Improvement of Ejector-Diffuser Performance by Reduction of Backflow

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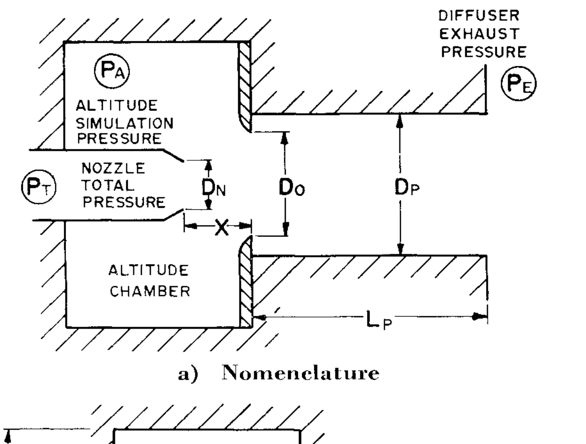
Introduction

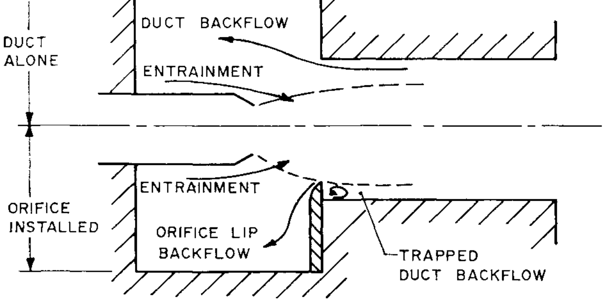
THE use of ejector-diffusers to produce low ambient pressures is an important technique in simulated altitude testing of jet aircraft engines. As engine airflows mushroom and flight Mach numbers and altitudes increase, this technique assumes ever greater significance.

Ejector-diffusers used in jet-engine testing are usually of the basic straight-duct geometry, although other configurations (e.g., second throat, guided inlet) are known to be capable of better performance. The reasons for this include the higher expense of high-performance designs and the necessity of testing a given engine over a wide range of conditions (airflows, nozzle pressure ratios, and nozzle area ratios). It is more practical, if sufficient exhauster capacity exists, to size a straight diffuser to operate unstarted over the entire range of test conditions for a given engine. Simulated altitude conditions are produced and controlled by exhauster machinery, with only a relatively modest boost from the ejector-diffuser.

If the improvement of ejector-diffuser performance is approached by focusing attention upon reduced exhaust backflow, it appears that sizeable improvements are possible in aircraft engine testing. This Note presents the results of model testing of one very simple backflow-reduction technique, consisting of an orifice plate installed at the inlet of a straight diffuser duct. This technique was observed to improve performance by a factor of about 2 under zero-pumping conditions. It could be used, for example, as a simple, low-cost way of changing existing facilities to accommodate modern jet engines that would otherwise overtax exhauster equipment. The orifice plate installation requires no alteration of the length, diameter, wall shape, or axial location of the basic diffuser.



a) Nomenclature



b) Flow patterns.

Fig. 1 Aircraft engine altitude test chamber schematic.

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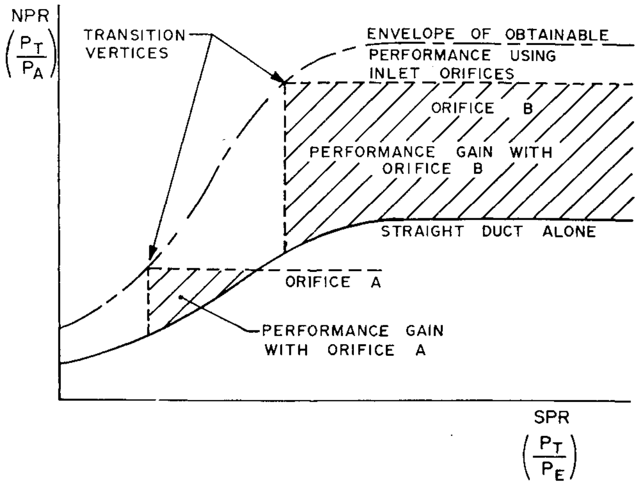

Fig. 2 Effect of inlet orifice plates on performance of a straight-duct diffuser (idealized).

Backflow as Performance-Limiting Mechanism

Figure 1 is a schematic of a jet engine installed in an altitude test chamber, sealed except for an air inlet supply duct and an ejector-diffuser exhaust duct. The pressure and dimensional parameters of interest are defined in Figure 1a, whereas 1b illustrates important flow-pattern characteristics. The upper half of Figure 1b represents the basic straight-pipe diffuser configuration. Viscous entrainment of fluid surrounding the jet occurs along the jet boundary, removing fluid from the altitude chamber and lowering P_A. However, the chamber is not evacuated completely; steady-state P_A is less than P_E, but greater than zero. In the absence of secondary flow, the only mechanism available to replace chamber fluid removed by entrainment is backflow from the diffuser duct.

The mechanism of backflow is implied in the discussion by Crocco.[1] This discussion is elaborated upon for "started" operation in Ref. 2, where downstream effects on rejection of jet fluid into the cell are considered.

Inlet-Orifice Backflow Trap

Alteration of the backflow or recirculation pattern thus appears as one potential means of significantly improving low-supersonic ejector-diffuser performance. The simplest backflow-reduction device suggesting itself to the authors was an orifice plate at the duct inlet, depicted in the lower half of Fig. 1b, which would pass the jet and entrained fluid but impede the movement of fluid upstream along the wall.

A model with the configuration in Fig. 1 was tested. Three ducts and eight orifice plates were tested with a single convergent nozzle (D_N = 0.75 in.). Duct-to-nozzle area ratios (A_P/A_N) of 5.5 nd 7.0 and duct length-to-diameter ratios (L_P/D_P) of 2.7 and 5.4 were tested. Orifice-to-nozzle diameter ratios of (D_O/D_N) ranged from 1.25 to 2.0. Further details of the test rig are presented, with the data obtained, in Ref. 3.

Figure 2 illustrates the results of testing with any given duct, with the performance of only two orifice plates shown for clarity. The solid line represents data obtained with the pipe alone, whereas dash lines show the alteration in performance produced by orifice plates. For a given orifice, for example orifice A, orifice-installed data were virtually indistinguishable from the basic duct-alone curve until a certain system pressure ratio (SPR = P_T/P_E) was reached. At this point, an abrupt rise in nozzle pressure ratio (NPR =

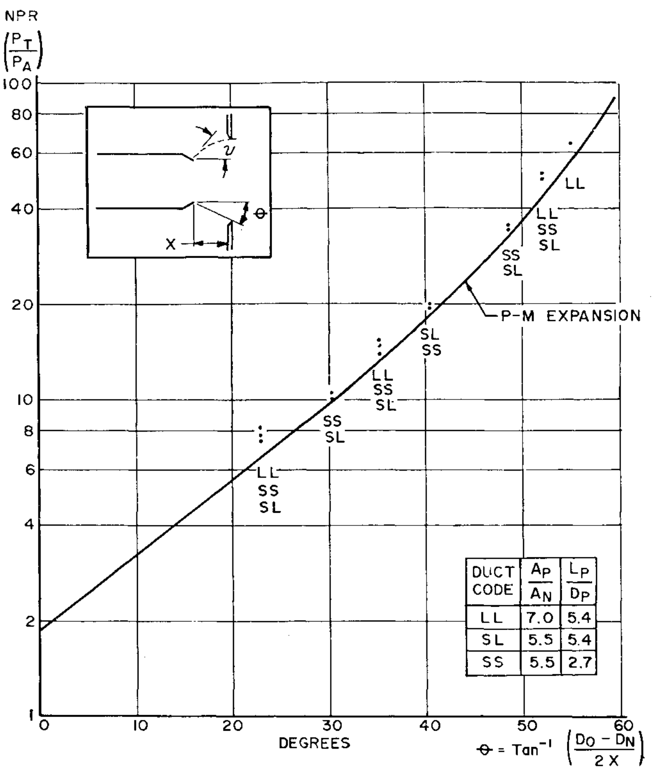

Fig. 3 Correlation of orifice-installed performance with Prandtl-Meyer expansion at nozzle exit.

P_T/P_A) occurred, after which further increases in SPR produced no effect on NPR. At the vertex of each transition, the NPR was roughly twice the NPR obtained by the duct alone at the same SPR. The SPR and NPR for each transition vertex increased with orifice size, axial position x being constant, until a maximum orifice size that was effective was reached. Increasing orifice size appreciably beyond this critical size resulted in the absence of any orifice effect at all.

Below transition, the jet evidently does not fill the orifice area, and backflow occurs from the duct into the chamber through the orifice. As SPR and hence NPR increase, the jet broadens and approaches the orifice lip until inadequate back-flow can occur to balance the fluid-removal rate from the chamber. At this point, P_A starts dropping rapidly and the jet expands until the lip is contacted. At this point, the original duct backflow is completely sealed off from the chamber and equilibrium is apparently established by a new recirculation pattern from the upstream lip of the orifice, as illustrated in the lower half of Fig. 1b.

The NPR established corresponds to a Prandtl-Meyer expansion at the nozzle throat through an angle ν approximately equal to the geometric angle θ defined in Fig. 3. This is demonstrated in Fig. 3 by the comparison between experiment and P-M expansion theory, plotted from Ref. 4, using θ as the turning angle. Experimental points lie slightly above the P-M line, since the actual turning angle ν is greater than θ due to jet curvature.

Conclusions

1) Backflow is the mechanism by which a steady-state chamber pressure is ultimately established in an ejector-diffuser under conditions of zero secondary flow. Therefore, reduction of backflow into the chamber and removal of backflow from the chamber by a route other than the diffuser duct are possible means of increasing performance. Experimental investigation of a single, simple technique (the inlet orifice plate) indicates that the potential gains are substantial.

2) Backflow is particularly significant for geometries and nozzle pressure ratios characteristic of aircraft engine testing. The basic assumption of normal shock recovery frequently is not satisfied in this case with a straight diffuser duct alone, but can be satisfied by the introduction of an appropriate inlet orifice plate.

3) The nozzle pressure ratio established above transition for a given orifice correlates with a nominal Prandtl-Meyer expansion angle from the nozzle throat to the orifice lip. It follows that axial position x, not investigated experimentally, is a governing parameter as well as orifice size.

4) Secondary flow effects, not investigated experimentally by the authors, are of practical interest for turbojet testing, since small secondary flows are generally present because of leakages (e.g., from inlet duct labyrinth seals) and the necessity for engine cooling. However, backflow is still presumably present over some small range of secondary flows, since an arbitrarily small secondary flow could not by itself balance the removal of chamber fluid due to jet-boundary entrainment. Therefore, appropriately sized orifice plates should produce some improvement in ejector-diffuser performance for small secondary-to-primary mass-flow ratios.

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Recent Flight-Test Results in Deploying a 20-ft-Diam Ribbon Parachute

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Introduction

Sandia Laboratory is conducting a continuing parachute research program to investigate the feasibility of deploying a heavy duty 20-ft-diam ribbon parachute at high dynamic pressures and Mach numbers of 2 to 3. The author[1] earlier reported results of tests up to $M = 2.2$- and 4290- psf dynamic pressure. This paper presents results of data from three additional tests at increased speeds up to $M = 2.43$ and 5700 psf dynamic pressure.

Apparatus

The specially designed 20-ft-diam ribbon parachute and 19.5-in.-diam test vehicle used on these three tests are described in detail in an earlier paper.[1] The parachute has 30 gores and 30 suspension lines of 12,000-lb tensile strength. Special reinforced selvage ribbons of 2000-, 3000-, and 4000-lb tensile strength are used with only one splice for each horizontal ribbon, the greatest strength being placed in the vent region. Figure 1 shows the 890-lb test vehicle and parachute

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