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Loss Sources and Magnitudes in Axial-Flow Compressors[1]

N. L. Sanger.[2] The authors have undertaken a very ambitious project, and are to be commended for their systematic and sensible methods of attack.

I have two questions relating to the procedures used in calculating profile losses. To calculate a turbulent boundary layer the analyst must supply some information which effectively defines the initial displacement and momentum thickness. What thickness values (or corresponding initial conditions) did you use, and were they varied with changes in other parameters?

Second, for some sets of conditions you surely calculated a turbulent boundary layer separation. What criterion was used to indicate separation, and how did you then arrive at a trailing edge momentum thickness?

[1] By C. C. Koch and L. H. Smith, Jr., published in the July 1976 issue of the JOURNAL OF ENGINEERING FOR POWER, TRANS. ASME, Series C, Vol. 98, pp. 411–424.

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Authors' Closure

The authors welcome the opportunity to clarify the points raised by Mr. Sanger. The compressible turbulent boundary layer calculations using the Mellor-Herring method were begun on the suction surface at the midpoint of the maximum-velocity "rooftop" region shown in Fig. 1. Calculations for the pressure surface were begun at the same chordwise position as used for the suction surface. The following flat-plate turbulent boundary layer equation, taken from Stratford and Beavers, was used to compute displacement thicknesses at these locations; in the equation, X is the distance from the leading edge.

$$\delta^*/X = 0.046(1 + 0.8M^2)^{0.44}\,\mathrm{Re}_x^{\,-0.2}$$

This displacement thickness, and the local Reynolds number based on δ^*, served as the initial conditions for the Mellor-Herring procedure that was used to calculate boundary layer growth on the remainder of the blade surfaces. Instead of supplying an initial value for momentum thickness, a dimensionless velocity profile (which utilized a transformed coordinate to account for compressibility) was assumed. An initial value of momentum thickness was implied by this profile. for each given δ^* and Mach number. Experience in using the Mellor-Herring method in this fashion has indicated that calculated airfoil trailing edge boundary layer properties are not particularly sensitive to changes in initial conditions, thus the approximations involved in obtaining the initial conditions are of small consequence to the overall results.

Suction surface calculations using this procedure were done at progressively higher diffusion ratio levels until the trailing edge skin friction became zero, and this was assumed to be the point of incipient separation. Suction surface diffusion ratios at separation ranged between 1.6 and 1.8 at low Mach numbers. The solid lines in Figs. 2(a) and 2(b) indicate trends of calculated momentum thickness and form factor for unseparated flow. For diffusion ratios greater than those producing separation, these trends were extrapolated consistent with Lieblein's correlation of experimental data; these extrapolations are indicated by the dashed lines in Figs. 2(a) and 2(b).