Analytical and Experimental Investigation of Diffusers for VSTOL Thrust-Augmenting Ejectors

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Abstract

A THRUST-AUGMENTING ejector is a pneumatic device in which the direct transfer of kinetic energy from a primary jet to air drawn in from the atmosphere (via turbulent mixing) produces an increase in the primary thrust. For VSTOL applications, the allowable length of the ejector is small and the diffuser (sidewall flap) design has an important effect on augmentor performance. It was experimentally demonstrated that improved augmentation can be obtained with cambered flaps or straight flaps with tabs. Various combinations of tab blowing and upstream Coanda blowing were experimentally and analytically examined with centerbody and total nozzle area held constant.

Nomenclature

A_0 = primary nozzle area (center jet + Coanda + tab) + boundary-layer control (BLC)
A_2 = throat area, $W \times s$
A_3 = exit area, Fig. 1
L = distance from throat to exit, Fig. 1
W = throat width, Fig. 1
ϕ = augmentation ratio = total load stand thrust/total nozzle isentropic thrust (including BLC)
s = span of augmentor

Contents

Turbojet engine static thrust can be increased significantly by diverting the exhaust flow through a thrust-augmenting ejector. This device increases the thrust by transferring the energy of the engine exhaust flow to a larger mass of air drawn in from the atmosphere. This transfer of energy is obtained by the turbulent mixing of the two streams. With high-performance ejectors it is possible to obtain the additional direct lift required for VTOL operation from the cruise engine itself. To demonstrate this technology, Rockwell International has built and is currently testing the XFV-12A, a VTOL prototype Navy aircraft employing ejectors in the wing and canard.

The design of the diffuser for such ejectors is an important consideration. "Simple" thrust augmentors generally use straight-walled diffusers, although this may not insure peak performance. Thrust augmentation ratio ϕ increases with the exit/throat area ratio (A_3/A_2) for a given throat/primary nozzle area ratio (A_2/A_0), until some limiting exit area A_3 causes flow separation. In general, the upper diffusion limit before the onset of separation is set by the flap length-to-throat ratio, L/W, the shape of the flap and the type of boundary-layer control, if used. In typical aircraft applications, short diffusers ($L/W \leq 1.5$) are normally required.

It is the purpose of this study to analytically and experimentally investigate 1) the effect of the diffuser flap shape, and 2) the effectiveness of trailing edge or tab blowing on augmentor thrust performance.

Augmentor Configurations Investigated

The augmentors used Coanda nozzle wall jets at the inlet, as shown in Fig. 1. In short ejectors, the problem becomes one of achieving the highest possible ratio, A_3/A_2, without flow separation occurring along the flaps, for a given distance L from throat to exit. A cambered flap, shown in Fig. 2a, may achieve this goal and offer a potential improvement in ϕ.

A second series of configurations involved a straight flap plus tab that approximated the shape of a cambered flap (Fig. 2b). From the aircraft manufacturing viewpoint, the straight flap plus tab versions are simpler. The cambered flap (Fig. 2a) was evaluated in a different ejector and had a length of 8 in., as compared to 7 in. for those in Fig. 2b.

Discussion of the Results

Cambered Flaps

In Table 1, performance of the cambered flap is shown as a function of the diffusion ratio, A_3/A_2. Cambered flaps

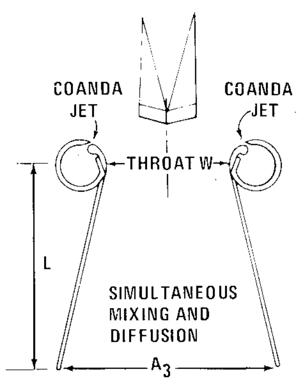

Fig. 1 Augmentor configuration.

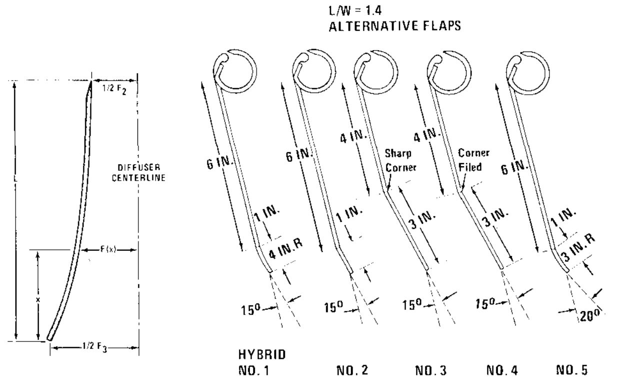

Fig. 2 Diffuser flap shapes.

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Index categories: Powerplant Design; Airbreathing Propulsion; Nozzle and Channel Flow.

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Table 1 Comparison of ϕ for straight and cambered flaps ($L/W=1.2$, $A_2/A_0=26$, nozzle pressure ratio = 2.1)

A_3/A_2	ϕ cambered	ϕ straight
1.5	1.56	1.43
1.6	1.58	1.45
1.75	1.605 (peak)	1.48
1.8	1.595	1.485 (peak)
1.9	1.58	1.475

provide about 0.12 improvement in ϕ over the straight flap for a wide range of A_3/A_2 values.

Straight Flaps Plus Tabs

The performance of these five alternate flaps is compared in Fig. 3 with that for a straight flap of $L/W=1.43$. The performance of the hybrid flaps are similar to one another, at least within experimental error; all give about an 0.05 improvement over the straight flap. All flaps, straight and hybrid, experience corner separation at or near $A_3/A_2=1.9$, as evidenced by the rapid decrease in ϕ.

Tab Blowing

It is also of interest to determine how the flap blowing should be distributed along the flap. This blowing may all originate on the Coanda surface, as shown in Fig. 2, or it may be distributed to one or more additional nozzles closer to the exit. In the present investigation, a wall jet was also installed in the vicinity of the "sharp corner" shown in Fig. 2b for configuration 3. The design of the tab blower was similar to the Coanda blower, with a smooth flow transition to the tab. Total nozzle area A_0 was held constant. Figure 4 summarizes the results. For the configurations tested, peak ϕ performance is obtained when the primary flow is assigned to the inlet Coanda jets. The result is greater mixing of primary and secondary air with the upstream blowing.

The trend of these results was verified analytically with a computer program employing the method of Gilbert and Hill.[1] The differential equations, describing the viscous compressible flow within the augmentor, were represented by a set of forward-marching, finite-difference equations. Wall jets were added to simulate the Coanda jet flow. Analytical results confirm that ϕ decreases with tab blowing for positive diffuser angles. This is due to a "blanketing" of the tab wall jet by the upstream Coanda jet, decreasing overall entrainment. With a negative diffuser angle, analyses show that ϕ increases with tab blowing. This configuration still needs to be tested.

Conclusions

For the range of operational conditions and augmentor configurations investigated, it can be stated that:

1) Cambered flaps can offer improved augmentation ratio when compared with straight flaps. For a baseline ϕ ratio of 1.48, this improvement is 0.12 and is due to an increased external diffusion and greater secondary mass flow.

2) Hybrid flaps that approximate a smooth camber can also provide improved augmentation ratio.

3) The best location for the wall jet nozzle is upstream of the throat on the Coanda surface.

Distributing primary air nozzles to locations near the augmentor exit cause wall jet momentum, secondary mass flow, and augmentation ratio to decrease.

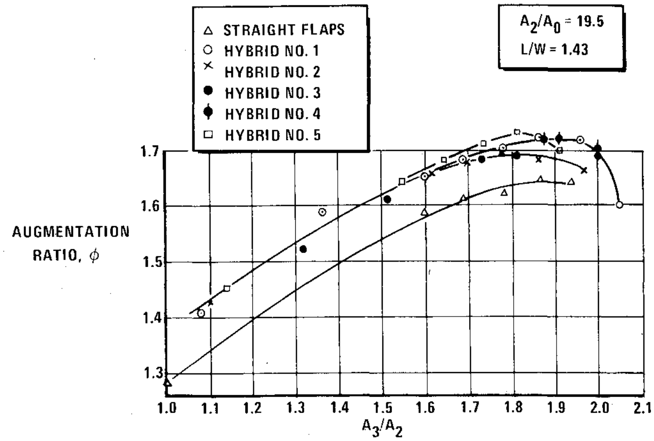

Fig. 3 Comparison of ϕ for straight flap plus tabs.

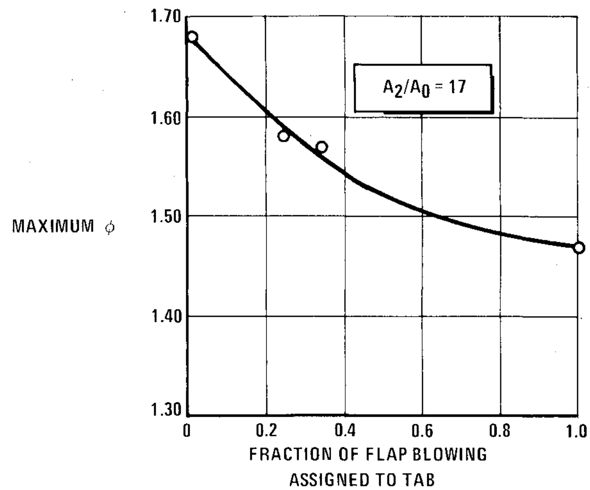

Fig. 4 Effect of the percentage of tab blowing on ϕ.

References

[1] Gilbert, G.B. and Hill, P.C., "Analysis and Testing of Two-Dimensional Slot Nozzle Ejectors with Variable Area Mixing Sections," NASA CR-2551, May 1973.