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Atomization of Liquid Sheets in High Pressure Airflow

Robert D. Ingebo
Lewis Research Center
Cleveland, Ohio

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ATOMIZATION OF LIQUID SHEETS IN HIGH PRESSURE AIRFLOW

Robert D. Ingebo
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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ABSTRACT

An investigation of liquid sheet atomization was made with combustor simulated inlet-air pressures varied from 0.10 to 2.1 MPa. Mean drop diameters were measured with an improved scanning radiometer and correlated with the liquid and airstream Reynolds numbers, Re_l and Re_a, and the airstream pressure sensitive group $gl/\bar{c}^2$. The reciprocal mean drop diameter, D_m^{-1}, produced for liquid sheet breakup with splash plate fuel injectors, may be expressed as:

$$D_m^{-1} = 2.8\times10^{-2}\ V_\ell P_a^{-0.33} + 13\ \rho_a V_a P_a^{-0.75}$$

which may be rewritten in terms of dimensionless groups as follows:

$$D_o/D_m = 2.05\ Re_\ell\ (gl/\bar{c}^2)^{0.33} + 1.2\times10^6\ Re_a\ (gl/\bar{c}^2)^{0.75}$$

where D_o is orifice diameter and it is assumed that $D_m \sim D_{32}$ (SMD), $Re = D_oV_\ell/\nu_a$, V_ℓ and V_a are liquid and airstream velocity, respectively, g is the acceleration due to gravity, l is mean free path which varies inversely with airstream pressure, and $\bar{c}$ is root-mean-square velocity of air molecules. For the atomization of swirling liquid sheets produced by pressure-atomizing simplex fuel nozzles, it was found that:

$$D_{m,a'}^{-1} = 13\ \rho_a V_a P_a^{-0.75}$$

and in terms of dimensionless groups:

$$D_o/D_{m,a'} = 1.14\times10^6\ Re_a\ (gl/\bar{c}^2)^{0.75}$$

where $D_{m,a'}$ is the mean drop diameter for aerodynamic breakup at values of $Re_a > 7500$.

NOMENCLATURE

$\bar{c}$	root-mean-square molecular velocity, cm/sec
D	diameter, cm
D_{32}	Sauter mean diameter, $\sum nD^3/\sum nD^2$, cm
g	acceleration due to gravity, 980 cm/sec^2
l	mean free molecular path, cm
M	molecular weight
n	number of molecules per unit volume
P	static pressure, MPa
R	universal gas constant, 8.31×10^7 ergs/(K)(mole)
Re	Reynolds number based on orifice diameter, D_oV/ν
V	velocity, cm/sec
w	exponent
x	exponent
ν	kinematic viscosity, cm^2/sec
ρ	density/ g/cm^3

Subscripts:

a'	aerodynamic
a	airstream
g	gas molecule
ℓ	liquid
m	mean
o	orifice

INTRODUCTION

An experimental investigation of the interaction of aerodynamic, hydrodynamic and liquid surface forces and their combined effect on the atomization of swirling and nonswirling sheets of water was conducted in high velocity and high pressure airflows similar to those encountered in the primary zone of gas turbine combustors. Mean drop diameter data for the sprays were obtained with an improved scanning radiometer recently developed at NASA Lewis Research Center. Such data are needed in analytical modeling of the combustion process, in demonstrating the importance of mean drop size on combustor performance and exhaust emissions and in extending our knowledge of liquid atomization into the regime of aerodynamic breakup in high pressure airflow.

In a previous investigation of the atomization of liquid jets (1) it was found that the mean drop diameter, D_m, varied inversely with airstream pressure raised to the 0.25 power, i.e., $D_m \sim P_a^{-0.25}$. As a result of the liquid jet study, the present investigation was undertaken to extend the knowledge of liquid sheet breakup from atmospheric to high pressure airflow conditions and compare the results with those obtained in liquid jet breakup studies. In (2), the atomization of liquid sheets in airflows at atmospheric pressure was investigated and mean drop diameter data were obtained and correlated with the liquid and airstream Reynolds numbers, Re_ℓ and Re_a, respectively. Liquid sheet breakup, with splash type fuel injectors and atmospheric pressure airflow, gave the following correlation of the ratio of orifice to mean drop diameter, D_o/D_m, with liquid and airstream Reynolds numbers: $D_o/D_m = 2.8 \times 10^{-4}\, Re_\ell + 2.4 \times 10^{-3}\, Re_a$ for hydrodynamic and aerodynamic breakup of a liquid sheet injected normal to the airflow.

Relationships involving liquid Reynolds numbers for hydrodynamic breakup and airstream Reynolds numbers for aerodynamic-wave breakup were investigated. The aerodynamic-wave breakup regime received the main emphasis in this study since high velocity airstreams are very important in simulating fuel atomization in gas turbine combustors operating at idle, take-off or cruise conditions. Thus, water sheets produced by splash plate and pressure-atomizing fuel nozzles were injected in axial airflows and mean drop diameters of the sprays were measured with an improved scanning radiometer that gave a high signal to noise ratio which is a very important requirement in the study of sprays in highly turbulent airflows. Combustor inlet-air static pressure was varied from 0.1 to 2.1 MPa over a range of airflow rates per unit area of 10 to 177 g/cm^2-sec, at 293 K. Two splash plate fuel injectors having orifice diameters of 0.1016 and 0.216 cm, respectively, were operated at a liquid flow rate of 68 l/hr. Pressure-atomizing fuel nozzle orifice diameters varied from 0.090 to 0.130 cm and operated at liquid flow rates of 27 and 68 l/hr, respectively. Mean drop diameter data were correlated with liquid and airstream Reynolds numbers and with the dimensionless group $gl/\bar{c}^2$, which is a molecular-scale momentum-transfer ratio that varies inversely with airstream pressure. This ratio is useful in deriving empirical relationships that predict the mean drop size of sprays produced by liquid sheet breakup in high pressure airflow.

APPARATUS AND PROCEDURE

The closed-duct high pressure test facility in which the test section was mounted is shown in Figs. 1 and 2. The test section shown in Fig. 3 has two 5.1-cm-diam windows passing the laser light beam through the spray formed in the high pressure and high velocity airflow. Airflow was drawn from the laboratory supply system at ambient temperature, 293 K, and exhausted into the altitude exhaust system to obtain drop size data at low airstream pressure and into the atmosphere for high pressure airflow test conditions. The airflow control valve was opened until the desired airflow rate per unit area was obtained. The bellmouth inlet to the high pressure test section, also shown in Fig. 3, has a total length of 15.2 cm, an inside diameter of 7.6 cm and is mounted inside of a duct that is 2.1 m in length with an inside diameter of 15.2 cm.

Water sheets were produced at the duct center line and directed axially downstream with the fuel injectors shown in Figs. 4(a) and (b). The splash plate fuel injector produced a liquid sheet injected radially or normal to the airflow. The conventional pressure-atomizing simplex fuel nozzle produced a swirling hollow-cone sheet with a cone-angle of 45° in quiescent air, i.e., no airflow in the duct. The water sheets, at 293 K as determined with an I.C. thermocouple, were formed by gradually opening a water flow control valve until the desired water flow rate over a range of 27 to 68 l/hr was obtained as measured with a turbine flow meter.

After water and airflow rates were set, mean drop diameter data were obtained with the scanning radiometer mounted 25.4 cm downstream of the fuel injector. The scanning radiometer optical system shown in Fig. 3 consisted of a 1-mW helium-neon laser, a 0.003-cm-diameter aperture, a 7.5-cm-diameter collimating lens, a 10-cm-diameter converging lens, a 5-cm-diameter collecting lens, a scanning or rotating disk with a 0.05-cm-diameter hole, a timing light, and a photomultiplier detector. A more complete description of the improved scanning radiometer and the method of determining mean particle size are discussed in (3) and (4).

EXPERIMENTAL RESULTS

To obtain a better technical understanding of atomization in the realm of aerodynamic-wave breakup of liquid sheets in high pressure airflow and thereby advance fuel injector technology for gas turbine applications, mean drop diameter data were obtained with an improved NASA scanning radiometer. Water sheets produced with splash plate fuel injectors and pressure-atomizing simplex fuel nozzles were injected axially downstream under simulated high pressure combustor inlet airflow conditions.

Splash Plate Fuel Injectors

For water sheets produced by splash plate fuel injectors and injected radially in high velocity airflow, mean drop size D_m was measured at inlet-air pressures ranging from 0.10 to 2.10 MPa, and plotted against airstream velocity as shown in Fig. 5. The ratio of orifice to mean drop diameter, D_o/D_m, is plotted against mass velocity, $\rho_a V_a$, for the 0.1016 and 0.216 cm-diameter splash plate fuel injectors as shown in Figs. 6 and 7, respectively. From these plots, the general expression for a splash plate type of sheet breakup may be written as a linear relationship:

$$D_o/D_m = D_o/D_{m,h} + D_o/D_{m,a}, \qquad (1)$$

where D_m is the measured mean drop diameter, $D_{m,h}$ is the hydrodynamic mean drop diameter obtained for quiescent air, $\rho_a V_a = 0$, and $D_{m,a}$ is the mean drop diameter for aerodynamic-wave breakup.

For hydrodynamic breakup of liquid sheets in "still" air, $\rho_a V_a = 0$, the following expression may be written: $D_o/D_{m,h} \sim Re_\ell$. In (2), it was found that:

$$D_o/D_{m,h} = 2.8 \times 10^{-4}\, Re_\ell \qquad (2)$$

for liquid sheet breakup in "still" air at atmospheric pressure, 0.10 MPa. To extend this expression to include high pressure "still" air, it is assumed that

$D_o/D_{m,h}$ is also a function of the dimensionless group $gl/\bar{c}^2$ which was used in (1) to correlate combustor inlet-air pressure with mean drop sizes produced by liquid jet atomization in high pressure airstreams. Thus, from the slope of the two plots shown in Fig. 8, it is evident that $D_o/D_{m,h} \sim (gl/\bar{c}^2)^{0.33}$. Therefore, Eq. (2) as derived in (2) can be rewritten as: $D_m^{-1} = 2.8\times10^{-2}\, V_\ell P_a^{-0.33}$ or as follows:

$$D_o/D_{m,h} = 2.05\, Re_\ell\, (gl/\bar{c}^2)^{0.33} \qquad (3)$$

for hydrodynamic breakup in "still" air at pressures of 0.10 to 2.1 MPa. Since $gl/\bar{c}^2 \sim P_a^{-1}$, Eq. (3) shows that $D_{m,h} \sim P_a^{0.33}$, i.e., hydrodynamic mean drop diameter varies directly with air pressure raised to the 0.33 power. This may be attributed to the fact that penetration of a sheet in high pressure air is poor as compared to penetration in low pressure air. As a result, the mean drop size is increased when air pressure is increased. This is an interesting result obtained for hydrodynamic breakup since, as will be shown below, the effect of air pressure on mean drop size is just the opposite in the case of aerodynamic breakup.

For aerodynamic breakup of liquid sheets in high velocity and high pressure airflow, it is shown in Figs. 6 and 7 that $D_o/D_{m,a'} \sim \rho_a V_a$ which agrees with the expression:

$$D_o/D_{m,a'} = 2.4\times10^{-3}\, Re_a \qquad (4)$$

that was derived in (2) for aerodynamic breakup of liquid sheets in atmospheric pressure, 0.10 MPa, airflow. To extend this expression to include high pressure airflow, values of $k = (D_o/\rho_a V_a)\,(D_m^{-1} - D_{m,h}^{-1})$ obtained from the slopes of the plots in Figs. 6 and 7 are plotted against $gl/\bar{c}^2$ in Fig. 9. From this plot, the general expression for aerodynamic breakup of liquid sheets may be written as:

$$D_{m,a'} = 13\, \rho_a V_a P_a^{-0.75} \qquad (5a)$$

or as follows:

$$D_o/D_{m,a'} = 1.2\times10^6\, Re_a\, (gl/\bar{c}^2)^{0.75} \qquad (5b)$$

for an airstream pressure range of 0.10 to 2.1 MPa. By substituting Eqs. (3) and (5) into Eq. (1), the following overall expressions are obtained:

$$D_m^{-1} = 2.8\times10^{-2}\, V_\ell P_a^{-0.33} + \rho_a V_a P_a^{-0.75} \qquad (6a)$$

or:

$$D_o/D_m = 2.1\, Re_p\, (gl/\bar{c}^2)^{0.33} + 1.2\times10^6\, Re_a\, (gl/\bar{c}^2)^{0.75} \qquad (6b)$$

for the breakup of liquid sheets produced with splash plate fuel injectors, over a mass velocity, $\rho_a V_a$, range of zero to 155 g/cm^2-sec and an inlet-air pressure range of 0.10 to 2.1 MPa. Thus, since $Re_a \sim P_a$ and $gl/\bar{c}^2 \sim P_a^{-1}$, the effect of P_a on $D_{m,a'}$ may be expressed in $D_{m,a'} \sim P_a^{-0.25}$. This shows that P_a has the opposite effect on aerodynamic as compared with hydrodynamic breakup, where $D_{m,h} \sim P_a^{0.33}$.

<u>Pressure-Atomizing Fuel Nozzles</u>

Swirling hollow-cone sheets of water produced by 45° cone-angle fuel nozzles were injected axially downstream in high velocity airflow with inlet-air pressures of 0.1 to 2.1 MPa. The effect of airstream velocity on the reciprocal mean drop diameter, D_m^{-1}, is shown in Fig. 10. The ratio D_o/D_m is plotted against mass velocity, $\rho_a V_a$, for fuel nozzles having orifice diameters of 0.090 and 0.130 cm, respectively, as shown in Figs. 11 and 12. The effect of $\rho_a V_a$ on D_m is similar to that obtained for the splash plate fuel injectors.

The two plots shown in Fig. 13 were obtained previously in (2) and demonstrate three breakup conditions. Initially, for the case of "still" air, only hydrodynamic breakup occurs since $\rho_a V_a = 0$. In the transition region of $\rho_a V_a$ varying from 0 to 15 g/cm^2-sec, both aerodynamic and hydrodynamic breakup occur. However, with $\rho_a V_a > 15$ g/cm^2-sec the aerodynamic force of the airstream controls the breakup process. This is the region of primary interest for this study and other investigations concerning liquid fuel atomization and combustion in gas turbine combustors. Thus, for the condition $\rho_a V_a > 15$ g/cm^2-sec, calculated values of $D_o/\rho_a V_a D_{m,a'}$ which were obtained from the slopes of the plots in Figs. 11 and 12, are plotted against the dimensionless group $gl/\bar{c}^2$ as shown in Fig. 14. From this plot, the following empirical expressions for swirling hollow-cone sheet breakup are derived:

$$D_{m,a'}^{-1} = 13\, \rho_a V_a P_a^{-0.75} \qquad (7a)$$

$$D_o/D_{m,a'} = 1.14\times10^6\, Re_a\, (gl/\bar{c}^2)^{0.75} \qquad (7b)$$

for aerodynamic-wave breakup, i.e., $D_m = D_{m,a'}$. From Eq. (7a) it is evident that the effect of inlet-air pressure on mean drop size may be expressed as $D_{m,a'} \sim P_a^{-0.25}$. This is the same effect of airstream pressure on mean drop size that was found in Eq. (5a) for sheet breakup with splash plate fuel injectors. Also, liquid jet breakup previously studied in (1) gave the same effect of airstream pressure on mean drop size as was obtained in this study of liquid sheet breakup.

In comparison of Eqs. (6a) and (6b) for splash plate fuel injectors with Eqs. (7a) and (7b) for pressure-atomizing fuel nozzles, expressions for $D_{m,a'}$ were approximately the same. However, hydrodynamic breakup appeared to have a significant effect on mean drop size $D_{m,h}$ in the case of splash plate type of breakup whereas it appeared to have negligible effect on breakup with the pressure atomizing fuel nozzles. This was attributed to the fact that liquid sheets were injected at 90° or normal to the airflow using the splash plate technique whereas in the case of pressure-atomizing nozzles swirling liquid sheets were injected downstream with a cone-angle of 45°.

The effect of gas properties and orifice diameter on the reciprocal mean drop diameter, D_m^{-1}, are shown in Table I for aerodynamic-wave breakup of liquid sheets and jets. Exponents for airstream velocity, V_a, orifice diameter, D_o, and airstream pressure, P_a, that were derived in this study are compared with values obtained by previous investigators (5-9). The exponents agree fairly well and there appears to be very little difference in exponents obtained for liquid sheet and liquid jet breakup in the aerodynamic-wave breakup regime.

SUMMARY OF RESULTS

Empirical correlations of reciprocal mean drop diameter with dimensionless group or force ratios were derived for the aerodynamic-wave breakup of nonswirling and swirling liquid sheets injected axially in high velocity airflow. A newly developed scanning radiometer was used to obtain atomization data with simulated combustor inlet-air pressures ranging from 1 to 21 atmospheres and an airstream mass velocity, $\rho_a V_a$, range of 10 to 177 g/cm^2-sec, at 293 K. The results of this investigation are as follows:

(1) With nonswirling liquid sheets produced by splash plate fuel injectors, the ratio of orifice to mean drop diameter, $D_o/D_{m,h}$ was correlated with the liquid flow Reynolds number, Re_1, and the molecular scale pressure sensitive group $gl/\bar{c}^2$, to give the expression: $D_o/D_{m,h} = 2.05\ Re_1\ (gl/\bar{c}^2)^{0.33}$ for hydrodynamic breakup in "still" air, i.e., $\rho_a V_a = 0$. Similarly, $D_o/D_{m,a'}$ was correlated with the airstream Reynolds number, Re_a, and $gl/\bar{c}^2$ to give the expression: $D_o/D_{m,a'} = 1.2\text{x}10^6\ Re_a\ (gl/\bar{c}^2)^{0.75}$ for aerodynamic-wave breakup in high pressure and high velocity airflow. Since $D_o/D_m = D_{m,h} + D_{m,a'}$ the following general expression for nonswirling liquid sheet breakup was obtained:

$$D_o/D_m = 2.05\ Re_1\ (gl/\bar{c}^2)^{0.33} + 1.2\text{x}10^6\ Re_a\ (gl/\bar{c}^2)^{0.75}$$

(2) With swirling liquid sheets produced by pressure-atomizing fuel nozzles, the ratio $D_o/D_{m,a}$ was correlated with airstream Reynolds number, Re_a, and the dimensionless group $gl/\bar{c}^2$ to give the expression for aerodynamic-wave breakup as follows:

$$D_o/D_{m,a'} = 1.14\text{x}10^6\ Re_a\ (gl/\bar{c}^2)^{0.75}$$

for values of $\rho_a V_a > 15$ g/cm^2-sec or $Re_a > 7500$. Aerodynamic forces appeared to control the breakup process whereas hydrodynamic forces showed negligible effect on atomization of the swirling hollow-cone sheets.

APPENDIX

Calculation of Molecular-Scale Momentum-Transfer Group, $gl/\bar{c}^2$

The mean free molecular path l may be expressed as:

$$l = 1/\sqrt{2}\ nD_g^2 = 6.11\text{x}10^{-6}\text{ cm}$$

since the number of molecules per unit volume n is $2.7\text{x}10^{19}$ at a temperature of 0° C and a pressure of 1 atmosphere and the diameter of an air molecule, D_a, is $3.7\text{x}10^{-8}$ cm.

The root-mean-square molecular velocity c may be expressed as $c = (3RT/M)^{0.5}$ which yields:

$$\bar{c}^2 = \frac{(3)(8.31\text{x}10^7)(273)}{(29)} = 2.35\text{x}10^9\ (\text{cm/sec})^2$$

Since g is 980 cm/sec:

$$gl/\bar{c}^2 = \frac{(980)(6.11\text{x}10^{-6})}{(2.35\text{x}10^9)} = 2.55\text{x}10^{-12}$$

For more detailed information concerning the derivation of the dimensionless group gl/c^{-2} and its effect on the heat transfer coefficient and vaporization rate of liquid drops in gas streams, see (10). Air, helium, aragon, and carbon dioxide gas streams were used at pressures of 0.059 to 0.197 MPa and temperatures of 286 to 366 K.

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TABLE I. - EXPERIMENTALLY DETERMINED EXPONENTS OF PROPERTIES PROPORTIONAL TO RECIPROCAL MEAN DROP DIAMETER, D_m^{-1}, FOR AERODYNAMIC-WAVE BREAKUP OF LIQUID SHEETS AND JETS

Sources for exponents	Airstream velocity, V_a, cm/sec	Orifice diameter, D_o, cm	Airstream pressure, P_a, MPa
Experimental (Eqs. (5a) and (7a))	1.0	0	0.25
Ingebo (1)	1.2	.2	.25
Nukiyama and Tanasawa (5)	1.0	0	0
Weiss and Worsham (6)	1.33	- .16	([a])
Kim and Marshall (7)	1.14	0	.57
Wolfe and Andersen (8)	1.33	[b]- .17	.67
Lorenzetto and Lefebvre (9)	1.0	0	.30

[a]Used variable $1 + \rho_a/\rho_\ell$.
[b]Exponent for initial drop diameter instead of orifice diameter.

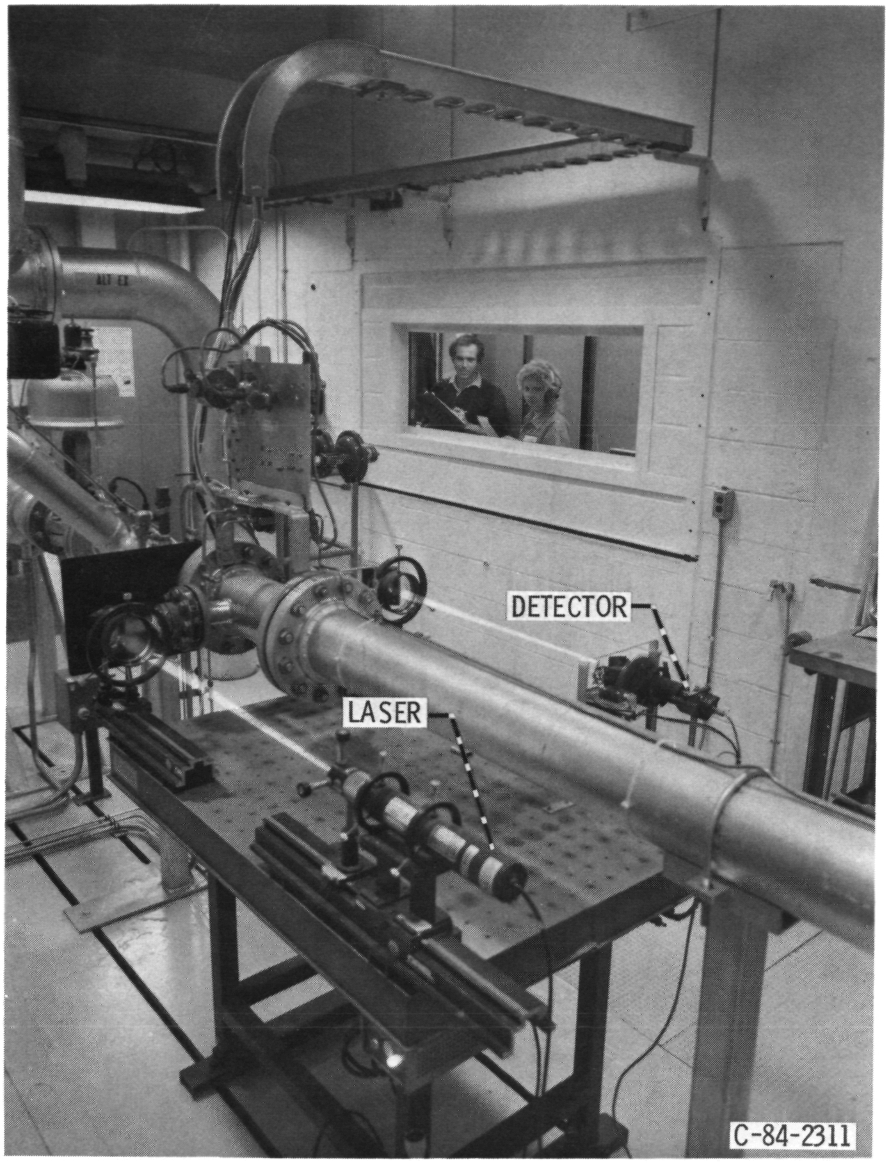


Figure 1. - Apparatus and auxilliary equipment.

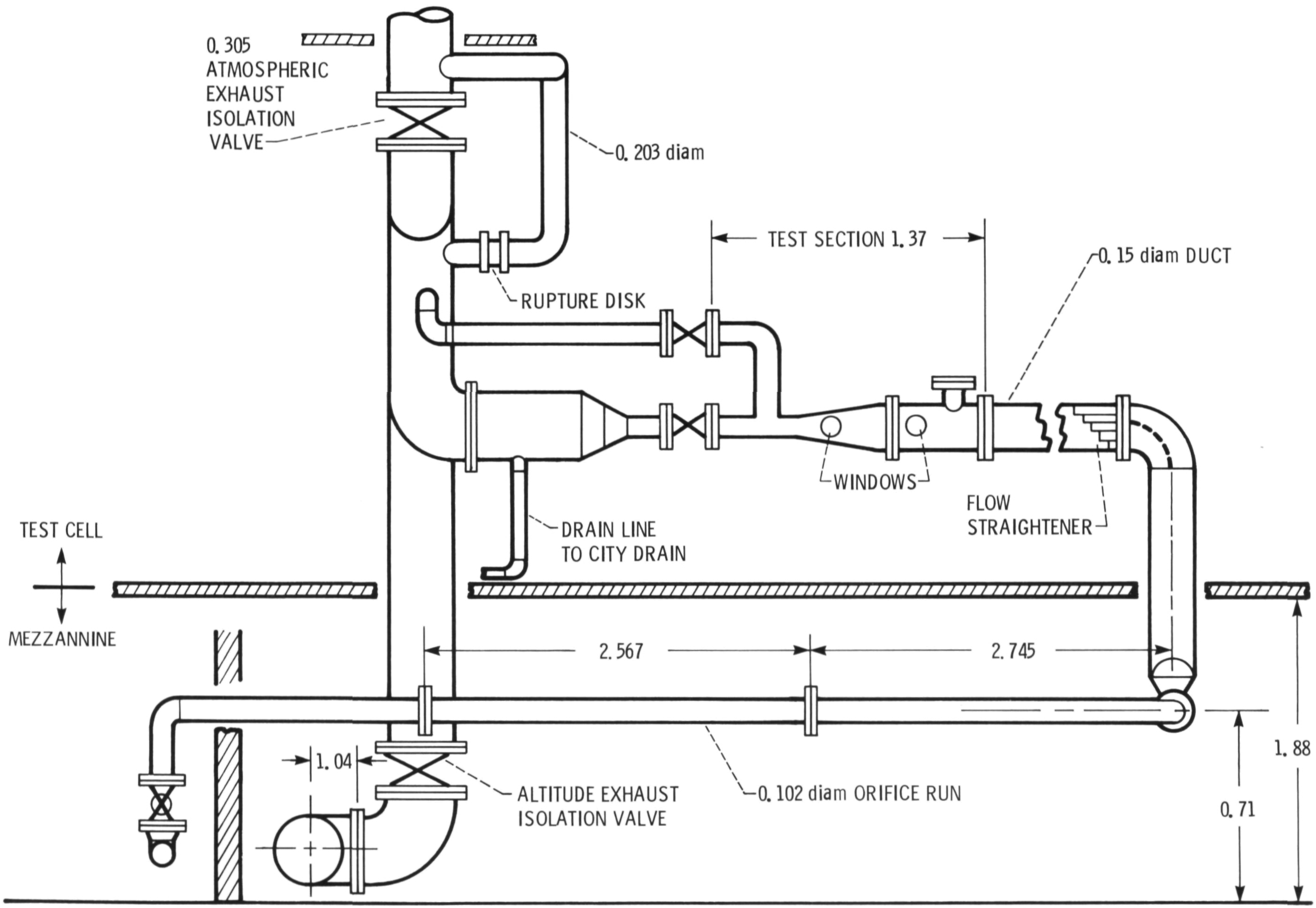


Figure 2. - Test facility and auxiliary equipment. (Dimensions are in meters.)

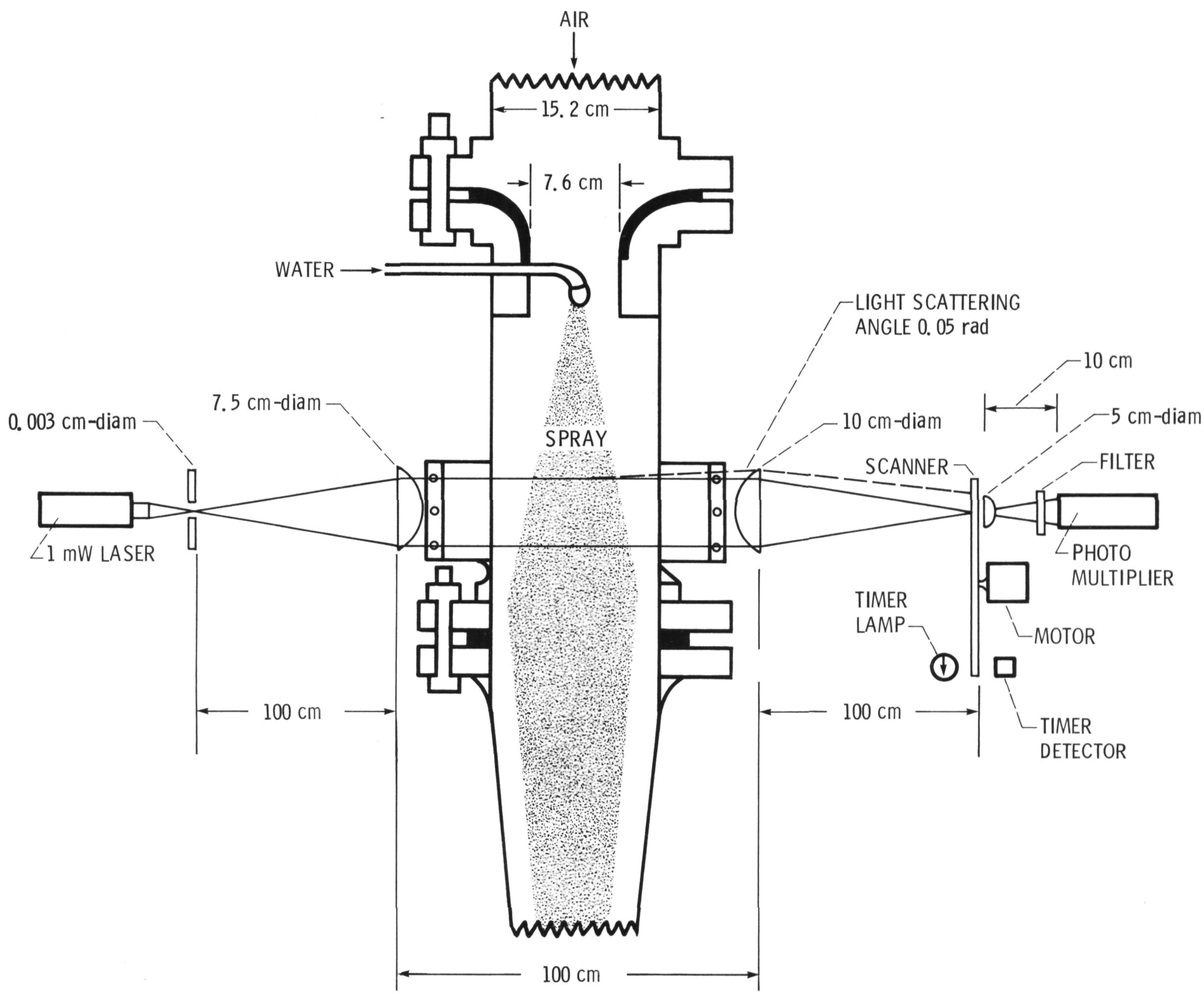
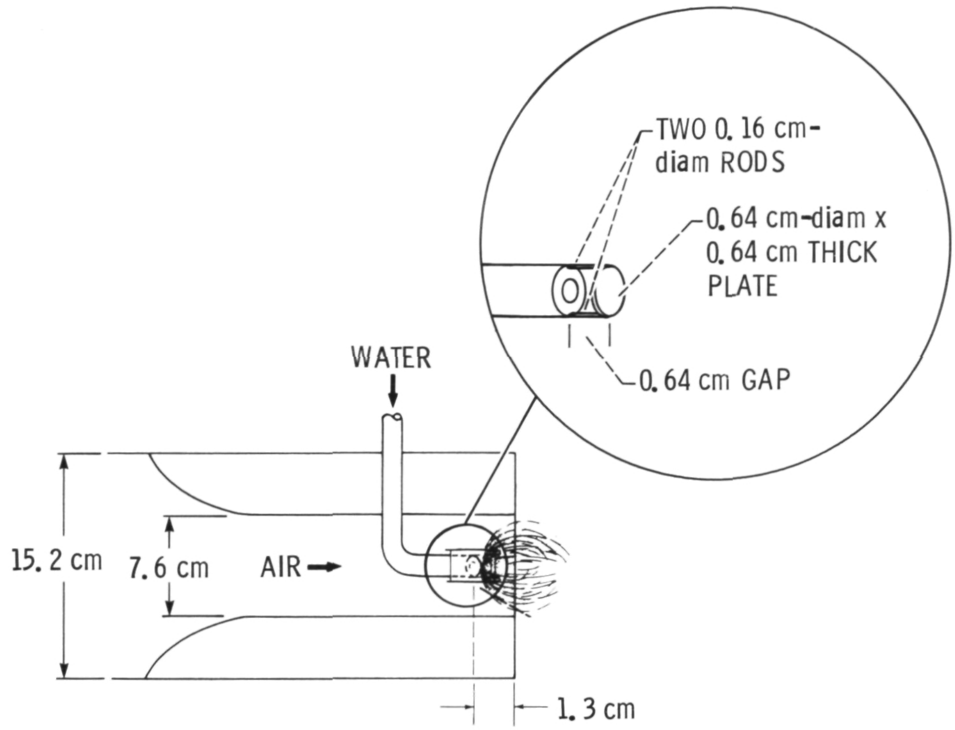
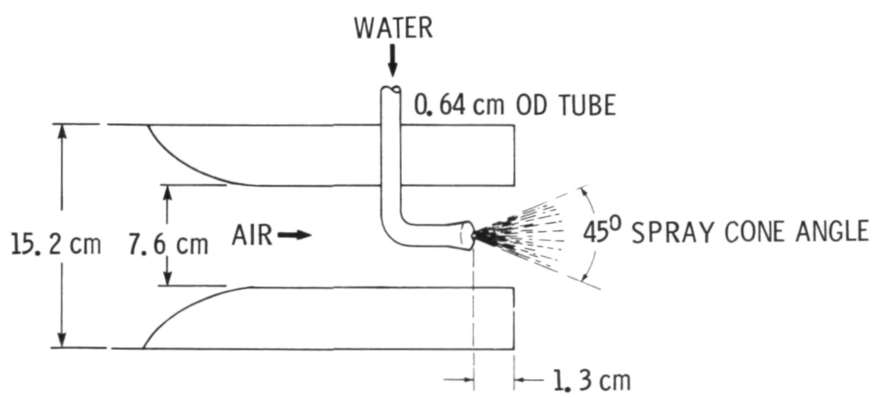


Figure 3. - High pressure test section and scanning radiometer optical path.

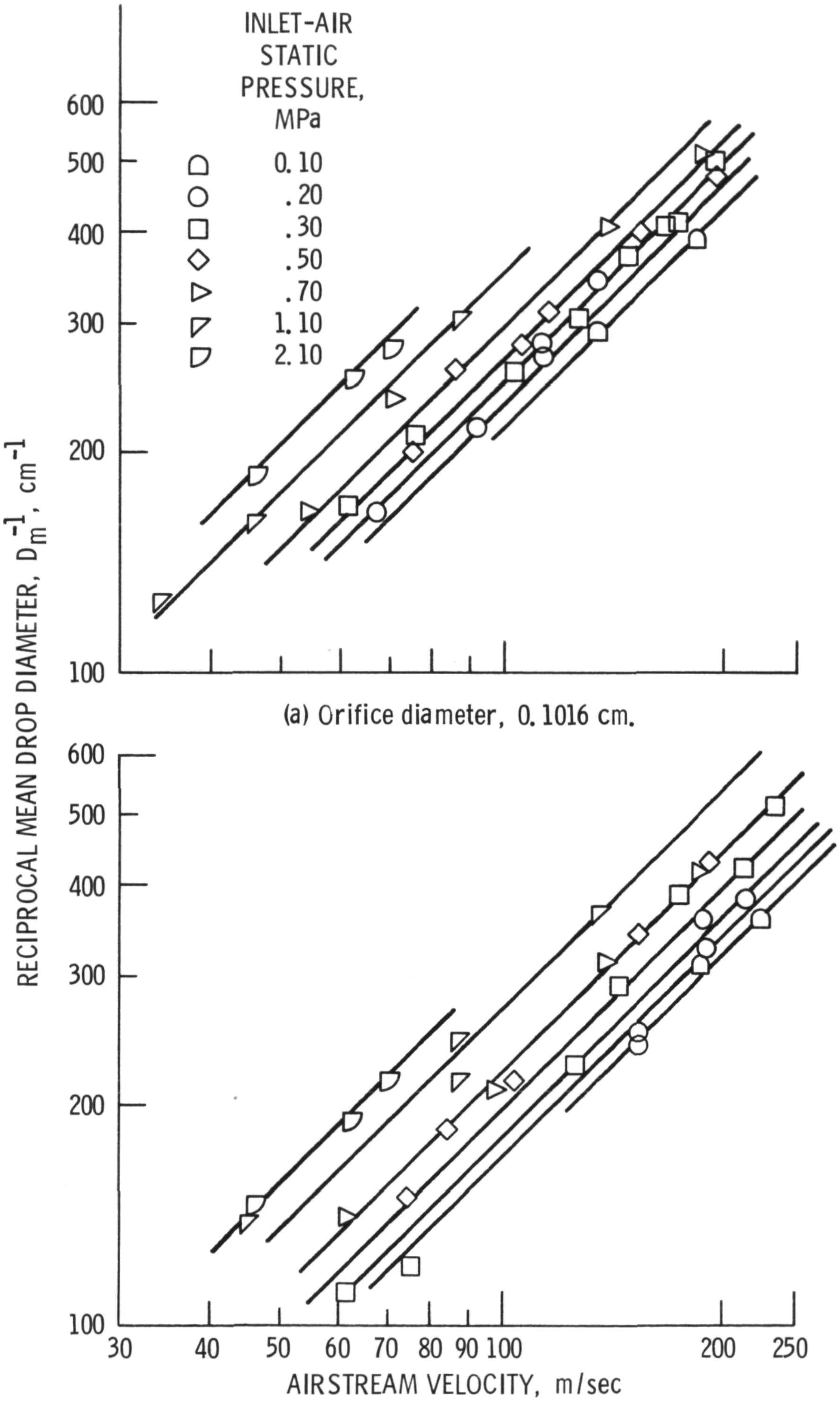


(a) Splash plate with radially injected flat spray.



(b) Simplex pressure atomizing nozzle with axially injected swirling hollow-cone spray.

Figure 4. - Liquid sheet fuel injectors.



(a) Orifice diameter, 0.1016 cm.

(b) Orifice diameter, 0.216 cm.

Figure 5. - Variation of reciprocal mean drop diameter, D_m^{-1}, with airstream velocity, V_a, for splash plate fuel injectors. $D_m^{-1} \sim V_a^{1.0}$.

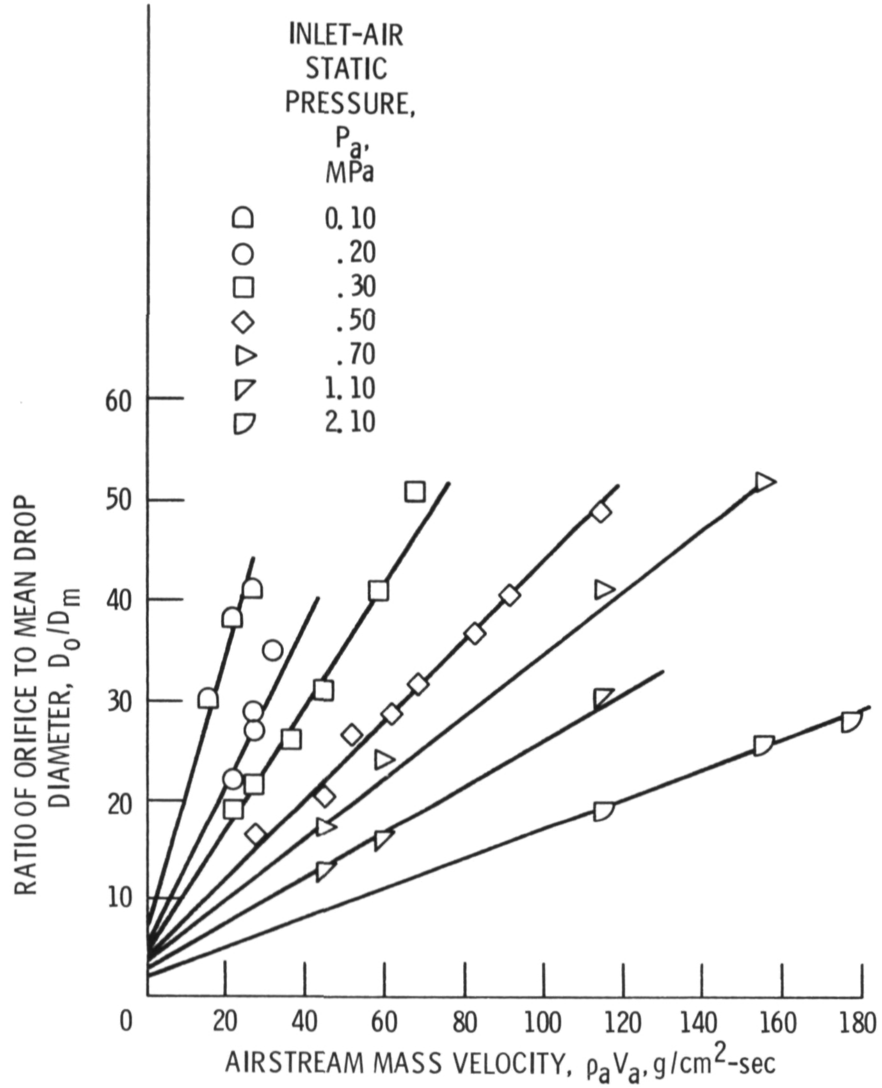


Figure 6. - Variation of orifice to mean diameter ratio, D_o/D_m, with airstream mass velocity, $\rho_a V_a$, for splash plate injector with D_o = 0.1016 cm. $(D_o/D_m - D_o/D_{m,h}) \sim (\rho_a V_a)^{1.0} P_a^w$.

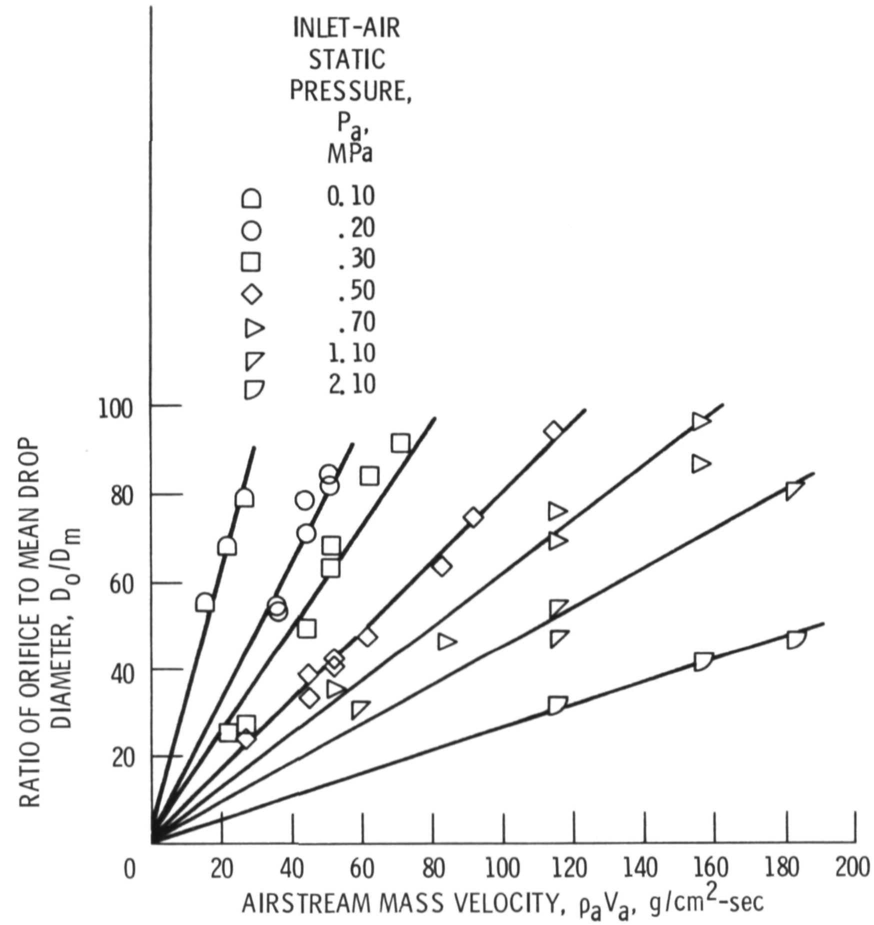
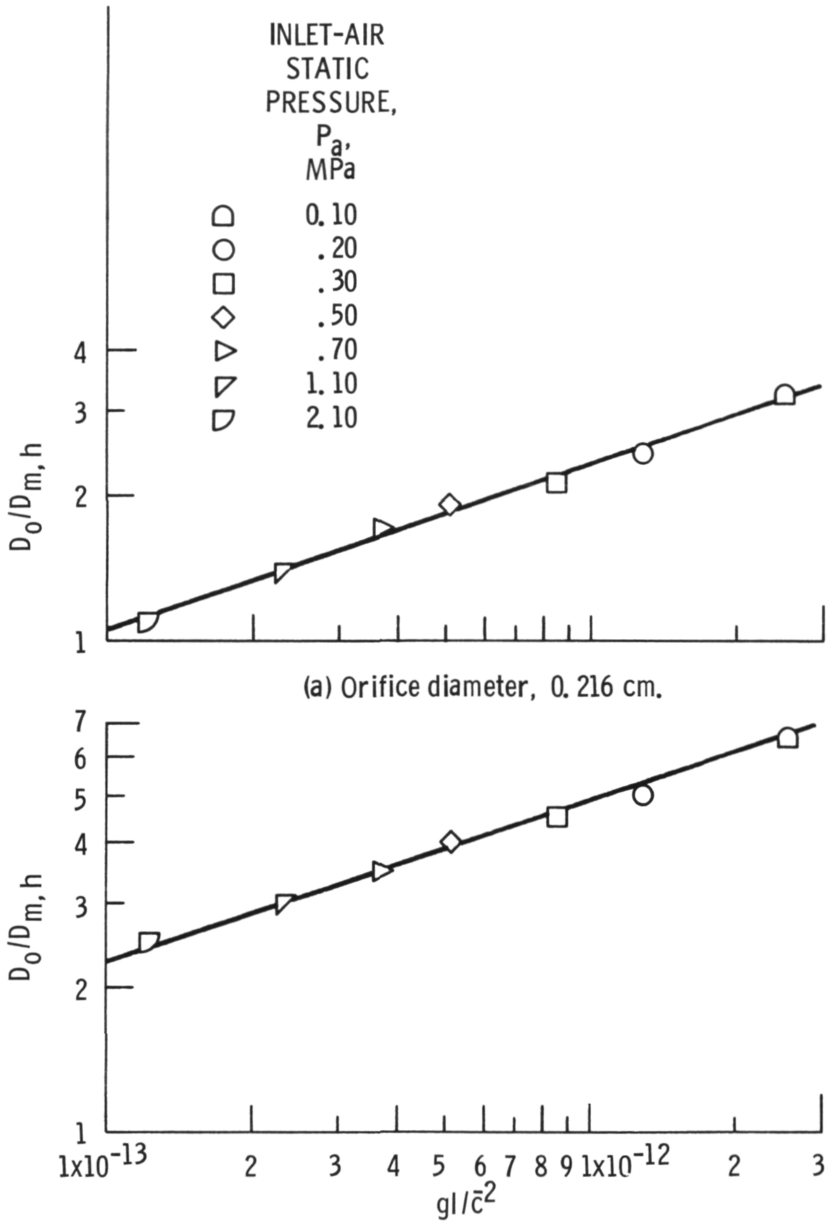


Figure 7. - Variation of orifice to mean drop diameter ratio, D_o/D_m, with airstream mass velocity, $\rho_a V_a$, for splash plate fuel injector with D_o = 0.216 cm. $(D_o/D_m - D_o/D_{m,h}) \sim (\rho_a V_a)^{1.0} P_a^w$.



(b) Orifice diameter, 0.1016 cm.

Figure 8. - Variation of orifice to hydrodynamic mean diameter ratio, $D_o/D_{m,h}$, with $gl/\bar{c}^2$ for splash plate fuel injectors with $\rho_a V_a = 0.$ $D_{m,h}^{-1} = 2.8\times10^{-2}\, V_\ell\, P_a^{-0.33}$, $D_o/D_m = 2.05\, Re_\ell\, (gl/\bar{c}^2)$.

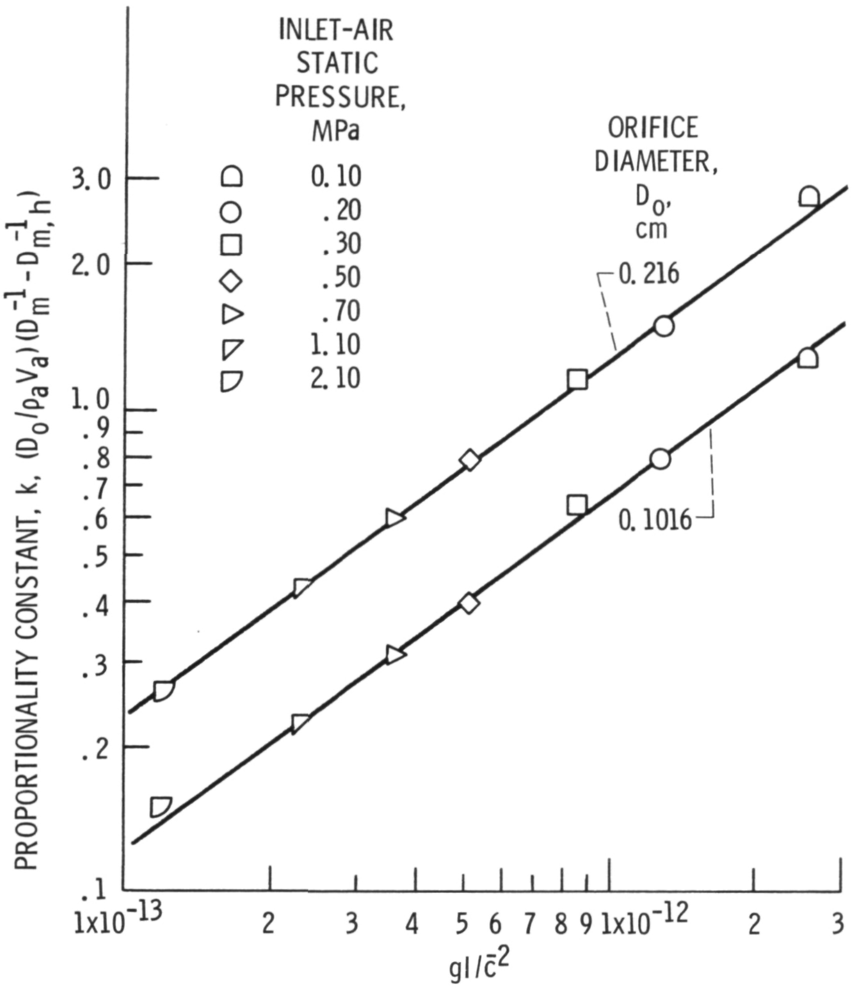


Figure 9. - Correlation of proportionality constant k calculated from figures 6 and 7 with dimensionless group $gl/\bar{c}^2$, for splash plate fuel injectors. $D_m^{-1} = D_{m,h}^{-1} + 13\rho_a V_a P^{-0.75}$, $D_o/D_m = 2.05\,Re_\ell\,(gl/\bar{c}^2)^{0.33} + 1.2\times10^6\,Re_a\,(gl/\bar{c}^2)^{0.75}$.

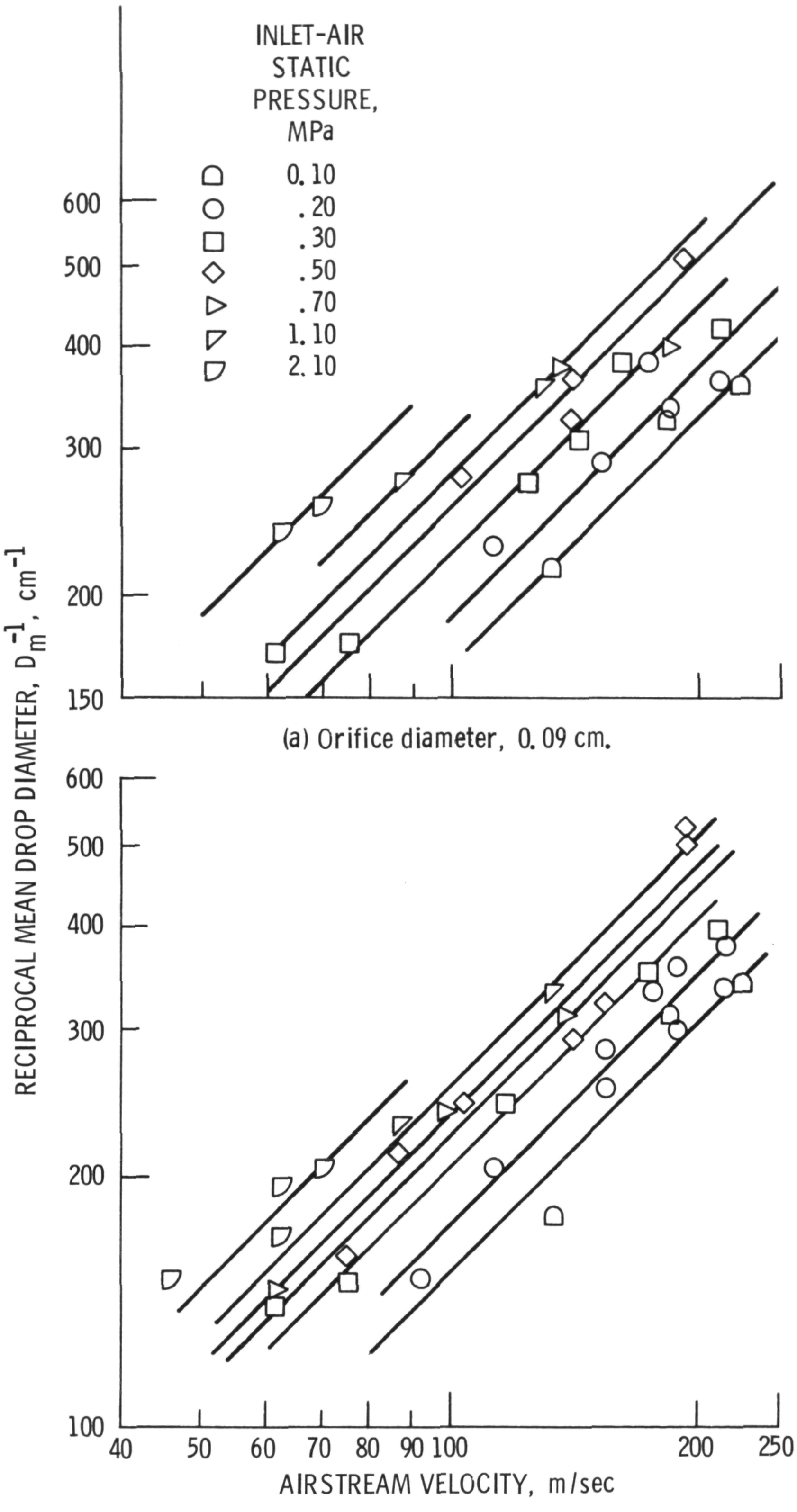


Figure 10. - Variation of reciprocal mean drop diameter, D_m^{-1}, with airstream velocity, V_a, for pressure-atomizing nozzles.

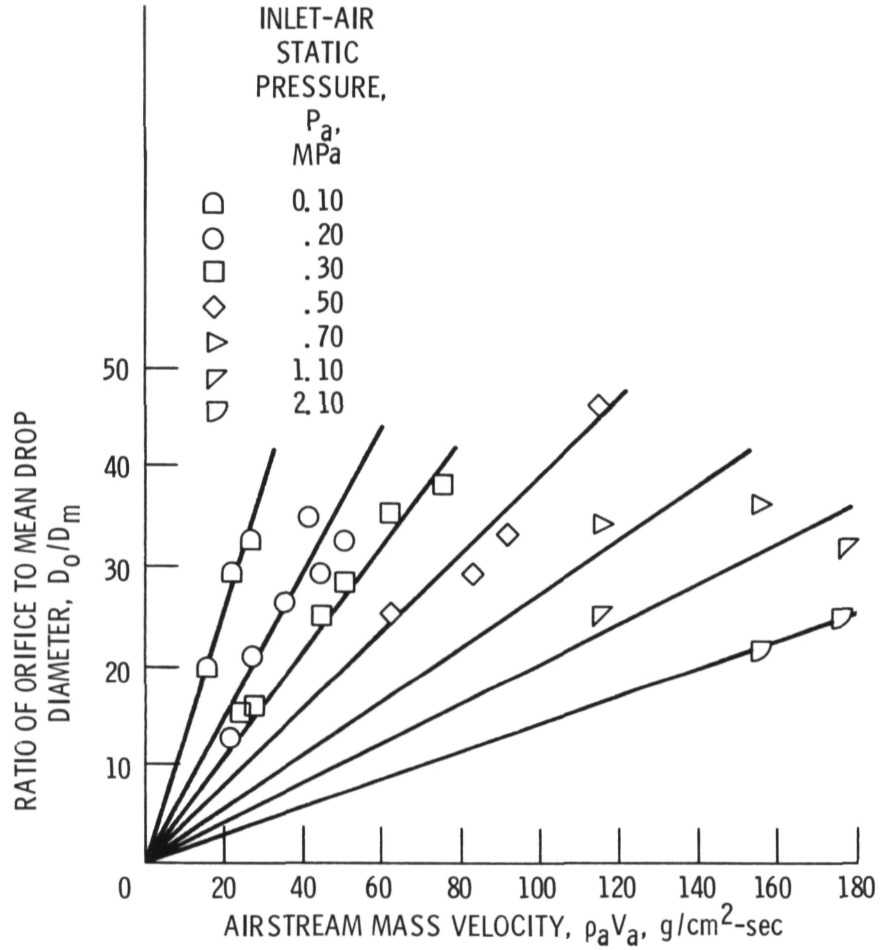


Figure 11. - Variation of orifice to mean diameter ratio, D_o/D_m, with airstream mass velocity, $\rho_a V_a$, for pressure-atomizing nozzle with D_o = 0.090 cm. $D_o/D_m \sim \rho_a V_a P_a^x$.

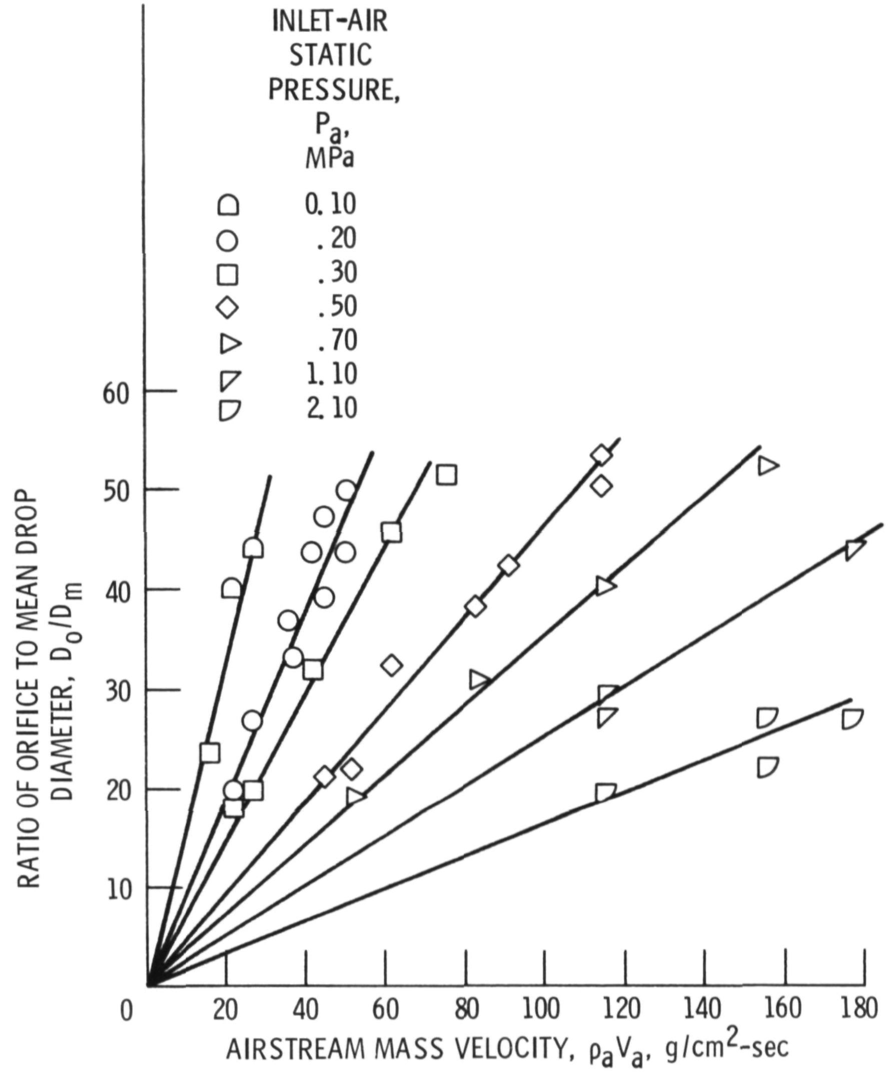


Figure 12. - Variation of orifice to mean diameter ratio, D_o/D_m, with airstream mass velocity, $\rho_a V_a$, for pressure-atomizing nozzle with D_o = 0.130 cm. $D_o/D_m \sim \rho_a V_a P_a^x$.

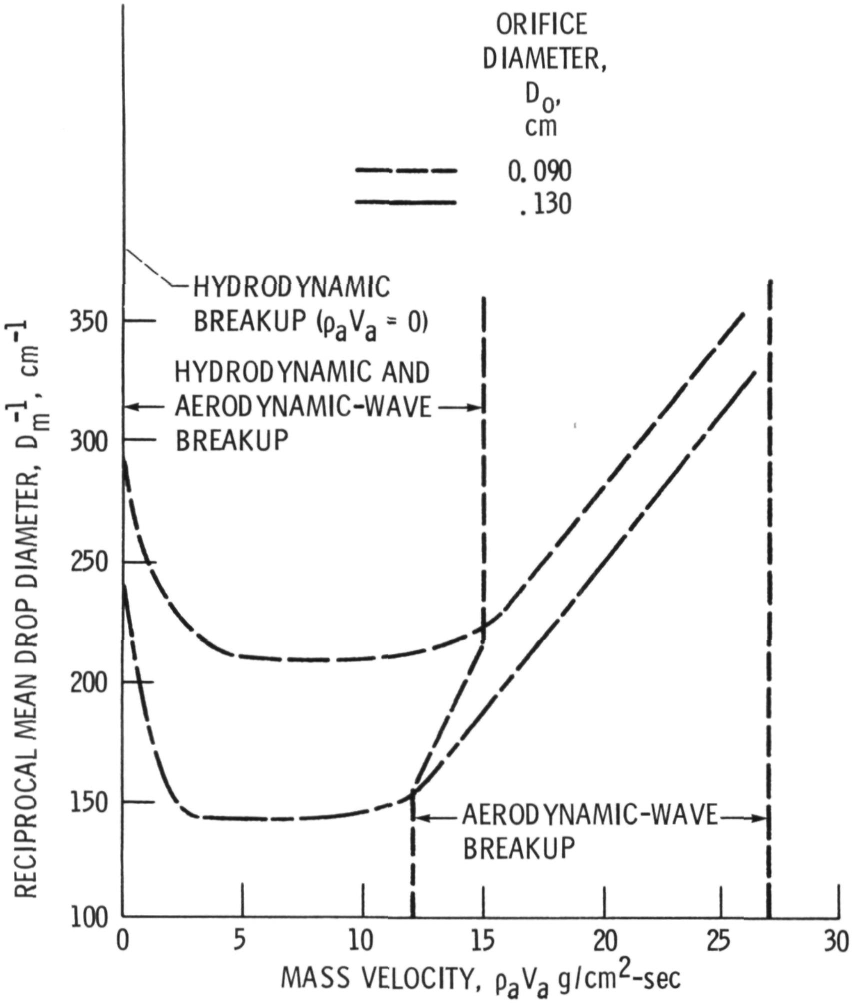


Figure 13. - Variation of reciprocal mean drop diameter with airstream mass velocity for simplex pressure atomizing fuel nozzles. (From ref. 7.)

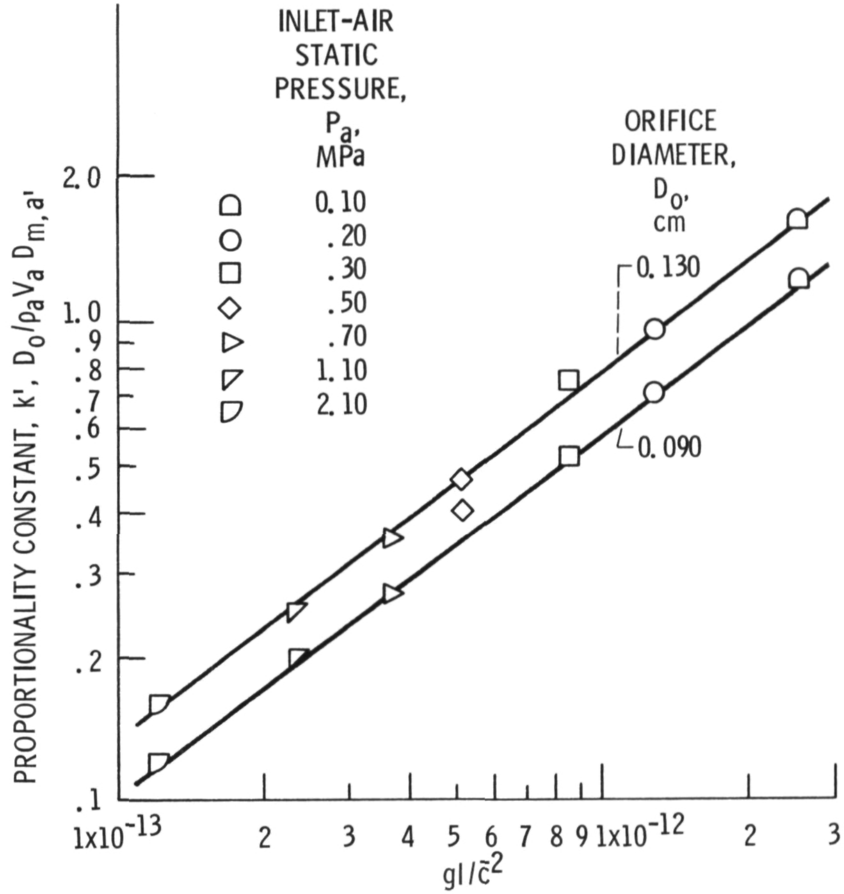


Figure 14. - Correlation of proportionality constant k' for aerodynamic breakup with dimensionless group $gl/\bar{c}^2$, for pressure-atomizing fuel nozzles. $D_{m,a'}^{-1} = 13\rho_a V_a P^{-0.75}$, $D_o/D_{m,a'} = 1.14\times10^6 \, Re_a \, (gl/\bar{c}^2)^{0.75}$.

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16. Abstract

An investigation of liquid sheet atomization was made with combustor simulated inlet-air pressures varied from 0.10 to 2.1 MPa. Mean drop diameters were measured with an improved scanning radiometer and correlated with the liquid and air-stream Reynolds numbers, Re_l and Re_a, and the airstream pressure sensitive group $gl/\bar{c}^2$. The reciprocal mean drop diameter, D_m^{-1}, produced for liquid sheet break-up with splash plate fuel injectors, may be expressed as:

$$D_m^{-1} = 2.8\times10^{-2}\, V_\ell P_a^{-0.33} + 13\, \rho_a V_a P_a^{-0.75}$$

which may be rewritten in terms of dimensionless groups as follows:

$$D_o/D_m = 2.05\, Re_\ell\, (gl/\bar{c}^2)^{0.33}$$

$$+ 1.2\times10^6\, Re_a\, (gl/\bar{c}^2)^{0.75}$$

where D_o is orifice diameter and it is assumed that $D_m \sim D_{32}$ (SMD), $Re = D_o V_\ell/\nu_a$, V_ℓ and V_a are liquid and airstream velocity, respectively, g is the acceleration due to gravity, l is mean free path which varies inversely with airstream pressure, and c is root-mean-square velocity of air molecules. For the atomization of swirling liquid sheets produced by pressure-atomizing simplex fuel nozzles, it was found that:

$$D_{m,a'}^{-1} = 13\, \rho_a V_a P_a^{-0.75}$$

and in terms of dimensionless groups:

$$D_o/D_{m,a'} = 1.14\times10^6\, Re_a\, (gl/\bar{c}^2)^{0.75}$$

where $D_{m,a'}$ is the mean drop diameter for aerodynamic breakup at values of $Re_a > 7500$.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Atomization; Liquid particles; Fuel injectors; Spray combustion; Mean drop size	Unclassified - unlimited STAR Category 34

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