DISCUSSION

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The authors have obtained a most impressive amount of data. We would like to offer some comments and questions about the experiment and data and to offer some cautionary observations based on our own experiments.

(1) Concerning the design of blades, we wonder why the velocity distribution has a peak near the leading edge even at design inlet angle of 40°? The conventional wisdom (see, for example, Hobbs and Weingold, 1984) is that one should have continuous acceleration up to a peak velocity quite well back on the blade, followed by a steep deceleration. The peak near the leading edge is presumably responsible for the separation bubble in the forward part. Was there a particular reason for giving results in Fig. 13 at 6° of incidence above that for design?

(2) The laser technique was unable to give measurements in the separation bubble. Would the authors care to comment on the relative advantage of boundary layer measurements on blades obtained with the laser compared with, say, a hot-wire? Were any tests done near the leading edge with an inlet angle of 46° to verify that the seeding giving most of the signal was of the correct size to follow the steep gradients without significant error?

(3) The data, as presented, are to a very small scale (Figs. 11 and 13) and for one incidence only (Fig. 13). Is there any summary conveniently available that interested persons could have with more complete and easier-to-use presentation?

(4) Our most important comments are based on our own measurements (Dong and Cumpsty, 1989), which, at risk of being repetitive, we must outline. By introducing moving wakes into the two-dimensional flow in a cascade of similar controlled-diffusion-type blades, we were able to see very substantial alterations in the suction and pressure surface boundary layers. The effects were most pronounced on the suction surface, since this boundary layer was dominated by a separation bubble in the absence of wakes or high free-stream turbulence. The wakes initiated turbulence before the separation point and temporarily prevented separation; after a wake had passed, the flow reverted to laminar and a separation occurred. After the turbulent spot there was a calmed region, in which transition was delayed, and the net effect of the wakes (and of high free-stream turbulence) was to delay the completion of transition to a position further along the chord. The transition, and therefore, the subsequent boundary layer development, depend on the size and frequency of the wakes and the whole process is an unsteady one.

Our measurements, therefore, bring us to suggest a caveat on the penultimate sentence of the Elazar and Shreeve's conclusions. Extreme caution should be exercised in the use of these data for the calibration of viscous codes intended for application to compressors. This is because the process of greatest uncertainty, transition, is probably quite different in character for this steady, low-turbulence test configuration from that which will be found in the majority of blade rows in a compressor.

Authors' Closure

In response to each of the preceding points:

(1) The reported cascade was designed somewhat before "conventional wisdom" was arrived at (Sanger, 1983). From the point of view of providing a test case for viscous analysis codes however, this may prove to be fortunate. It is useful to have data for a case in which a leading-edge separation bubble does occur but trailing-edge separation does not, even with much increased incidence. From the point of view of blade design, the off-design behavior of the reported cascade is interesting in that downstream of reattachment, the adverse pressure gradient progressively decreases as the incidence is increased. This is not a bad characteristic if off-design performance is a critical issue.

The data at 6° above design incidence were shown as a selected example of the data obtained because the scale of the viscous effects was largest at this angle and they could therefore be seen most easily. The selection was otherwise arbitrary.

(2) Since an early goal was to obtain data corresponding to incipient stall, the intrusion of probes into the blade passages was considered to be unwise. Experience with hot-wires and LDV in the present cascade has nevertheless shown that there is no advantage whatsoever to using hot-wires over using the LDV system where optical access is available and the flow is steady. Such a conclusion might be different if an experienced LDV operator and a precision traverse (such as the milling machine table that we used) were not available, or frequency analysis of unsteady effects was required in the experiment.

The size of the seed particles was measured very carefully (Elazar, 1988) and, with reference to previous work (Dring, 1982), it was concluded that the particles would follow the streamlines very closely except, possibly, around the leading-edge curvature. Thus the observations that the surface pressure implied higher peak velocities around the leading edge than were measured for the particles in the flow in that region, and that particles were absent from the leading-edge separation bubble, which began just downstream of the leading-edge curvature (Sanger and Shreeve, 1986), were consistent with expectations.

(3) A complete listing of the LDV data will be given in a technical report (Shreeve and Elazar, 1989).

(4) The measurements and observations reported by Dong and Cumpsty (1989) are certainly interesting since most blading in a machine operates in the wakes of other blades. However, two points need to be made. First, understanding the unsteady situation requires that you first understand the steady one. From the point of view of CFD descriptions of cascade behavior, we do not have today a code that can predict with certainty a steady viscous cascade flow field if it contains transitions and separation in any form. It will be much more difficult to predict the unsteady viscous flow correctly. Our reported measurements do provide a test case for a steady flow description and can be used as a limiting test case for an unsteady code description. It would not be prudent however to interpret the results of such predictions as being totally representative of flow within a machine, but rather as being an engineering baseline from which to start.

Second, while introducing wakes, as Cumpsty and Dong have done, takes a step closer to creating the machine environment, it is nevertheless only a partial step. In multistage machines, the multiplicity of wakes present a truly complex unsteady flow to aft blade rows. However, even the second blade row in a machine sees wakes that are quite different than those produced in Cumpsty and Dong's experiments. As has been shown in the present work (Elazar, 1988), the compressor (cascade) blade wake is highly asymmetric in nature, retaining a pressure side and a suction side with different turbulence levels, and being free of the alternating vortex structure that can occur in symmetric blunt body wakes. Whether these differences are important or not can only be resolved by additional systematic experiments of the type that Cumpsty and Dong have reported.

Additional Reference

Shreeve, R. P., and Elazar, Y., 1989, "Laser Velocimeter Data From a Controlled Diffusion Compressor Cascade for Viscous Code Validation," Technical Report NPS67-89-001, Naval Postgraduate School, Monterey, California.

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