JOURNAL OF PROPULSION AND POWER
Vol. 10, No. 5, Sept.-Oct. 1994

Technical Notes

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Supersonic-Ejector Characteristics Using a Petal Nozzle

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Nomenclature

L/D = length to diameter ratio of ejector shroud
P = stagnation pressure
W = weight flow rate

Subscripts
a = ambient
p = primary
s = secondary

Introduction

BASED on analytical predictions, ejectors are known to have tremendous potential as an air-pumping or thrust augmenting device in aircraft and rocket technology. But so far the ability to practically apply the ejector principle to produce an efficient system has been limited. This is mainly because of the slow rate of shear-type mixing between the primary and entrained secondary streams associated with a conventional ejector system. Hence, it requires a long mixing duct resulting in high friction losses and additional weight. A comprehensive review of conventional ejectors is available in Ref. 1.

Considerable work has been carried out towards producing short and efficient subsonic ejector systems using unconventional primary nozzles.[1-7] The studies reported in Refs. 3-7 have employed the mixer-ejector concept, wherein an array of large-scale, low intensity, streamwise vortices are generated that enhance mixing through an inviscid stirring process. Recently, Tillman et al.[8] applied this concept to the supersonic primary flow regime and obtained excellent results. Recently, the authors developed a lobe-type supersonic nozzle, referred to as the Petal nozzle,[9] by which large-scale axial vortices are generated to enhance mixing between two high-speed streams.[10-12] Although most of these experiments were aimed at establishing the mixing characteristics of two high-speed streams, some tests were also conducted in the supersonic ejector mode. In the present study, only air pumping characteristics were determined, i.e., no thrust measurements were carried out. Typical results obtained from these ejector mode tests with Petal and Conventional primary nozzles are compared in this Note.

Experimental Setup and Procedure

The test setup employed, shown in Fig. 1, consists of 1) the primary air line which ends in a contraction cone onto which either of the two nozzles, Conical or Petal, may be attached; 2) the secondary flow settling chamber which is annular and coaxial with the primary air line; 3) two venturimeters, one on either side of the secondary settling chamber, for measurement of secondary mass flow rate; 4) bellmouths to facilitate proper entry of the secondary entrained flow; and 5) ejector shroud. Air was used as the working gas for the primary stream. Both nozzles have a throat diameter of 22 mm and area ratio of 1.34 (design pressure ratio = 5:1). Exit Mach number is about 1.7. All tests were done using constant ejector area ratio. Cylindrical acrylic tubes of L/D varying from 4.35 to 0.87 were used for the ejector shroud.

Two types of tests were conducted: 1) with no secondary flow and 2) with secondary flow. For tests with no secondary flow, the venturimeters were replaced by end-plates, thus sealing the secondary flow settling chamber from the ambient.

Results and Discussion

Tests with No Secondary Flow

Figure 2a shows the characteristics of the entrained flow using the conventional nozzle ejector, which are similar to the data presented in Refs. 13 and 14. At low primary nozzle pressure ratios, the expansion of the jet is insufficient to attach the free-mixing layer to the shroud wall, and therefore the secondary pressure remains close to ambient. As the nozzle pressure ratio increases, the free-mixing layer attaches which then causes the secondary pressure to drop rapidly due to flow entrainment (secondary flow choking).[14] Figure 2b shows the corresponding curves for the Petal nozzle ejector. These are seen to be fundamentally different from the curves shown in Fig. 2a in the following aspects. Firstly, for any chamber length, secondary pressure falls off much more steeply with an increase in primary blowing pressure. Secondly, primary pressure at which secondary flow choking occurs is not so well defined. Thirdly, after choking has occurred (lowest point on

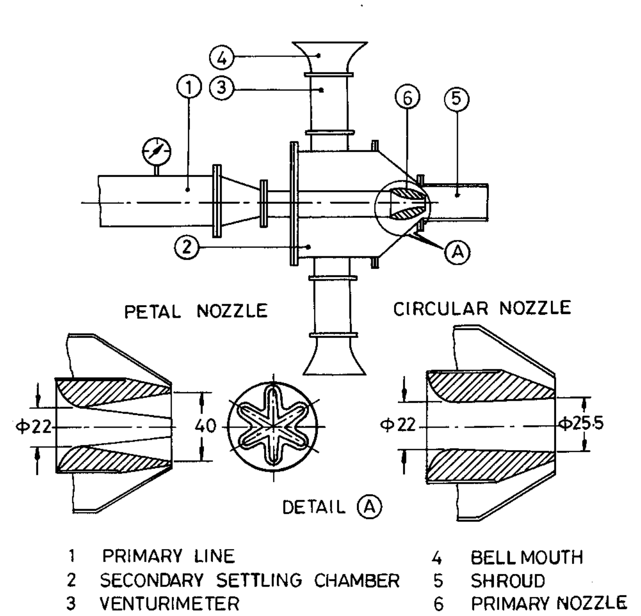

Fig. 1 Test setup showing details of the primary nozzles.

Received Oct. 2, 1992; revision received Sept. 20, 1993; accepted for publication Oct. 11, 1993.

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the curve), secondary pressure variation with primary pressure is not linear.

Figure 2 brings out the effect of ejector shroud length on the secondary pressure for Conventional and Petal nozzles. In the case of an ejector with a Petal nozzle, the secondary pressure does not increase to ambient values, even for a low shroud L/D of 1.74.

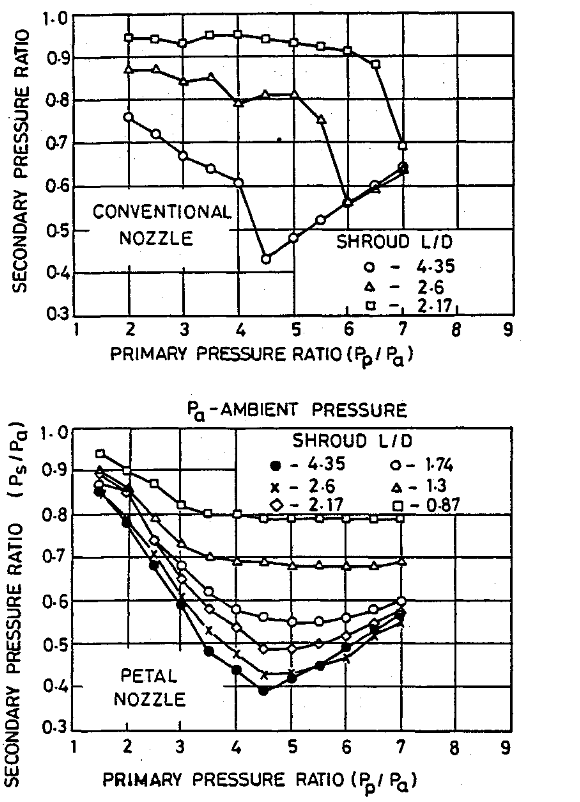

Fig. 2 Variation of secondary pressure ratio width primary pressure ratio.

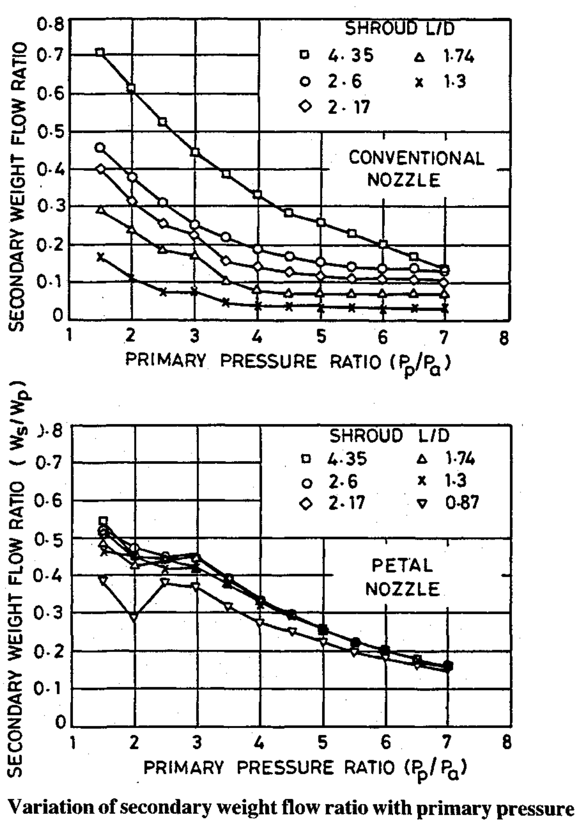

Fig. 3 Variation of secondary weight flow ratio with primary pressure ratio.

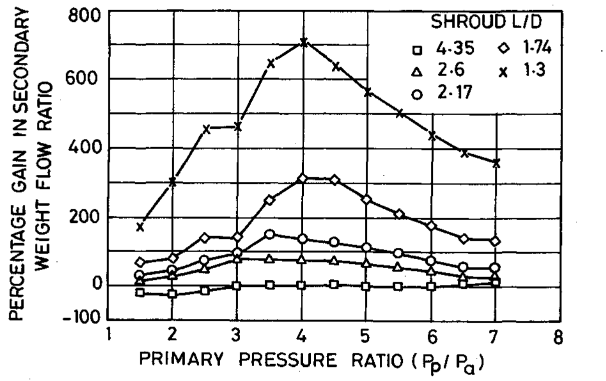

Fig. 4 Percentage gain in secondary flow ratio of a Petal nozzle.

Tests with Secondary Flow

Figures 3a and 3b show typical variation of weight flow ratio W_s/W_p with primary pressure ratio for an ejector with Conventional and Petal nozzles, respectively. Figure 3a data correlates well with the data presented in Ref. 13 in the sense that weight flow ratio increases with increase in chamber length. However, Fig. 3b (Petal nozzle) shows that shroud length has practically no effect on W_s/W_p. From these two figures it is also seen that the secondary mass pumping achieved by a Conventional ejector using a shroud length of L/D = 4.35 can be achieved by a Petal nozzle ejector using a shroud length of L/D = 1.3. Figure 4 compares the pumping gain of the Petal nozzle ejector with the Conventional nozzle one. It is observed that for a shroud L/D of 1.3, the Petal nozzle ejector entrains a maximum of over 700% secondary mass flow as compared to the ejector with a Conventional nozzle.

Conclusions

The ejector with a Petal nozzle for the primary flow has been shown to be very much superior to the one with a Conventional, Conical nozzle. The large-scale, inviscid mixing process associated with the Petal nozzle provides tremendous pumping benefits using very short shroud lengths.

Acknowledgments

The authors express their gratitude to G. A. Venceslas, Senior Technical Officer, and S. Manoharan, Technical Assistant, of the Aerospace Engineering Department, IIT, Madras, India, for their help during various phases of this work.

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Combustion of Microemulsion Sprays

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Nomenclature

D = drop diameter
L = flame length
S = mass concentration of surfactant
T = temperature
W = mass concentration of water
x = axial distance from the nozzle

Subscript
32 = Sauter mean

Introduction

IN the last two decades there has been considerable interest in using water-oil emulsions in spray combustors. Several studies on the combustion of drops and sprays of emulsions[1–3] in laboratory furnaces and in practical devices[4,5] have appeared in literature. A principal mechanism proposed to explain the effects of emulsification is the so-called microexplosion of drops attributed to the early vaporization of the internal-phase water leading to shattering of the parent oil drop. Some studies[2,3] suggest that microexplosion may not occur or may not be strong enough to explain the effects observed during spray combustion, particularly of the distillate oil. It has been shown that the internal-phase drop size is a critical parameter that could determine whether or not microexplosion occurs.[2] Most of these studies have been conducted with *macroemulsions* in which the internal-phase drop size is usually on the order of micrometers. On the other hand, the internal-phase droplet size in the so-called *microemulsions* is in the submicron range (100–600 Å) and microemulsions appear to be clear solutions,[6] and hence, the role of microexplosion is questionable in microemulsion flames. The studies by Naegeli and Moses[7] and Adiga[8] have shown that smoke emissions from a gas turbine combustor and a steam boiler were reduced when microemulsions were substituted for pure distillate fuels. However, the study by Naegeli and Moses showed that CO and NO emissions increased, but Adiga's study showed they decreased when microemulsions were used in place of pure fuels. The present study was conducted to compare the burning characteristics of air-assist atomized sprays of Jet-A fuel and its microemulsion with water (5% by mass) in a laboratory combustor where the conditions could be controlled much better than in practical combustors.

Received March 16, 1993; revision received Nov. 15, 1993; accepted for publication Jan. 16, 1994.

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Experimental Apparatus and Procedure

An air-assist atomizer nozzle producing a solid spray with a cone angle of 20 deg with no swirl was used in this study. Since the density of emulsion varied with water content, the fuel rotameter was calibrated for each emulsion. The burner was mounted horizontally at the center of the exit section of an open-jet wind tunnel. The flames were confined mostly to the middle two-third section of the wind tunnel except for the tip regions of the flame. A steady airstream with a turbulence intensity of less than 5% was maintained in the test section.

The 35-mm color photographs exposed for 1 s were used to measure flame length. The drop size distribution in the near-nozzle regions of nonburning sprays was measured with a phase Doppler particle analyzer. Total thermal radiation emitted from the flame was measured using a water-cooled 150-deg view-angle thermopile radiometer with an absorptivity of 0.96. Temperature measurements were taken using a chromel-alumel (type K) thermocouple (bead diameter 0.3 mm) and were corrected to account for conduction and radiation losses from the bead following Fristrom and Westenberg.[9] An emissivity of 0.9 for the bead was used in the calculations.

The volumetric concentrations of O_2 (%), NO (ppm), and CO (%) were measured along the radial direction at a distance of two-thirds flame length from the atomizer. Gas samples were drawn from the flames through a water-cooled stainless steel tube (orifice diameter = 1 mm), were treated to remove particles and moisture, and were analyzed with chemiluminescent, nondispersive-infrared, and polarographic analyzers for NO, CO, and O_2 concentrations, respectively. Emulsions were prepared by adding the desired amount of surfactant (sodium dioctyle sulfosuccinate) to the mixture of water and Jet-A fuel and stirring the mixture until a clear solution was produced. The measurement uncertainties are quoted at 95% confidence level.

Results and Discussion

Microemulsions were clear transparent liquids when they were freshly prepared. When examined after storing them for 2 months at room temperature, the microemulsions with 5 and 10% (mass) of water still appeared as transparent liquids, whereas the microemulsions with 15 and 20% (mass) of water exhibited a slight milky appearance. This observation, which agrees with the study of Shah and Hamlin[6] suggests that a higher water content lowers the stability of microemulsions. In this study, flame structure was examined only for the microemulsion with a water content W of 5% and $S/W = 0.7$, where S and W are surfactant and water contents in the emulsion. The average values of the Sauter mean diameter D_{32} on a cross section located 38 mm from the nozzle in the nonburning Jet-A fuel and microemulsion sprays were 87 ± 13 and 90 ± 12 μm, respectively, and were not markedly different.

The pure Jet-A fuel flame was yellow and luminous over most of its length except over a small portion near the burner where some blue color was observed at the flame edges. No marked difference in the flame color was noticed between pure fuel and emulsion flames, although the luminosity of the