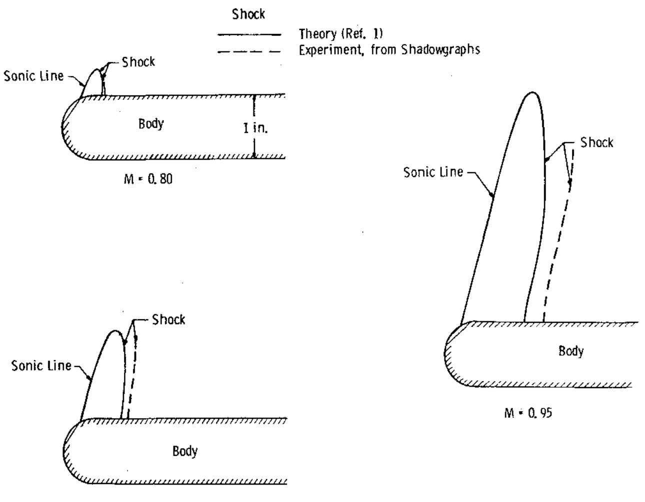

Fig. 2 Comparison of supersonic pocket and normal shock.

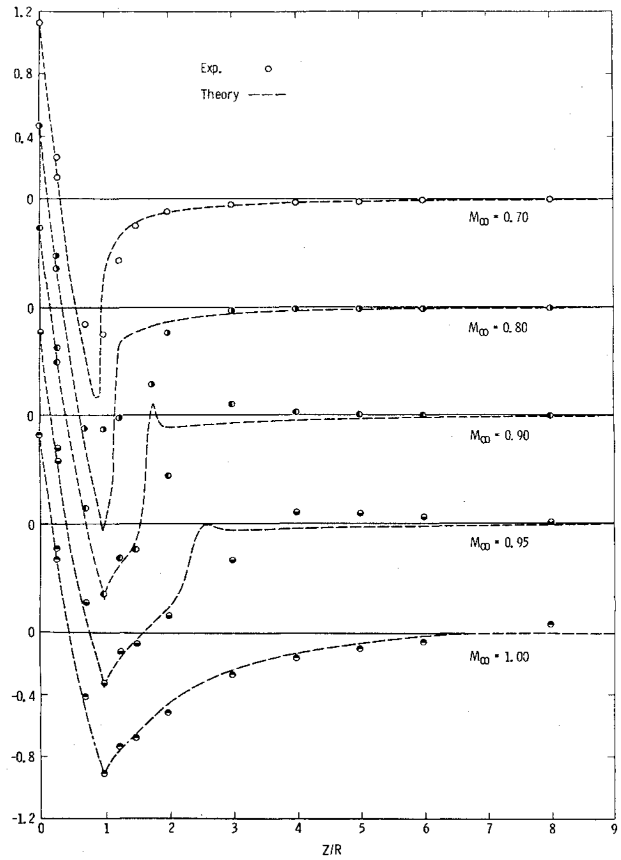

Fig. 3 Comparison of calculated pressure with experiment.

parison of the location of the supersonic pocket and shock calculated by the relaxation method and obtained from the shadowgraphs of Fig. 1 is presented in Fig. 2. The shape of the shock is predicted correctly, but the location of the shock obtained experimentally is shifted some distance downstream.

The surface pressure calculated by the relaxation method is compared with the experimental data for M_∞ from 0.7 to 1.0 in Fig. 3. The theory predicts the pressure distribution correctly from the nosetip until the point at which the shock seems to appear. For $M_\infty = 0.8$ there is significant disagreement between the theoretical and experimental pressure distributions. The corresponding shadowgraph given in Fig. 2 does indicate a pronounced boundary-layer separation; therefore, the inviscid theory fails to work there. For $M_\infty = 1$, it is surprising to see the good agreement between the predicted and measured surface pressure.

In conclusion, from experimental and theoretical results it is shown that an interaction of boundary-layer separation and shock waves strongly influences the flow over a hemisphere-cylinder in the transonic Mach number range; therefore, the inviscid theory fails to predict the flow. Such interaction is particularly strong when $M_\infty \sim 0.8$. Further study, both theoretical and experimental, is required to have a better understanding of the flow.

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Fuel Atomization in a Flowing Airstream

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Nomenclature

SMD = mean drop size, microns (10^{-6}m)
V = air velocity, m/sec
ΔP = fuel injection pressure, N/m^2
FN = atomizer flow number (liters/hr)/(N × m^2)$^{0.5}$
R = volume fraction of spray composed of drops larger than d
d = drop diameter, μ
$\bar{d}$ = drop size parameter, μ
x = drop size distribution parameter

Introduction

WHEN a swirl atomizer is used to inject fuel into a flowing airstream the resultant mean drop size represents the combined effects of a) the initial atomization produced by the swirl atomizer, plus b) the secondary atomization arising from the airblast action of the flowing airstream. In conventional gas turbine combustion chambers the primary-zone velocity is usually too low to have any discernible influence on atomization quality. However, in duct burners of the type employed in some modern turbofan engines, and in the "premix-prevaporization" systems designed for low-emission combustors, the air velocity may be so high as to affect appreciably the mean drop size of the spray. Under these conditions calculations of fuel evaporation

Received, March 17, 1975; revision received May 23, 1975.

Index categories: Airbreathing Propulsion, Subsonic and Supersonic; Combustion in Heterogeneous Media.

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simplex atomizers spraying into stagnant air could lead to sizable errors. It was the need to acquire more accurate information on the influence of air velocity on fuel spray characteristics, notably mean drop size and drop-size distribution, that prompted the present investigation.

Experimental

Apparatus

The apparatus employed is shown schematically in Fig. 1. A rotary blower conveyed air at atmospheric pressure and temperature into a test section of 75 mm square cross section, fitted with schlieren-quality glass windows on two opposing walls. Aviation kerosene fuel supplied to specification D. Eng.R.D. 2494 (specific gravity = 0.795) was sprayed in the direction of the airstream from interchangeable atomizers mounted centrally on the pipe axis upstream of the test section. The atomizers employed were simplex-type Delavan nozzles having an 80° cone angle and flow numbers ranging from 0.0182 to 0.0364 in steps of 0.0046.

Drop-Size Measurement

Drop sizes were measured using the light-scattering technique suggested by Dobbins, Crocco, and Glassman[1] and developed by Godfrey.[2] It is based on the forward scattering of a parallel beam of monochromatic light resulting from its passage through a spray. An important advantage of the method in the present application is that it creates no disturbance in the flowing airstream. For more detailed information on the design and calibration of the optical system reference should be made to Godfrey,[2] Bryan, Godbole, and Norster[3] and Rao.[4]

Drop-Size Distribution

The method adopted to determine drop-size distribution employed a specially designed probe in which liquid nitrogen was used to freeze the fuel drops contained in the inflowing spray sample. The probe was mounted in the test section with its inlet facing the flowing spray, and cold, gaseous nitrogen was conveyed to the tip of the probe and injected into the incoming spray sample through a narrow annular slot. The nitrogen, at a temperature of around 140 K, rapidly froze the kerosene drops, which were then collected in a nitrogen-cooled perspex pot and subsequently photographed through a microscope. The final prints showing the drops enlarged by a factor of 50 or more were later analyzed using a specially calibrated scale to determine the number and size of the drops in the sample.

Drop-Size Analysis

The drop-size distribution in a spray may be described by the Rosin-Rammler equation $R = \exp - (d/\bar{d})^x$, where R is the volume fraction of the spray occurring in drops of diameter greater than d, $\bar{d}$ is a size parameter, and x is a distribution parameter which provides a measure of the spread of drop

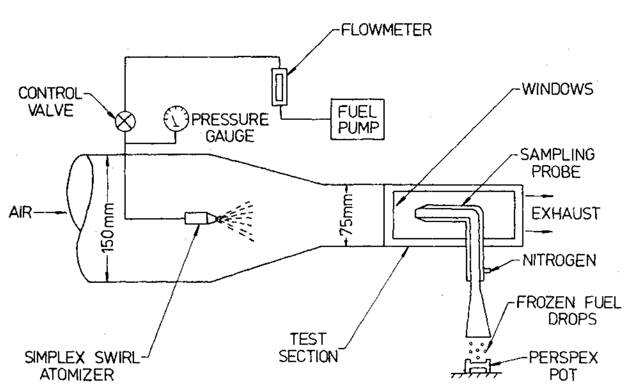

Fig. 1 Schematic diagram of test rig with sampling probe.

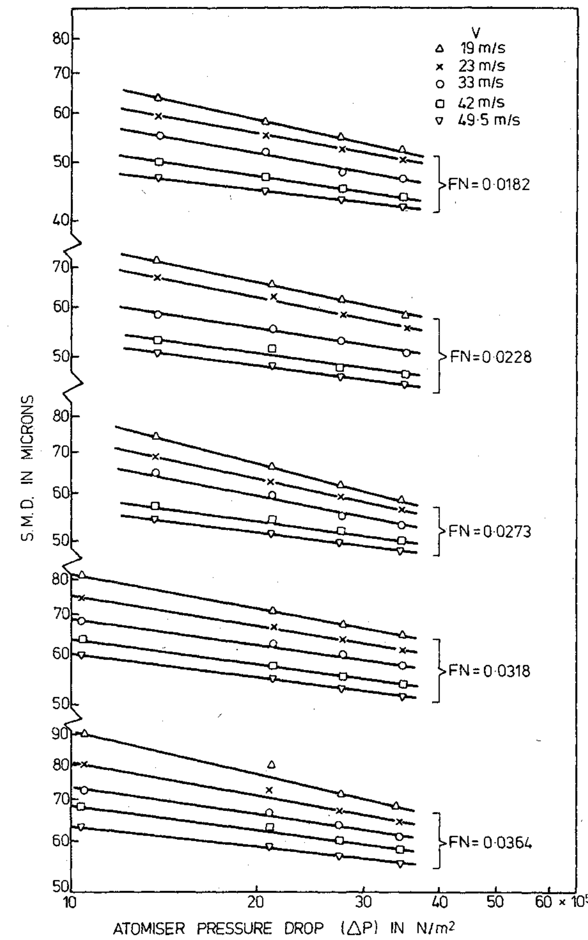

Fig. 2 Experimental data illustrating the effect on SMD of fuel injection pressure, atomizer flow number, and air velocity.

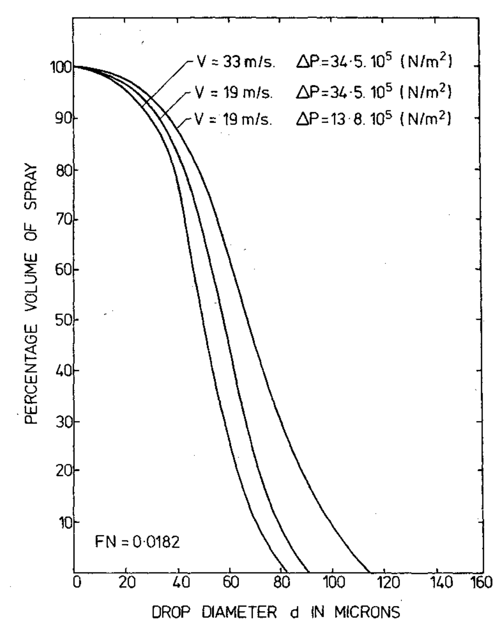

Fig. 3 Influence of fuel injection pressure and air velocity on drop-size distribution.

rates based on drop sizes equivalent to those obtained from sizes. The higher the value of x the more uniform is the spray.

For any given spray x must be derived from the experimental data by plotting log-log R^{-1} against log d. The value of x is obtained as the slope of the resulting straight line, and $\bar{d}$ as the value of d for which $R = e^{-1}$. SMD is then calculated as

Table 1 Results on mean drop size and drop-size distribution

Atomizer flow number	Air velocity (m/s)	Fuel-injection pressure ($10^5 N/m^2$)	Distribution parameter (x)	SMD (light scattering technique) (μ)	SMD (nitrogen freezing technique) (μ)
		13.8	3.06	63	63.6
0.0182	19.0	20.7	3.22	58	58.8
		34.5	3.48	53	55.8
		13.8	3.10	55	61.1
0.0182	33.0	20.7	3.48	52	52.8
		34.5	3.92	47	49.3
		13.8	2.68	69	73.4
0.0273	23.00	20.7	2.88	64	66.2
		34.5	2.82	57	59.8

SMD $=\bar{d}$ $\{\Gamma(1\text{-}1/x)\}$, where Γ is the gamma function.

Results

The results of the drop-size measurements carried out with the light-scattering technique are shown plotted in Fig. 2. Not surprisingly, they indicate that atomization quality is improved by increases in fuel injection pressure and reduction in atomizer flow number, but they also demonstrate the marked effect of an increase in air velocity in reducing the mean drop size. This result could be very relevant to the design and performance of many practical combustion systems.

Correlation of the experimental data yields an equation of the form

$$\text{SMD} = 13{,}500\left[(\text{FN})^{0.34}/(\Delta P)^{0.27}\right] - 1945\left[V/(\Delta P)^{0.56}\right]$$

Detailed analysis of the drop-size date provided by the nitrogen-freezing technique yielded the results listed in Table 1 and shown plotted in Fig. 3. They show that increase in fuel-injection pressure and air velocity, and reduction in atomizer flow number, all tend to produce a higher value of x, indicating a more uniform drop size in the spray. Also of interest in Table 1 is the close agreement between the drop sizes measured by the light-scattering and nitrogen-freezing techniques.

Conclusions

The results of drop-size measurements carried out on a number of swirl atomizers when injecting fuel into a flowing airstream show that atomization quality is improved by: 1) increase in fuel-injection pressure, 2) reduction in atomizer flow number, 3) increase in air velocity.

The following relationship satisfactorily correlates the measured values of SMD.

$$\text{SMD} = 13{,}500\left[(\text{FN})^{0.34}/(\Delta P)^{0.27}\right] - 1945\left[V/(\Delta P)^{0.56}\right]$$

It is also found that all the factors which reduce the SMD of a spray also end to make the drop size more uniform.

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Correlation between Combustion and Decomposition in Solid Propellants

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Introduction

THE understanding of the heterogeneous condensed phase reactions during the combustion process could be greatly facilitated by a study of the thermal decomposition of the solid propellant and its ingredients. Some attempts have been made in the past regarding the heat release estimations of the condensed phase.[1-4] However, very few attempts have been made to correlate the rate of thermal decomposition of the propellant and the oxidizer to the propellant combustion behavior.[5] In view of the aforementioned, the objective of the present Note is twofold. First, to seek a correlation between the burning rate and the thermal decomposition of the propellant and oxidizer, and second, to see whether the burning rate increases when the oxidizer is doped with potassium chromate. It may be mentioned here that ammonium percholorate decomposition is sensitized by chromate doping.[6]

Experimental

Recrystallized ammonium perchlorate (AP) was used for doping. AP and potassium chromate solutions were made in definite proportions and the coprecipitation was done by cooling the saturated aqueous solution at 70°C to room temperature. Particle size of doped and undoped AP was kept constant. Making of the propellant strands and the burning rate measurements were done as described earlier.[7] Thermal decomposition studies of AP and the propellant at 276°C were done in a home made TGA assembly.[8] The results of burning rate, AP decomposition and the propellant decomposition are presented in Figs. 1 and 2.

Results and Discussion

Figure 1 shows that burning rate of the propellant at ambient pressure increases by increasing the dopant concentration and so is the behavior of AP decomposition. Figure 2 shows that burning rate bears a linear relationship to the propellant decomposition. Thus, the data presented in Figs. 1 and 2 reveal that not only is the burning rate of the propellant related to the thermal decomposition of the propellant, but it is also related to the thermal decomposition of its oxidizer AP. This, in fact, supports our earlier observation from DSC studies that AP decomposition plays a significant role in the propellant decomposition, and that condensed phase reactions are important in the combustion of the propellant.[9,10]

Received June 17, 1975.
Index categories: Fuels and Propellants, Properties of; Solid and Hybrid Rocket Engines.

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