portions of the flow. Doing this here gives uncharted vent plane region velocities of $-0.49V_\infty$ and $+0.65V_\infty$ for the unsteady and steady cases, respectively. Considering the rapidly expanding canopy, the reverse flow in the unsteady case is not at all unreasonable. It is a well known fact that at $T = 1$ the canopy is being compressed in the axial direction.

Concluding Remarks

The velocity profiles about a flat circular parachute model have been found for both a time late in the inflation process when the canopy shape is close to the steady-state value and in steady-state. The previous unavailability of any similar data for the former case makes it quite useful for assessing any analytical attempts at describing the kinetics of opening. The data also suggest that the extent of the flow which is turbulent during opening is probably small enough that a potential flow mathematical model would give a reasonable description of the opening process.

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Experimental Study on Optimization Parameters of a Supersonic Jet Ejector Thrust Augmentor

Dah Yu Cheng* and Peter Wang†
University of Santa Clara, Santa Clara, Calif.
and
Dean M. Chisel‡
NASA Ames Research Center, Moffett Field, Calif.

Introduction

THE present experimental data were aimed at obtaining the effect of jet mixing, the effective length/diameter of the ejector tube, the entrance length shape factor, the shape loading, and the optimum primary jet location. The most effective thrust weight of the ejector tube was also examined from airborne vehicle point of view.

Simplified Theory

The similarity velocity profiles of a turbulent jet issuing from a wall was first analyzed by Schlichting.[1] The streamlines were shown in Fig. 1a. The velocity profiles

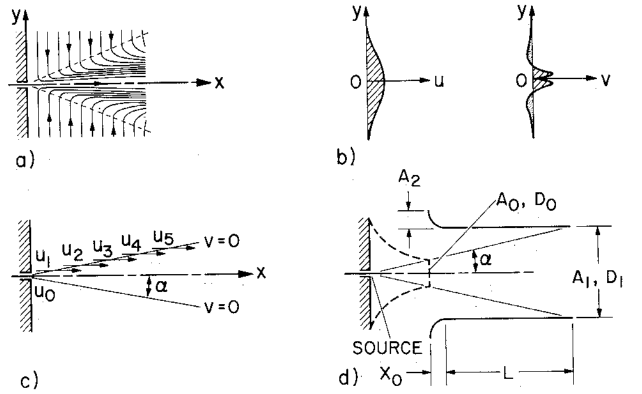

Fig. 1 a) Streamlines of a circular wall jet. b) The velocity profiles u, v, as a function of y at an arbitrary x location. c) $v = 0$ line, and the induced velocity. d) Parameters of a jet agumentor experiment.

have similarity solutions given as

$$u = \frac{3}{8\pi}\frac{K}{\epsilon_0 x}\frac{1}{(1 + \frac{1}{4}\eta^2)^2};$$

$$v = \frac{1}{4}\left(\frac{3}{\pi}\right)^{1/2}\frac{(K)^{1/2}}{x}\frac{[\eta - (1/4)\eta^2]}{[1 + (1/4)\eta^2]^2}$$

where

$$\eta = \frac{1}{4}\left(\frac{3}{\pi}\right)^{1/2}\frac{(K)^{1/2}}{\epsilon_0}\frac{y}{x};\ K = 2\pi\int_0^\infty u^2 y dy$$

ϵ_0 is the turbulent kinematic viscosity. In subsonic flow $\epsilon_0/(K)^{1/2}$ was found to be a constant[2]; therefore, variation of jet momentum K does not change the geometrical pattern of the streamline with respect to y, and x. The velocity profile of the radial component v has a zero point (Fig. 1b) due to the expansion of the streamlines in the center region just compensated by the induced inward velocity. This occurs at $\eta = 2$. The velocity crossing $\eta = 2$ line has u component only and it is a measure of the induction mass. From experimental data of Riechardt[2] $\epsilon_0/(K)^{1/2} = 0.0161$, hence $\eta = 2$ line has an angle of $\alpha = 7.5°$ (Fig. 1c). If an ejector is added to a jet, from the above streamline analysis apparently the ejector length beyond the interception point of ($v = 0$) line contributes nothing to the ejector pumping action; therefore, the ejector only requires a fixed L/D according to α regardless of their diameter.

A finite diameter jet for the real experimental case can be simulated by a jet source at an appropriate location in-

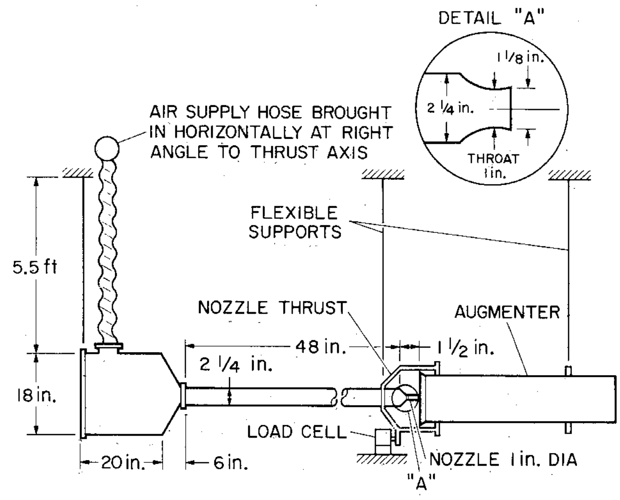

Fig. 2 The test setup.

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*Senior Research Associate, Mechanical Engineering Department. Member AIAA.
†Research Assistant.
‡Research Scientist.

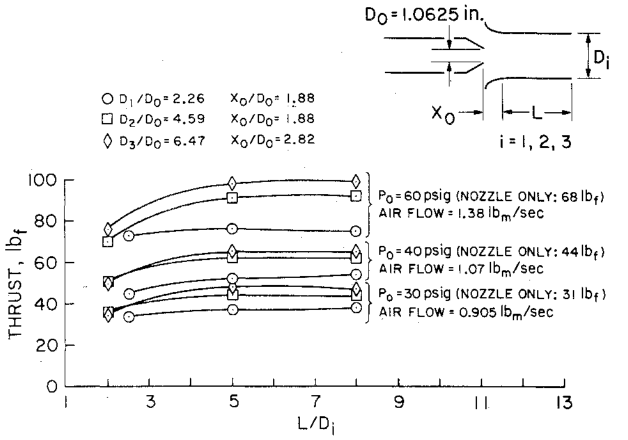

Fig. 3 The effect of L/D on the ϕ at different nozzle pressure p_0 and ejector diameter D_i's.

side the nozzle;[3] so that the similarity solution is still valid (Fig. 1d). The induced flow is given by Schlichting[1] as $Q = 0.404\ x\ (K)^{1/2}$; therefore, the distance x_0 of primary nozzle (Fig. 1d) to the throat of the ejector will change the effect of ejector entrance streamline around the lip. The pressure difference across the lip due to those streamlines constitutes the main source of thurst augmentation. Additional length beyond $\eta = 2$ and wall intercepting point will not increase the augmented thrust.

Experimental Setup

The compressor out-bleed from a gas turbine engine was used as the air supply. The bleed air was fed through a flexible hose into a large plenum chamber. In order to eliminate the inlet momentum effects the inlet port to the plenum was perpendicular to the outlet. The plenum chamber was rigidly connected to the primary nozzle and augmentor. The entire test assembly was supported by a long flexible support strap as shown in Fig. 2. The assembly movement in the axial direction was opposed by a load cell. The output of the load cell was a measurement of the augmentor thrust performance. The nozzle has a 2° short divergent section, and 1⅛ in. i.d. The ejector diameters tested are 2½ in., 5 in., and 7 in. at various lengths. The nozzle stagnation pressure p_0 was also considered a testing parameter. The experimental results are presented in the following section.

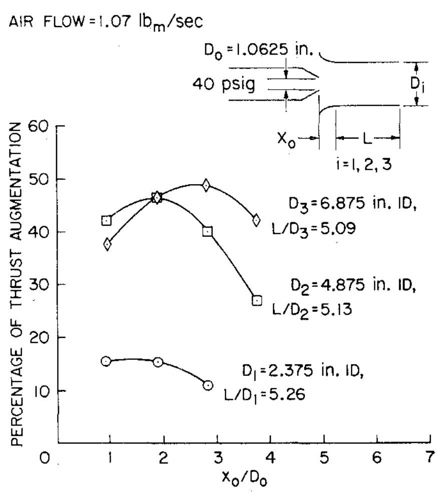

Fig. 4 The optimum location of the primary jet X_0/D_0, for D_i = 2 in., 5 in., and 7 in. a) p_0 = 60 psig and b) p_0 = 40 psig.

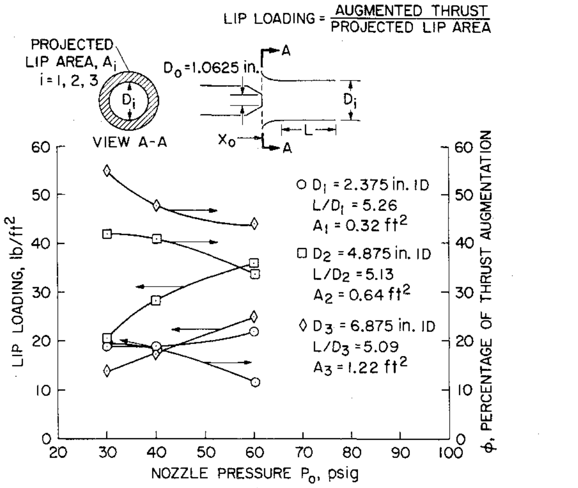

Fig. 5 Effectiveness of turbulent mixing and the entrance lip loading as function of p_0, D as indicated by ϕ for each D_i's.

Effect of L/D_i of the Ejector and Prime Jet Location

The α of $v = 0$ line of a turbulent jet is 7.5° if $\epsilon_0(K)^{1/2} = 0.0161$ as tested at subsonic conditions.[2] In slightly supersonic flow, the similarity condition is expected to hold, maybe with a different α. The ejectors as a function of L/D with a lip at p_0 = 60, 40, and 30 psig were tested as shown in (Fig. 3). The total thrusts recorded were increased from L/D_i about 2 to a plateau at L/D_i of 5, beyond that increasing L/D_i did not result to further thrust augmentation, for all D_i's and all pressure p_0's. This indicates that similarity profiles do exist for slightly supersonic flow, as the optimum L/D is not influenced by p_0. If the amount of thrust augmentation to the thrust without the ejector is defined as ϕ. Up to 40% ϕ was obtainable.

The optimum positions of the jet for different ejector sizes were shown in Fig. 4, such that too far away from the ejector lip reduces the velocity around the lip and too close to the ejector choked off the induction flow.

Discussion

From the experimental data just shown, the total augmented thrust is proportional to the diameter of the ejector, but this does not mean the most economical choice for a practical design. There is no question that the jet mixing efficiency is of the prime importance, but the data also show for a practical design the entrance lip shape and the stream lines (a function of X_0/D_0) around the lip is also important in order to optimize the percentage augmentation ϕ. Since the jet has a slightly under expanded supersonic velocity, the eddy viscosity ϵ_0 may be different than the subsonic case. In Fig. 5, ϕ drops off towards higher nozzle pressure. ϕ up to 55% was obtained for 7 in. o.d. ejector at lowest nozzle pressure tested.

Since the augmented thrust hinges on the way the pressure differences across the entrance lip, a lip loading can be defined as the ratio of augmented thrust to the projected lip area. The lip loading is also plotted in Fig. 5 as a function of D_i and p_0. The data shown, D_i = 5 in. has the best lip loading for all p_0 values. The structure weight of ejector can be optimized around those test results.

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