A Novel Concept for Subsonic Inlet Boundary-Layer Control

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Nomenclature

- $\mathfrak{D}_{max}$ = index of maximum distortion [(maximum total pressure) − (minimum total pressure)]/(average total pressure)
- $D_{60°}$ = index of circumferential distortion [(average total pressure) − (minimum average total pressure over any 60-deg sector]/(average total pressure)
- IDC = index of circumferential distortion[1]
- IDR = index of radial distortion[1]
- $\bar{M}_t$ = average throat Mach number assuming one-dimensional flow
- p = surface static pressure
- P = total pressure at diffuser exit
- P_0 = freestream total pressure
- $\bar{P}$ = average total pressure at diffuser exit
- V_0 = freestream velocity
- ψ = angular circumferential displacement from windward position, deg

Introduction

BOUNDARY-LAYER bleed systems are used to improve the performance and control of supersonic inlets where the problems of shock-boundary layer interactions and supersonic diffusion are encountered.[2] The diffusion of supersonic flow has not usually been associated with subsonic inlets so that boundary-layer control was not generally required. Supersonic diffusion can arise, however, in subsonic flight if the inlet is subjected to a sufficiently high combination of forward velocity and angle of attack.[3] Some examples where this has been encountered are inlets for VTOL and STOL aircraft[4] in the departure and approach portions of flight. The inlets for highly maneuverable military aircraft may also have similar problems.

This Note describes a novel boundary-layer bleed concept tested for a subsonic inlet designed to operate in the flowfield generated by high angles of attack. Naturally occurring surface static pressure gradients were used to remove the boundary layer from a separation-prone region of the inlet and to reinject it at a less critical location with a net performance gain.

Inlet Design and Analysis

The sketch and table at the top of Fig. 1 show the overall proportions of the test inlet. The 30.48-cm-diam model was tested at a forward velocity of 41 m/sec (80 knots) over a range of angles of attack in the Lewis Research Center's Low-Speed Wind Tunnel. A vacuum system was used in place of an engine or fan to induce inlet flow. The inlet proportions are suitable for a high subsonic cruise speed aircraft.

Previous tests with this inlet indicated that flow separation occurred in the forward portion of the diffuser at the windward side for increasing angles of attack. The boundary-layer bleed system designed to eliminate this separation is shown by the lower left-hand sketch of Fig. 1. It consisted of a slot just downstream of the throat in the diffuser and two rows of holes located on the lip at either side of, and displaced circumferentially from, the slot. Details of the slot and holes are shown by section views AA and BB. The system was designed to eliminate flow separation by using the low static pressure on the lip as a source of suction to remove, via the slot, the boundary layer from the critical portion of the diffuser. The flow path for the removed boundary layer was formed by constructing the inlet with a circumferential plenum open to the slot and holes. The suction holes on the lip were displaced circumferentially from the slot to avoid recirculation of the removed boundary-layer flow.

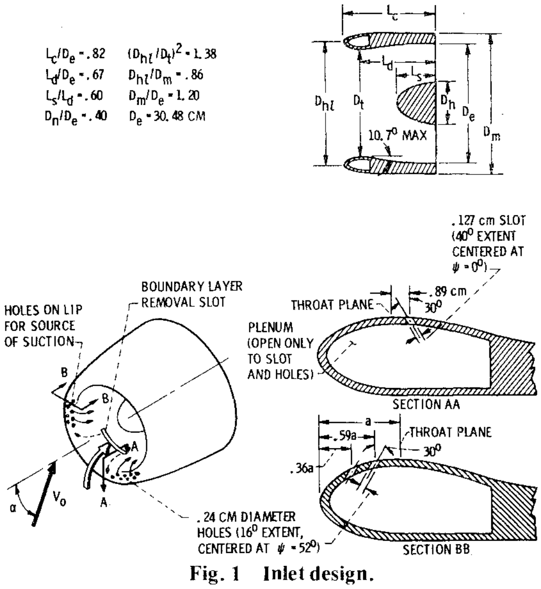

Fig. 1 Inlet design.

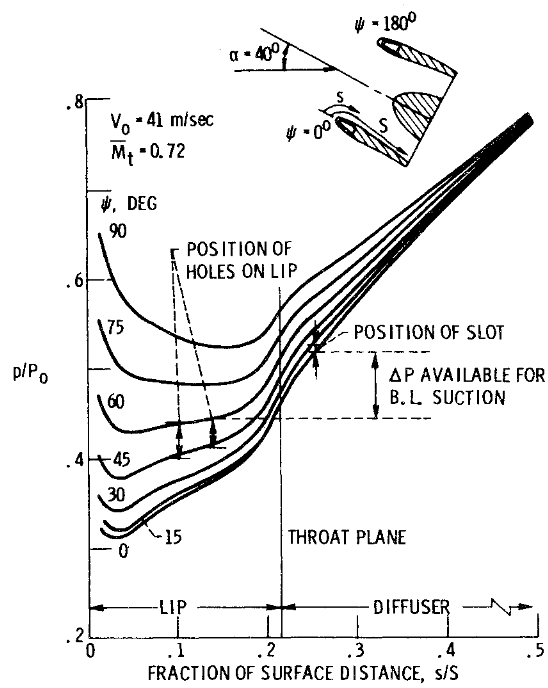

Fig. 2 Potential flow analysis showing predicted surface static pressure distributions as a function of surface distance from the highlight and circumferential displacement (ψ) from the most windward position.

Figure 2 shows the inlet surface static pressure distributions determined from incompressible potential flow calculations corrected for compressibility.[5] These were used as a guide in selecting locations for the slot and holes. The figure indicates how the differential pressure available for boundary-layer removal is affected by circumferential position ψ and longitudinal surface position s. The location selected for the

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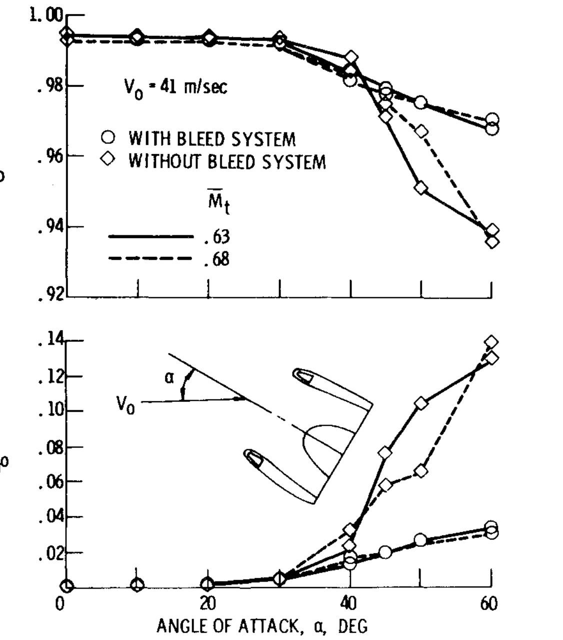

Fig. 3 Improvement in total pressure recovery and reduction of distortion obtained with bleed system.

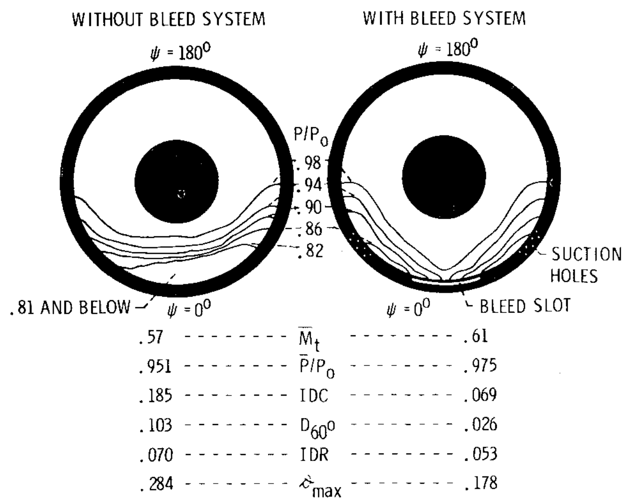

Fig. 4 Total pressure contours at diffuser exit: $\alpha = 50$ deg, $V_0 = 41$ m/sec.

bleed slot within the diffuser is downstream (to the right) of the throat plane. Note that circumferential positions then available on the lip for the low-pressure suction source were limited in the direction of higher values of ψ by a diminishing differential pressure, and in the direction of lower values of ψ by the possibility of developing a recirculating flow between the intake slot and the exit holes. The position selected for the two rows of suction holes represents a compromise between these two extremes. The axial location and spacing of the holes were chosen to reduce the differential pressure between the rows so that locally recirculating flow would be avoided.

Results

The improvement in pressure recovery and reduction of diffuser exit distortion obtained with the bleed system are shown in Fig. 3 as a function of angle of attack. Data for two values of average throat Mach number show a clear advantage with the bleed system for angles above approximately 40 deg. At lower angles performance was unaffected. This apparent lack of a performance penalty at low angles is attributed to reduced bleed flow owing to the much diminished differential pressure between the lip and throat region.[6] The bleed system thus tends to be somewhat self-adaptive by increasing or decreasing the amount of boundary-layer control depending upon the magnitude of the differential pressures, or adverse pressure gradients, that exist within the inlet.

The diffuser exit total pressure contours of Fig. 4 present a graphic picture of the improved flow obtained with the bleed system. The left-hand contour, obtained without bleed, shows a large region of total pressure loss centered about the most windward position ($\psi = 0$). This resulted from diffuser flow separation. The right-hand contour with bleed shows much higher pressure in this region, indicating fully attached, or nearly fully attached flow. The regions of relatively modest total pressure loss to either side of the windward position reflect the diffuser boundary layer ejected back into the inlet through the holes on the lip.

In addition to throat Mach number and pressure recovery, Fig. 4 also lists several distortion indices to permit a quantitative comparison of the two patterns. Circumferential distortion, as defined by IDC and D_{60°, was reduced approximately three- to four-fold with the bleed system. Radial distortion, IDR, was reduced 25% while the maximum overall distortion, D_{max}, was reduced approximately 40%.

The lack of rotating machinery with the present model precluded making any measurement to assess what impact, if any, the bleed system might have on fan or compressor noise generation.

Concluding Remarks

The encouraging results presented here suggest that this self-bleeding method for boundary-layer control might be successfully applied to other inlets operating at extreme aerodynamic conditions. Additionally, the flow stabilization possible with this concept could be used to design new shorter, lighter, induction systems that would otherwise suffer flow separation at normal conditions. Although analysis of inlet potential flow will serve as a guide in selecting locations for the bleed and suction ports, detail design of the bleed system will likely require trial and error testing to obtain optimum results.

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Applications of an Improved Nonlinear Lifting-Line Theory

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Introduction

PRANDTL'S lifting-line theory has been well developed in the past to allow the use of nonlinear section data in the

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