L. H. Smith[1]

In Fig. 7 it is seen that the calculated peak pressure rise is reduced from 0.74 to 0.66 (11 percent) as the tip clearance/chord ratio is increased by 1 percent from 0.25 to 1.25. This is a rather large effect; some time ago this discussor correlated mostly subsonic test data and concluded that the slope should be more like 5 percent for 1 percent clearance/chord ratio. Could the authors clarify how the tip clearance flow was modeled in their calculations?

N. A. Cumpsty[2]

This is a very useful contribution to our understanding of the difficult problem of tip clearance flow. I think that our understanding could be further helped if the authors would complete the test cases given in Fig. 16 and show the effect of having clearance near the front of the blade but zero clearance near the rear.

It is in a multistage compressor where the hub–casing radius ratio is relatively high that the effect of tip clearance flow is often experienced most acutely. I would like to encourage the authors to continue this work to look at stages more typical of a multistage compressor, in particular looking at the numerical instability when the flow is largely or entirely subsonic.

Authors' Closure

The authors thank Dr. Smith and Professor Cumpsty for their interest in the results given in the paper. We regret that we were not more explicit in describing the clearance model used in the numerical simulations. As modeled, the full clearance height is the height of the leakage jet; this is a consequence of the simple description that was adopted for the jet flow. The clearance that would exist in an actual rotor are therefore larger than the values quoted in the paper. The proportionality between actual and quoted clearance, which is associated with the occurrence of a vena contracta, is not certain. The value for this ratio obtained from "classical" free streamline theory is $\pi/(\pi+2)$, or 0.611, but Storer and Cumpsty (1991) used a higher value (0.8) to match data in their cascade, and computations of Chen et al. (1991) imply a contraction coefficient of roughly 0.7.

For the present rotor, the value of 0.5 is judged to be the most appropriate. This value was found to give best agreement with measurements of the peak pressure rise at one value of clearance. Based on that study, the magnitude of clearance used in the calculations (and specified in the paper) would be viewed as one-half the actual clearance. The sensitivity of peak pressure rise to clearance would therefore be only half as great as for an actual rotor, i.e., the sensitivity obtained from the computations should be multiplied by a factor of one-half for comparison with rotor data. Doing this yields results for the change of peak pressure rise with clearance that are closely in accord with the results of the experiments described by Dr. Smith.

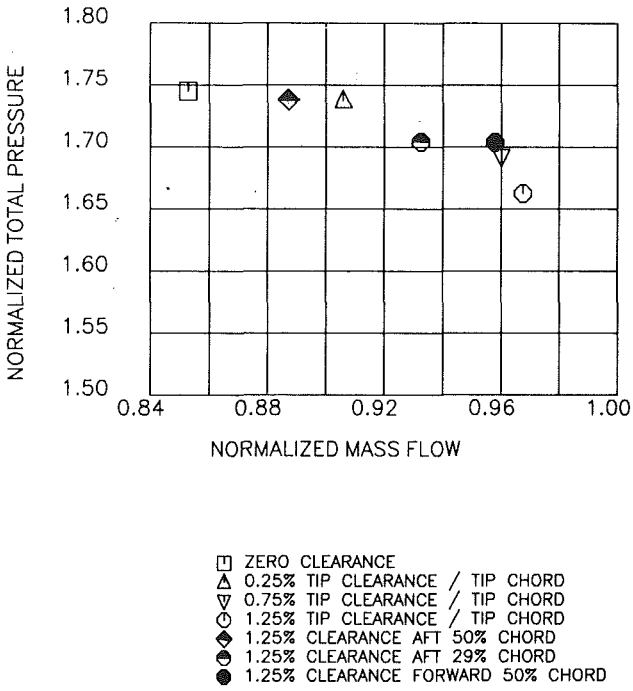

Fig. 19 Predicted pressure ratio at near-stall points for tip clearance/tip chord ratios of zero, 0.25 percent, 0.75 percent, and clearance of 1.25 percent aft of 29 percent and 50 percent chord and forward of 50 chord

Based on Professor Cumpsty's suggestion, we have executed a simulation in which the clearance from the leading edge to midchord was set at 1.25 percent of blade chord, while aft of midchord the clearance was set to zero. The predicted peak pressure ratio and corresponding mass flow are indicated by the solid octagon in the accompanying figure, along with the results previously presented in Fig. 16. By opening the clearance over the forward 50 percent of chord, the peak pressure and corresponding mass flow are nearly those for the same clearance over the entire blade chord. However, as previously shown, for clearance over the aft 50 percent of chord, zero clearance over the forward 50 percent chord, the peak pressure and corresponding mass flow lie closer to those for zero clearance.

The computations show that the clearance over the forward portion of a fan blade is far more important than that over the aft portion of a blade in establishing the peak pressure rise of a fan. Further, by reducing the clearance to zero over the forward portion of a fan blade, the interaction between the in-passage shock and the clearance vortex is reduced, leading to an increase in the operating range.

References

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