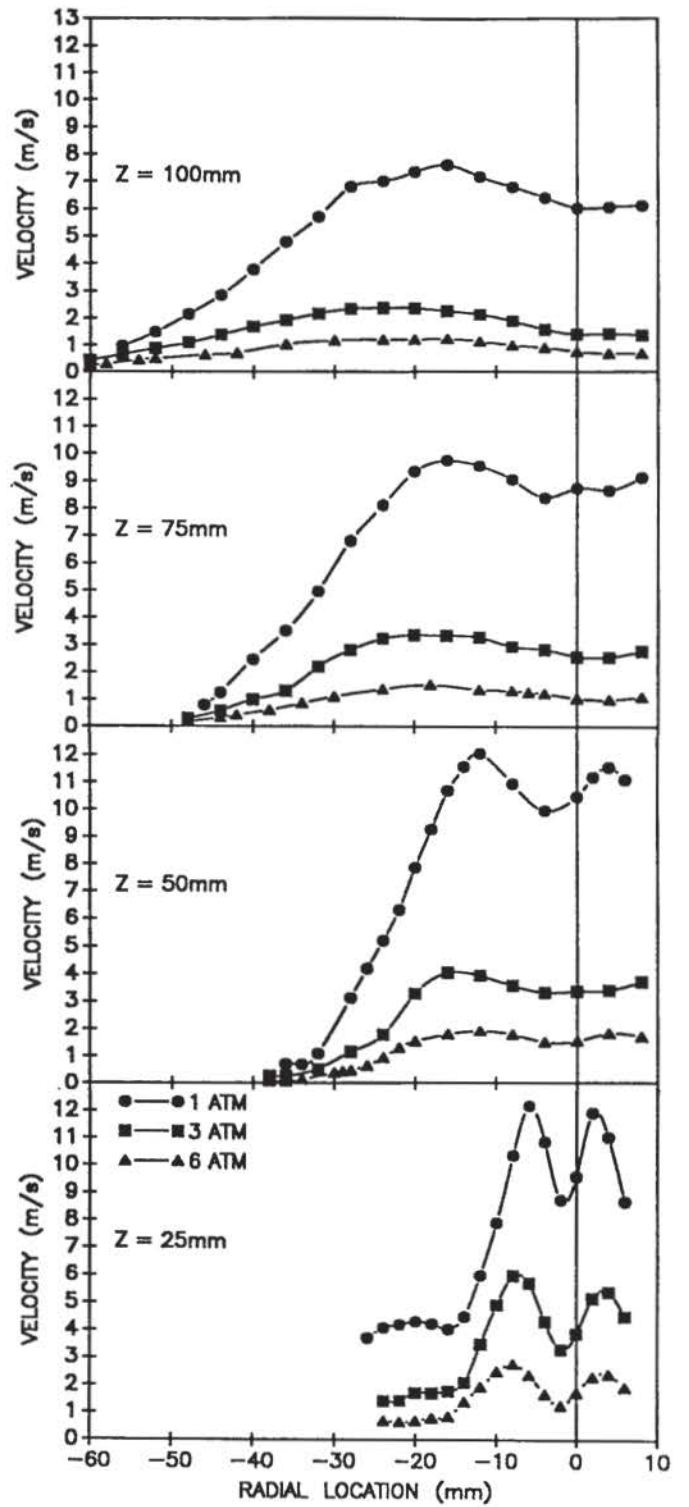
FIGURE 7: Effect of Ambient Pressure on Local Droplet
Mean Axial Velocity.

Results of others have shown an increase in atomization quality with increasing ambient pressure, just the reverse of the present study (Rizk and Lefebvre, 1984). However, the studies of Rizk and Lefebvre were conducted at constant ALR (the same as the present case) and constant U_R which differs from that of the present study. Hence, as the ambient pressure in this study was increased, the momentum ratio between the nozzle air and fuel decreased. As a consequence, the present results are consistent with the accord that atomization quality in a twin-fluid atomizer will generally be correlated to the momentum ratio of the two fluids.

CONCLUSION

A combination simplex/twin-fluid atomizer has been tested at the elevated pressures of 1, 3, and 6 atmospheres. It can be concluded that, for the twin-fluid Research Simplex Atomizer evaluated here, an increase in ambient pressure at constant fuel and air flow rates leads to a degradation in atomization quality and liquid penetration strength. This is consistent with the fact that an increase in atomizing air density decreases both atomizing air velocity and, as a result, the momentum ratio of atomizing air to liquid.

ACKNOWLEDGEMENTS

REFERENCES

Bachalo, W.D. and Houser, M.J., 1984, "Phase/Doppler Spray Analyzer for Simultaneous Measurements of Drop Size and Velocity Distributions," *Optical Engineering*, Vol. 23, No. 5, pp. 583-590.

Dodge, L.G. and Biaglow, J.A., 1986, "Effect of Elevated Temperature and Pressure on Sprays From Simplex Swirl Atomizers," *Journal of Engineering for Gas Turbines and Power*, Vol. 108, pp. 209-215.

Dodge, L.G., Rhodes, D.J., and Reitz, R.D., 1987, "Drop-Size Measurement Techniques for Sprays: Comparison of Malvern Laser-Diffraction and Aerometrics phase/Doppler," *Applied Optics*, Vol. 26, No. 11, pp. 2144-2154.

Lefebvre, A.H., 1989, *Atomization and Sprays*, Hemisphere Publishing Corp., New York.

Mao, C.-P., Wang, G., and Chigier, N., 1986, "The Structure of Air-assisted Swirl Atomizer Sprays," *Atomisation and Spray Technology*, Vol. 2, pp 151-169.

McDonell, V.G., Wood, C.P., and Samuelsen, G.S., 1986, "A Comparison of Spatially-Resolved Drop Size and Velocity Measurements in an Isothermal Chamber and a Swirl-Stabilized Combustor," *Twenty-first Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 685-694.

Rizk, N.K. and Lefebvre, A.H., 1983, "Influence of Atomizer Design Features on Mean Drop Size," AIAA *Journal*, Vol. 21, No. 8, pp. 1139-1142.

Rizk, N.K., and Lefebvre, A.H., 1984, "Spray Characteristics of Plain-Jet Airblast Atomizers," *Transactions of the ASME, Journal of Engineering for Gas Turbines and Power*, pp. 634-638.

Rizkalla, A.A. and Lefebvre, A.H., 1975, "The Influence of Air and Liquid Properties on Airblast Atomization," *Transactions of the ASME: Journal of Fluids Engineering*, pp. 316-320.

Wang, X.F. and Lefebvre, A.H., 1987, "Influence of Ambient Air Pressure on Pressure-Swirl Atomization," *Atomisation and Spray Technology*, Vol 3., pp. 209-226.

An American National Standard, 1987, "Measurement of Gas Flow by Means of Critical Flow Venturi Nozzles," ASME/ANSI MFC-7M, The American Society of Mechanical Engineers, New York.