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DISCUSSION

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As an experimentalist, I am pleased to see engineers compare my data with their numerical computations. This particular data set offers measurements of a very complex flow field to those attempting to compute the incompressible flow through a turbomachine. The authors should be commended for attempting to use their code in such a severe test case.

First, I would like to clear up a few discrepancies between the authors' paper and the experimental report of Zierke et al. (1993). The authors' description of the rotor blade thickness and camber distributions is incorrect, although I am sure that they did in fact use the correct blade coordinates for their computations. Also, the experimental data used in the inlet axial-velocity profile of Fig. 2(a) must have been some preliminary data, since these data do not correspond to data from the experimental report. Finally, the computations in Fig. 5(b) were performed with lifting surface theory, not lifting line theory.

Next, I would like to address some of the comparisons between the experimental and computational results. First, the authors stated that the secondary velocity vectors predicted in Figs. 5(c) and 6(a) came from single blade passages; and yet, the radial components do not seem to show periodicity. Is the entire passage shown in each of these figures? Then, for the predicted axial-velocity contours of Fig. 6(b), the authors predict a "separation induced vortex" not shown in the measurements. Lee et al. feel that this vortex is damped out quicker in the measurements than in the prediction. And yet, Zierke et al. (1993) report additional data measured much closer to the trailing edge near the rotor blade root and these data also show no sign of this vortex. Therefore, our laser-Doppler velocimeter measurements do not detect a significant vortex in this region—in contrast to the computations. Finally, the velocities predicted downstream of each blade row are fair, although the tangential velocities predicted downstream of the inlet guide vanes are poor and this leads to a poorly predicted harmonic content. Downstream of the rotor blades, the mismatch in the comparisons does not necessarily mean that the measured and computed strengths of the tip leakage vortex are different. The plots in Fig. 8 are simply two-dimensional cuts through a complex, three-dimensional flow field. The computed vortex strength could be very good—but simply computed to be in the wrong location.

Finally, I would like to comment on statements made by the Lee et al.—in particular, those concerning the flow patterns near the rotor blade suction surface. Contrary to their statement, the flow reversal in the corner separation does not produce the strong radial flow in the experimental flow visualization. Centrifugal effects cause this radial migration. By altering characteristics of the rotor blade design (such as the blade lean), one could design a blade with a flow reversal in the corner separation without having a strong radial migration. Later, in their alternate computation with a variation in their turbulence model, Lee et al. stated that our water tunnel experiment could produce a characteristic length scale of the incoming turbulence that might be much larger than the length scale based on the IGV dimension. Using this reasoning, they increased the inlet length scale to 100 times their original length scale. I have a very difficult time following this argument. As stated by Zierke et al. (1993), the water tunnel turbulence is controlled using a honeycomb. This honeycomb will establish an inlet turbulent length scale that is much smaller than the IGV dimensions. Even without a honeycomb, the inlet turbulent length scale cannot be larger than the IGV dimensions. If the authors need to change their length scale so dramatically—and change it in the wrong direction—one should question both the sensitivity and the utility of using their turbulence model for this type of flow field.

In summary, I feel that the comparison of these computations with our experimental data show just how difficult it is to compute the flow through a turbomachine. This type of complex, unsteady, three-dimensional flow field places a large burden on the numerical analyst. Issues with the numerical algorithms, the turbulence models, and the computational grids must all be addressed in order to improve the predictions of this and similar turbomachinery flow fields. Again, the authors should be commended for testing their code by performing these computations.

Authors' Closure

As the computational analysts, we are delighted to see the experimentalist providing his view about our computational results.

First of all, these computational results were obtained almost two and half years ago. We were the first group attempting to

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solve the Reynolds-averaged Navier–Stokes equations numerically for this marine propulsion pump. Similar efforts from several other groups were thereafter shown in the literature. This paper was prepared even before the experimental report (Zierke et al., 1993) was completed.

We have modified the paper to reflect most of Dr. Zierke's recommendations. There are, however, two issues he raised that we would like to discuss. The first issue concerns the quality of the solution, particularly the comparisons near the rotor tip area. We consider this solution to be valuable and it has served as our baseline solution for further code development. It provides not only the directions for improvements, but also further understanding of this complex flow as Dr. Zierke pointed out. Our recent papers, addressing the prediction improvement of the rotor tip vortex (Lee et al., 1995; Hah et al., 1995), were derivatives of the present benchmark calculation.

The second issue concerns the turbulence length scale used in specifying the turbulence dissipation at the rotor inlet. Dr. Zierke provides an evaluation of the length scale at the IGV inlet after the honeycomb. As we stated in our paper, the present steady-state stage calculation was accomplished by employing a mixing plane between the IGV and the rotor. For the rotor-flow calculation, the turbulence level at the inlet section, i.e., the location of the mixing plane, is certainly different from that at the IGV inlet. In our calculation, we used two different length scales to reflect the difference in turbulence levels between the IGV inlet and its exit. From the solutions depicted in Figs. 11(b) and 11(c), the trailing-edge separation is closely related to the rotor inflow turbulence level. This requirement of providing the turbulence length scale for the rotor calculation is eliminated if the stage calculation is treated unsteadily.

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