Performance Prediction of High-Inlet-Blockage Diffusers

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Abstract

A METHOD, based on "full viscous calculations" (i.e., the flow is calculated without separating it into a boundary layer and a core), is presented to predict the performance of straight two-dimensional diffusers. The method predicts adequately the experimental pressure recovery data up to the point of maximum pressure recovery, for both low and high inlet blockages. It is shown that, at the point of maximum pressure recovery, the streamwise velocity in the near wall region varies as $Z^{0.22}$, where Z is the distance from the wall.

Contents

A considerable amount of experimental work has been carried out to determine the performance of straight two-dimensional diffusers. Attempts to theoretically predict diffuser performance, in particular with high inlet blockage, have so far met with limited success.

The difference between the calculated pressure recovery C_{pt} and the measured pressure recovery C_{pm} (see, for example, Fig. 1) is due to the partial flow separation that occurs in the real flow but is not accounted for in the theoretical calculations. Based upon the fraction of diffuser wall area from which the flow has separated, Fox and Kline[1] have classified various flow regimes. As can be seen from Fig. 1 and in greater details in the figures in Ref. 2, C_{pt} is reasonably close to C_{pm} up to the point where C_{pm} reaches its maximum. The agreement is even closer up to the regime of no appreciable stall, which occurs at a lower area ratio for a given diffuser length. However, because the partial separation is not accounted for in the theoretical calculations, these various flow regimes cannot be identified directly from the calculated values of C_{pt}. To predict the performance of a diffuser theoretically, one needs to use some other calculated flow parameter to determine when a desired flow regime has been reached.

The first effort along these lines was made by Reneau.[3] He found that for diffusers with small inlet blockage the line of no appreciable stall is reached when $d\delta_2/dx$, the streamwise gradient of the boundary-layer momentum thickness, reaches a value approximately equal to 0.012. This correlation did not hold for diffusers with appreciable inlet blockage and the present author has confirmed these results.

In the present study the point of maximum C_{pm} was selected as the flow regime for correlation. This is the only flow regime that can be unambiguously identified in the experimental data over the entire range of the inlet blockages. The point of maximum C_{pm} was correlated with the calculated parameter m, defined by the relation $u \sim Z^m$, where u is the streamwise velocity in the near wall region just outside the viscous sublayer and the transition zone and Z the normal distance from the diffuser wall. Shown in Fig. 2 is a typical set of calculated velocity profiles at various distances along the diffuser in terms of the reduced boundary-layer parameters Z^+ and u^+. (In the figures AR represents the area ratio, L the diffuser length, H_0 half the diffuser height at the inlet, δ_l/H_0 the inlet blockage, and θ the diffuser half angle.) Dots on the curves in Fig. 2 represent computational grid points along

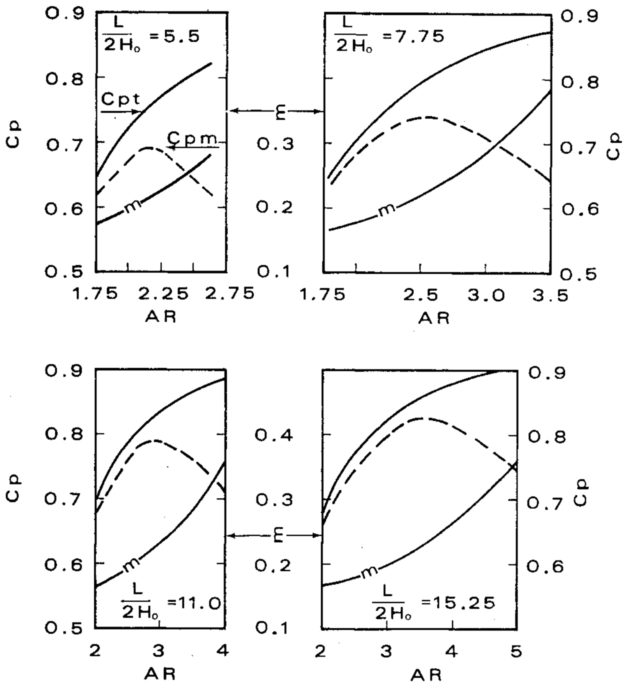

Fig. 1 Distributions of C_{pt} and C_{pm} from Ref. 4 and m as functions of area ratio for different diffuser lengths, $L/2H_0$ (inlet conditions: blockage = 0.007, area ratio = 8, velocity = 69 m/s, fluid-air at NTP).

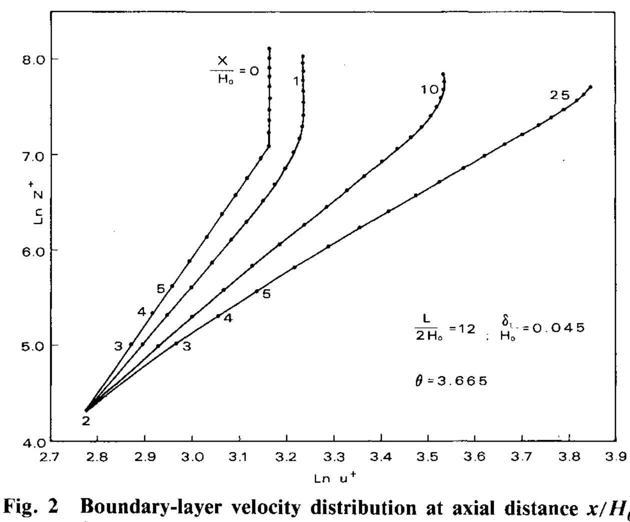

Fig. 2 Boundary-layer velocity distribution at axial distance x/H_0 equal to 0.1, 10, and 25 ($L/2H_0 = 12$, $\delta_l/H_0 = 0.045$, and $\theta = 3.665$).

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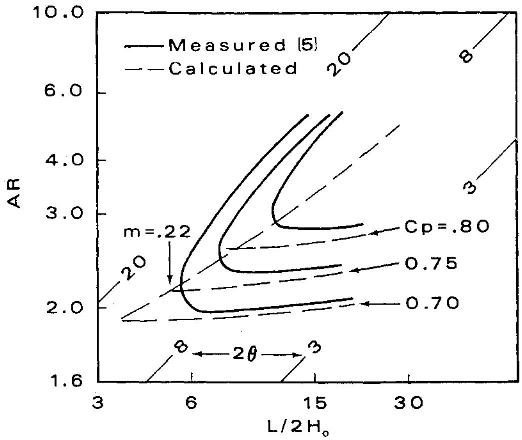

Fig. 3 Measured and calculated contours of constant C_p for inlet blockage equal to 0.007; also shown is the calculated locus of C_p maximum using criterion $m=0.22$ at C_p maximum.

which u was computed and x is the streamwise distance measured from the diffuser inlet. The first grid point next to the wall (grid point 2 in Fig. 2) was selected such that the local Reynolds number was equal to ≈ 1200. Details of the calculations are given in Ref. 2. It can be easily seen that if we approximate the velocity distribution near the wall by $u \sim Z^m$, then the slope of the velocity profiles as plotted in Fig. 2 is equal to m. The correlation parameter m presented in this study is the slope of the straight line fitted, using regression analysis, through grid points 2-5 in Fig. 2.

The parameter m was found to grow monotonically with x for a given diffuser half-angle. Further, the rate of growth of m was found to increase with an increase in the diffuser half-angle or with an increase in the inlet blockage. Typical growth curves for m are shown in Ref. 2.

Correlation between m and the point of maximum C_{pm} was determined by plotting on the same graph the calculated m and the experimental C_{pm} as functions of AR for a fixed diffuser geometry and a fixed inlet blockage. Calculations were repeated for various diffuser geometries and inlet blockages. A typical set of such plots is shown in Fig. 1. Also shown in this figure, although not required for the correlation study, is the calculated pressure recovery C_{pt}.

It was found that the experimentally measured pressure recovery reaches its maximum value when the calculated value of m reaches a value equal to 0.22. This correlation was found to be satisfactory over the entire range of diffuser lengths, area ratios, and inlet blockages investigated. The highest inlet blockage included in the correlation study was 12%—the highest inlet blockage for which systematic experimental data were available.

Loci of maximum C_p on the $L/2H_0$ vs AR graph, calculated using the correlation value $m=0.22$, is shown in Fig. 3. Also shown in this figure are the experimental and the calculated pressure recovery coefficients.

References

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