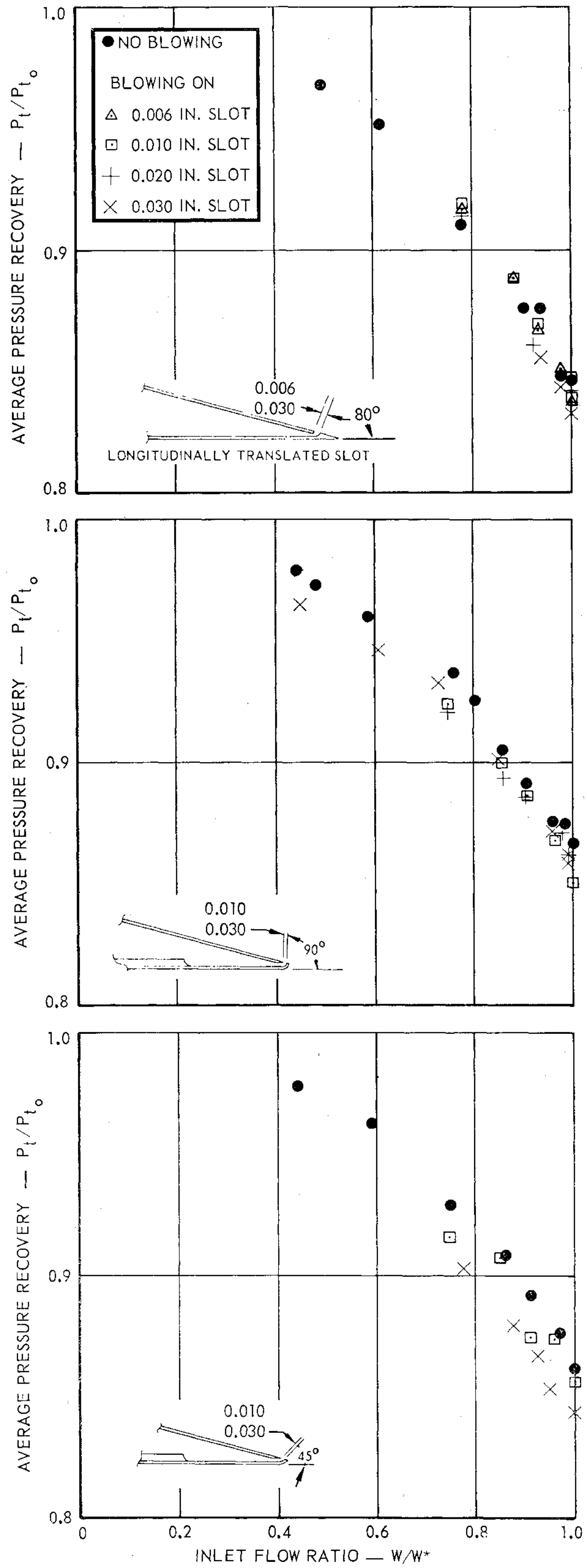

Fig. 3 Inlet performance comparisons.

and that the jet flow would attach at the inlet lip. The inspections of Fig. 4 shows that the round lip, created by the jet flow, extended well inside the inlet lip and restricted the inlet flow area. Thus, the pressure recovery improvements that might have been realized as the result of rounding the lip were offset by higher pressure losses associated with inlet flow area restriction.

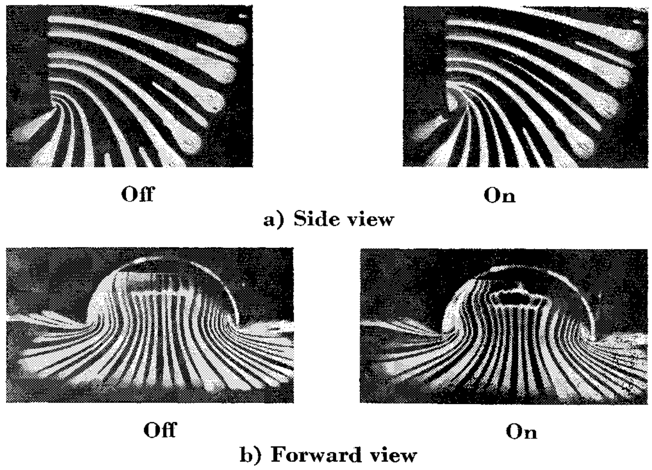

Fig. 4 Inlet streamlines with and without blowing.

In conclusion, the test program showed that the concept was not feasible, regardless of the amount of jet flow. Should some technique for attaching the blown air at the lip develop, the predicted improvements may be possible.

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Vortex Separation above Delta Leading Edges

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As the inclination of a delta wing in a subsonic or moderately supersonic flow increases, there is a tendency for vortex separation to occur and cause a lowering of pressure

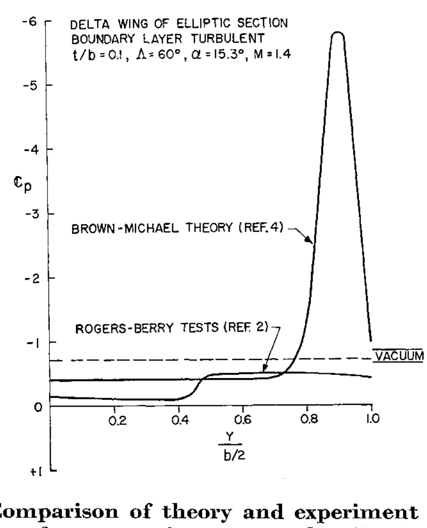

Fig. 1 Comparison of theory and experiment for upper-surface, spanwise pressure distribution.

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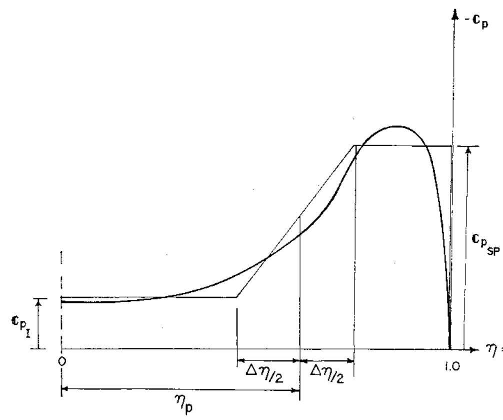

Fig. 2 Typical upper-surface, spanwise pressure distribution and suggested approximation.

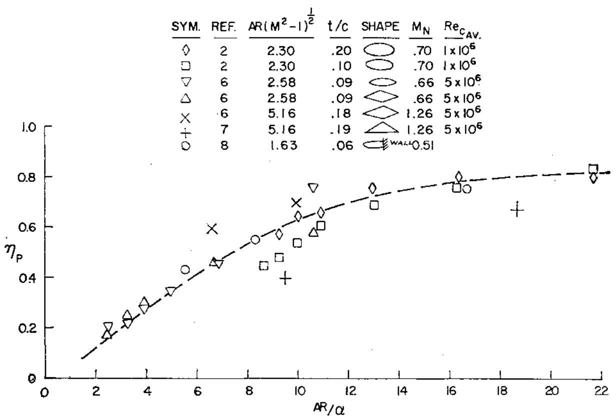

Fig. 4 Collected data for spanwise stations at which pressures change from inboard levels to suction peak levels.

above the leading edge. If the flow is subsonic, this usually appears as a second "suction peak" behind the primary one.[1] If the flow is supersonic with subsonic leading edges, the effect is a general magnification of the suction region[2]; see the bottom curve in Fig. 1. In either event, the onset of vortex separation can be identified by noting the onset of nonlinearity in the $C_L(\alpha)$ curve. If the edges are supersonic, a vortex separation phenomenon seldom appears.[3]

Several analyses of vortex separation flow exist in the literature. In Ref. 4 the rolled up vortex is approximated by a core and a feeding sheet from the leading edge. The potential equation is linearized,

$$(1 - M^2)\varphi_{xx} + \varphi_{yy} + \varphi_{zz} = 0 \qquad (1)$$

and then the further approximation of high sweep is made and the first term is dropped. In the ensuing cross-flow plane analysis, the vortex system is allowed to sustain no forces. The conical solution does exhibit suction peaks, but the answers can be quantitatively unsatisfactory (see Fig. 1). Therefore, the chief usefulness of Ref. 4 would seem to be in identifying the significant parameter groups for the correlation of experimentally observed pressure distributions. The predicted functional relation is

$$C_p/\alpha^2 = fn(\eta \equiv y/b/2, \alpha/AR) \qquad (2)$$

This is the same result as predicted by the classical analysis of Ref. 5, which was also an inviscid cross-flow plane treatment, but for delta wings without the leading edge vortices. Again, Mach number effects were not treated explicitly.

A more general similarity analysis (of the inviscid, linearized equations) is easily accomplished, and the similitude (not surprisingly) turns out to be

$$C_p/\alpha^2 = f_n[\eta, \alpha/AR, AR(|M^2 - 1|)^{1/2}] \qquad (3)$$

Equation (3), of course, represents two relations; subsonic and supersonic flows have to be treated separately.

It is suggested that the separated vortex pressure distribution in the supersonic case can be approximated as shown in Fig. 2. The inboard pressure C_{pI}, the suction peak pressure C_{psp}, and the spanwise dimensions η_p and $\Delta\eta$ are expected to have some functional dependency similar to Eq. (3). Pressure distributions from Refs. 2 and 6–8 have been collected and examined in this light.

Figure 3 shows the collected data for suction peak pressure. It should be noted that there is a serious scarcity of data for $AR(M^2 - 1)^{1/2}$ different from about 2.5; nevertheless, it seems established that a correlation does exist. Figure 4 is presented for the determination of η_p, which shows little dependence on $AR(M^2 - 1)^{1/2}$. The quantity $\Delta\eta$ showed no systematic variation, but a good average value is 0.25. Attempts to correlate C_{pI} were completely unsuccessful; this probably is because of ridgeline interference effects. It can only be suggested that inboard pressures be calculated according to any method employed for wings without leading edge separation. An approximation for the upper-surface pressure distribution then is completely determined.

A few other remarks concerning the collected data are in order. Thickness, as represented by t/c, was not always small compared with angle-of-attack α. In such cases the similarity rule requires that t/c be proportional to α. Also, those data for which normal Mach number component M_N exceeds 1.0 were not expected to correlate well. Finally, certain possibly important factors such as frontal section shape, leading-edge geometry, and Reynolds number have not been accounted for.

In conclusion, this note has assembled data from the literature on vortex-separated deltas in supersonic flow. Correlations for estimating separation effects on pressure distributions have been presented. A systematic experimental program for the establishment of reliable formulas in both the subsonic and supersonic problems would seem to be called for at this time.

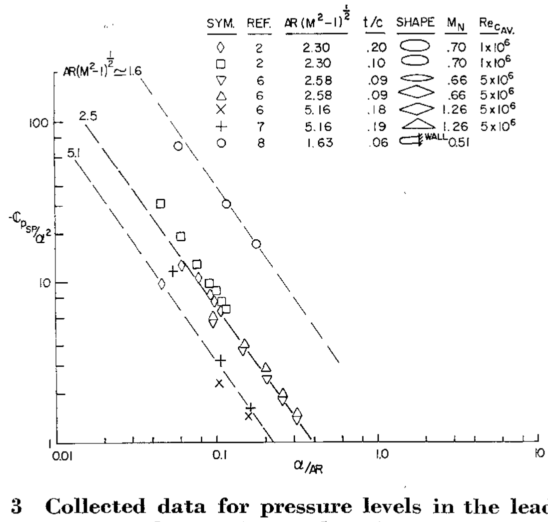

Fig. 3 Collected data for pressure levels in the leading-edge suction peak region.

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Thrust Deflection for Cruise

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Introduction

The use of thrust deflection to improve cruise range is surely an old idea and one which has been investigated numerous times. But it may be particularly applicable to hypersonic airbreathing vehicles because of the combination of two technical factors: the moderate lift/drag ratios of hypersonic cruise vehicles and the low gross-thrust/ram-drag ratios of hypersonic airbreathing power plants. Low lift/drag ratios are known to make thrust deflection more effective, but the effects of gross-thrust/ram-drag ratio on thrust deflection have not, to the author's knowledge, been discussed. It is the primary purpose of this note, therefore, to indicate that hypersonic airbreathing vehicles may benefit substantially from thrust deflection.

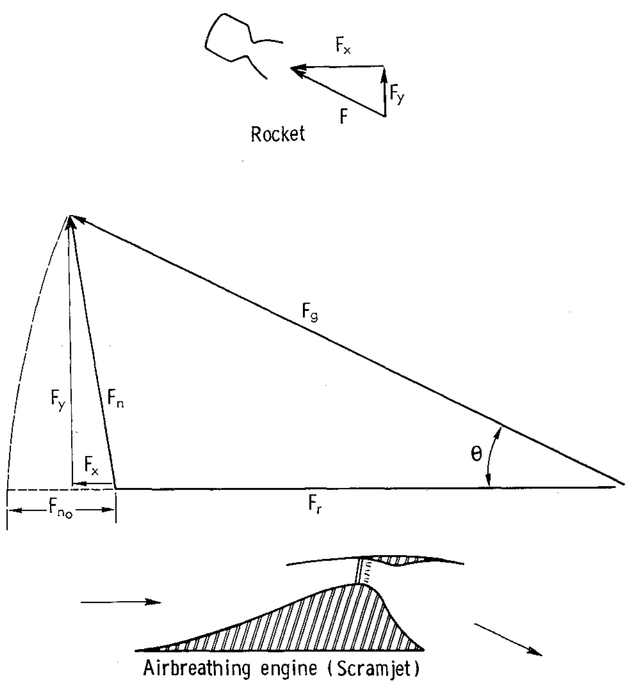

Fig. 1 Schematic of deflected rocket and airbreather.

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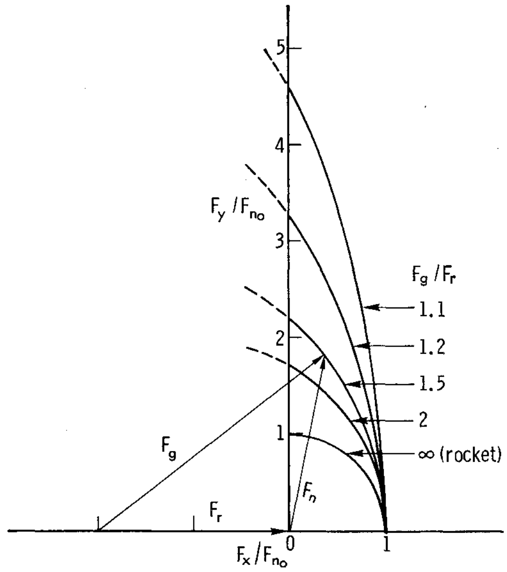

Fig. 2 Construction of thrust-component curves.

Discussion

The gross-thrust/ram-drag ratio (F_g/F_r) for a hypersonic airbreathing power plant may easily be as low as 1.1 at Mach 10 or 12, and, although estimates are quite uncertain, it tends to become still lower at higher speeds. Since this ratio is close to unity for ramjets or supersonic-combustion ramjets the vertical component of thrust, for a given deflection angle, is larger for these engines than for a rocket power plant. Figure 1 contrasts rocket and airbreathing power plants having the same undeflected thrust under the same nozzle deflection angle.† The essential point is that the gross thrust, which can be much larger than the net thrust in an airbreather, is the part that is deflected.

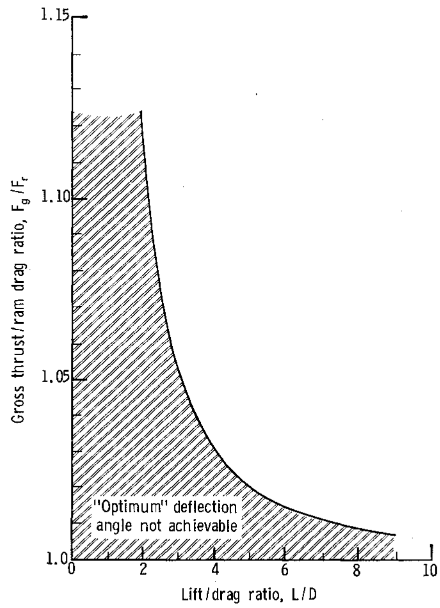

Fig. 3 Combinations of L/D and F_g/F_r for which the "optimum" deflection angle of Eq. (1) can be reached.

† A sketch like the vector diagram for the airbreather of Fig. 1 was given in a paper by G. S. Schairer, "Looking ahead in VSTOL," at the Eighth Anglo-American Aeronautical Conference, London, in 1961. Although his discussion made it clear that the features considered here were appreciated, they were not quantified and were not relevant to the subject under discussion there.