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Mixing Pressure-Rise Parameter for Effect of Nozzle Geometry in Diffuser-Ejectors

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Nomenclature

D = diameter
m = mass flow rate
p = static pressure
ϕ = pressure-rise parameter

Subscripts

p = primary
s = secondary

I. Introduction

ONE of the technological areas in aerospace engineering where the ejector has proved indispensible is in high-altitude simulation.[1] Altitude testing requirements for space propulsion systems have led to the development of facilities that utilize the energy of the rocket exhaust itself in conjunction with ejector–diffuser systems to reduce the pressure in the test cell to values that simulate high-altitude conditions. Considerable theoretical and experimental work has been done with respect to the design and development of these systems.[2–8] However, most of these works have centered around circular cross-section primary nozzles. Little data seem to be available on the use of unconventional primary nozzles for ejector–diffuser systems. Therefore, it was considered appropriate to examine the performance of these systems using primary nozzles of various geometries. Results of these tests are presented in this Note.

II. Experimental Setup and Testing

The experimental facility used for these tests can be divided into the following subsystems: 1) air supply system, 2) test setup including nozzles, and 3) an instrumentation and data acquisition system.

A schematic diagram of the general test setup is shown in Fig. 1a. Compressed air was employed as the driving fluid for the ejector. The various primary nozzles to be tested were screwed onto the nozzle adapter. Pressure transducers of appropriate ranges were attached to the wall static ports. The transducer outputs were fed to the data acquisition system for real-time display and storage.

Seven primary nozzles of various geometries were tested (Fig. 1b). These include the conical nozzle (as a reference), three elliptic nozzles, two injector (shower) head types, and one petal[9] type of nozzle. The conical, elliptic, and petal nozzles were of the converging–diverging (C–D) type, whereas the two injector head nozzles were of the converging type. Exit area of the two latter nozzles was equal to the throat area of the other C–D nozzles. All of the C–D nozzles had circular

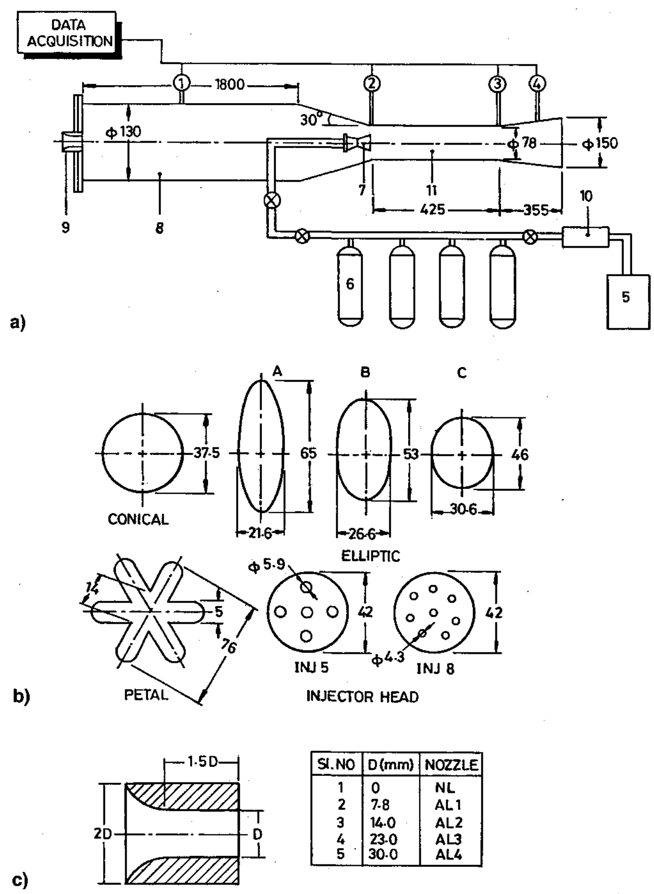

Fig. 1 a) Experimental setup (1, 2, 3, 4 = wall static ports, 5 = compressor, 6 = storage tank, 7 = primary nozzle, 8 = secondary chamber, 9 = air-loading nozzle, 10 = dessicator, and 11 = mixing tube); b) primary; and c) air-loading nozzles.

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throats 13.2 mm in diameter and equal exit areas. The area ratio of these nozzles was 8.0 and the corresponding exit Mach number at a full-flow condition was about 3.7.

To simulate and study the effect of the main engine mass flow on ejector performance in high-altitude simulation systems, air-loading nozzles of various sizes were attached to the upstream end of the secondary chamber. During ejector operation these nozzles were choked and gave a fixed mass flow rate of ambient fluid into the secondary chamber. Five air-loading nozzles of various throat diameters, including a no-load, were employed (Fig. 1c).

III. Results and Discussion

A. No-Load Tests

In these tests a blank was used as the air-loading nozzle, isolating the secondary chamber from the ambient. Figure 2a shows the no-load variation of chamber pressure with primary blowing pressure for the conical and elliptic nozzles. At lower primary blowing pressures there seems to be little difference in the performance of the various nozzles. For higher pressures however, differences in performance become clear. It is observed that beyond a blowing pressure of 26 bar the elliptic nozzle A, with largest aspect ratio, gives the minimum chamber pressure followed by nozzle B of lower aspect ratio. Nozzle C, of lowest aspect ratio, is seen to yield higher chamber pressures than the conical nozzle that lies between B and C. Further, the curve for nozzle A shows a distinct choking point at about 26-bar primary pressure. This figure brings out the importance of aspect ratio on the performance of elliptic nozzles in ejector–diffuser systems.

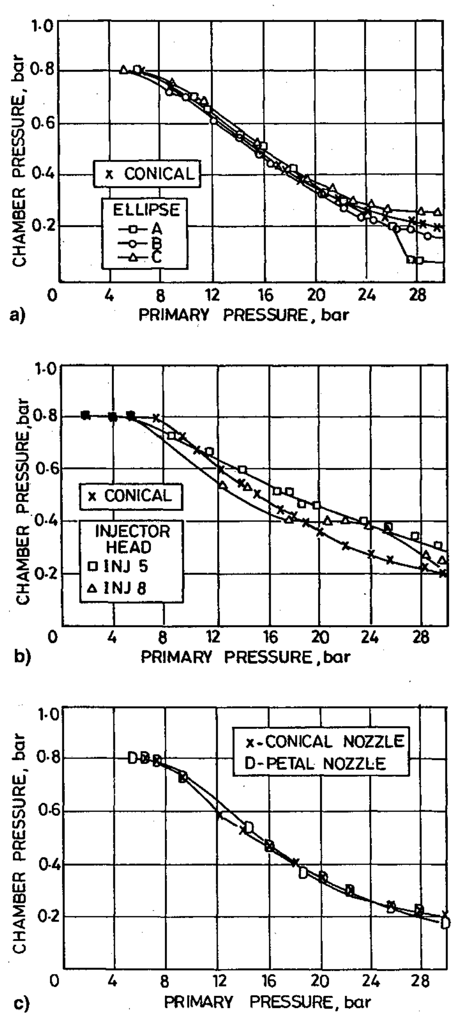

Fig. 2 No-load variation of chamber pressure.

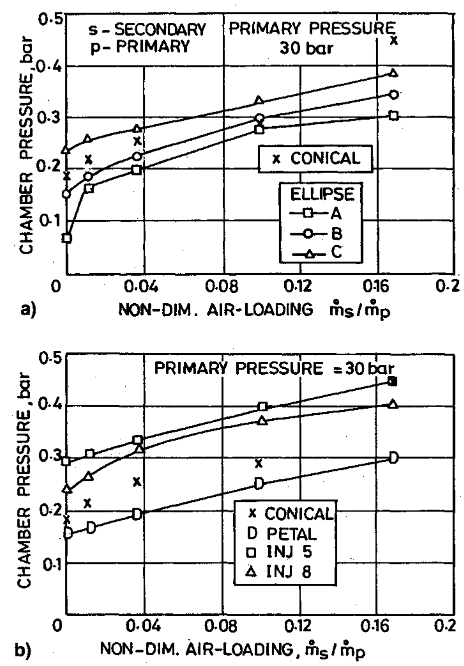

Fig. 3 Variation of chamber pressure with air loading.

The injector head type of nozzle is used extensively in industrial ejector jet pumps where high rates of entrainment of ambient or secondary fluid are required. Its mixing characteristics in jet pumps are known to be superior to that of the conical nozzle.[10] Figure 2b brings out the performance of these nozzles in the ejector–diffuser mode. At low pressures (<10 bar) both the injector head nozzles are seen to give lower chamber pressure than the conical nozzle. Between 10–18 bar, the performance of the conical nozzle is seen to lie between those of nozzles INJ 8 and INJ 5. At higher pressures (>18 bar), the performance of both the injector head types is poorer than the conical nozzle. Within the injector head types, the nozzle with the larger number of holes (INJ 8) is seen to yield lower chamber pressure.

The petal type of nozzle has recently been shown to give extremely rapid mixing for supersonic flows in ejectors and supersonic combustors.[9] Figure 2c shows the no-load characteristics of the petal nozzle to be close to that of the conical nozzle.

B. Tests with Air Loading

Figure 3a compares the performances of the elliptic nozzles under various air loads for a primary blowing pressure of 30 bar. It can be observed that nozzle A, with maximum aspect ratio, yields minimum chamber pressure at all air loads. It is followed by nozzle B and then C. Thus, a similar trend as seen for the no-load case is exhibited for loaded cases also, with larger aspect ratio nozzles performing better. While the conical nozzle gives a lower chamber pressure as compared to nozzle C for low air loads, at higher air loads the reverse seems to be true. Similar curves, for the injector head types and the petal nozzle, are shown in Fig. 3b. From this figure, both the injector head nozzles are observed to yield higher pressures, as compared to the conical nozzle, for all air loads below 0.14. The petal nozzle is seen to give low chamber pressures at all air loads.

C. Pressure-Rise Parameter

It is noted that between stations 2 and 3, that is across the mixing tube, there is a significant jump in the wall static pressure. Nondimensionalizing this pressure with the wall static pressure at station 3, we obtain the pressure-rise parameter ϕ:

$$\phi = (p3 - p2)/p3$$

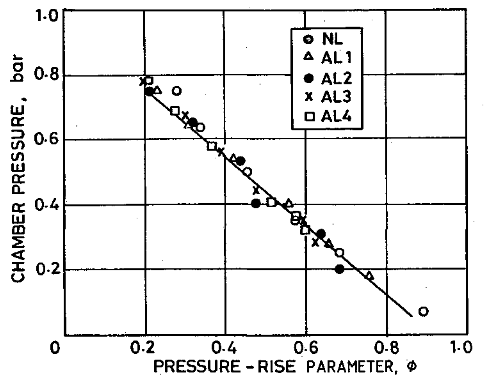

Fig. 4 Variation of chamber pressure with ϕ.

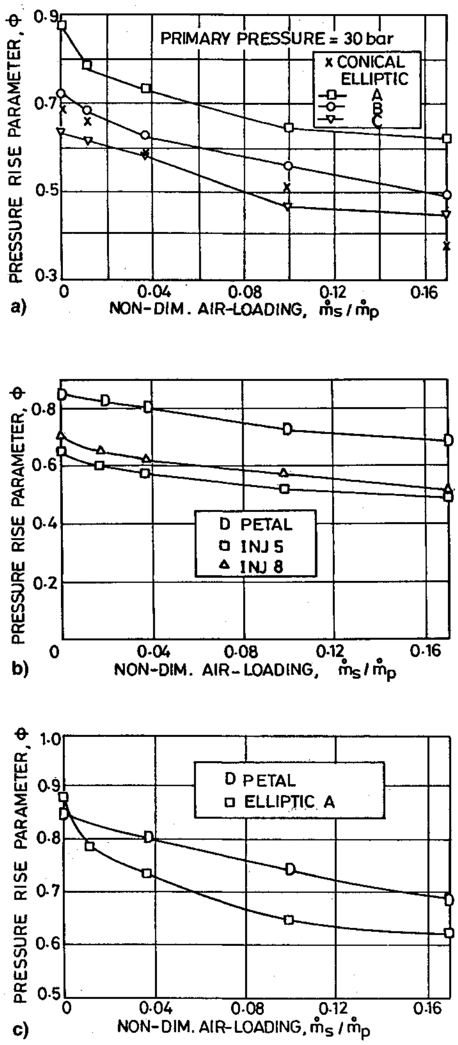

Fig. 5 Variation of ϕ with air loading.

The variation of ϕ with respect to chamber pressure for various air loads, for elliptic nozzle A, is shown in Fig. 4. The ϕ data for all air loads for this nozzle are seen to correlate in a linear fashion with chamber pressure. A similar result was obtained for all of the nozzles tested.

The variation of ϕ with air loading for the elliptic and conical nozzles is plotted in Fig. 5a. On comparing Fig. 5a with Fig. 3a, it is seen that ϕ may possibly be a parameter to indicate the level of performance of a primary nozzle in ejector–diffusers. Higher values of ϕ seem to indicate better (lower) values of chamber pressure. Thus, elliptic nozzle A is seen to give the best results, then B and then C. From Fig. 3a it may be noted that the conical nozzle's performance lies between B and C until an air loading of about 0.1. After this its performance drops below C. This fact is indicated in Fig. 5a. The value of ϕ for the conical nozzle lies between B and C until an air loading of about 0.1, after which it falls below that for nozzle C.

Figure 5b shows the variation of ϕ with air loading for the petal and injector head nozzles. From this figure and the preceding arguments, it is indicated that the petal nozzle would give much lower values of chamber pressure than either of the two injector head types. Also, the injector head nozzle INJ 8 is seen to be somewhat better than nozzle INJ 5. These inferences are borne out by data presented in Fig. 3b.

Finally, the two best performing nozzles, the petal nozzle and the elliptic nozzle A, are compared using ϕ in Fig. 5c. The variation of ϕ shows that for a no-load condition, the elliptic nozzle is superior to the petal nozzle. For all other air loads the petal nozzle performs better. This inference is shown to be true in the data from Figs. 3a and 3b.

IV. Conclusions

The following conclusions may be drawn from this experimental study on the effect of primary nozzle geometry in ejector–diffusers:

1) Aspect ratio plays an important role in the performance of elliptic primary nozzles in ejector–diffusers.

2) Injector-head type of primary nozzles that are used extensively in ejector jet pumps are not suitable for ejector–diffusers in high-altitude simulation systems.

3) The petal type of nozzle performed better than all other nozzles in the loaded condition. It would be a likely candidate for short, efficient ejector–diffuser designs. However, much more data are required before such designs can be attempted.

4) A parameter, namely, the pressure rise parameter, has been identified as a quantitative measure of ejector–diffuser performance in high-altitude simulation systems. It has been correlated with the chamber pressure.

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