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AVERAGE-PASSAGE FLOW MODEL DEVELOPMENT

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A research effort has been underway to develop a three-dimensional model for simulating multistage turbomachinery flows using today's supercomputers. This model, referred to as the "average passage" flow model, describes the time-averaged flow field within a typical passage of a bladed wheel within a multistage configuration. To date, a number of inviscid simulations have been executed to assess the resolution capabilities of the model. Recently, the viscous terms associated with the "average passage" model have been incorporated into the inviscid computer code along with an algebraic turbulence model. A simulation of a stage-and-one-half, low-speed turbine has been executed. The results of this simulation, including a comparison with experimental data, is the subject of this report.

A goal of computational fluid dynamics for turbomachinery is the prediction of performance parameters and the flow processes which set their values. Achieving this goal for multistage machinery is made difficult by the wide range of length and time scales in the associated flow fields. Currently, the procedure used in the design and off-design analysis is based on a quasi-three-dimensional flow model whose origins can be traced to the late forties and early fifties.

Although proven useful, this flow model has its limitations. Among these are the inability to analyze off-design performance and unconventional machinery where extrapolation of the underlying empirical data base is required. Other problems arise whenever there are large local variations in the radial velocity component within a blade passage. It is generally agreed that a way of overcoming these shortcomings is the development of true three-dimensional flow models. The "average passage" flow model under development at Lewis Research Center is such a model. The objective of this paper is to present the status of the development of this model for multistage turbines. This will include several comparisons with measurements obtained from a recently completed experimental program at the United Technologies Research Center.

SIMULATION RESULTS

The simulation executed was the low-speed rotating rig at United Technologies Research Center. The low-speed rotating rig (LSRR) is a stage-and-one-half turbine consisting of an inlet guide vane, a rotor, and a stator. The inlet guide vane contains 22 blades, and the rotor and stator both contain 28 blades. The flow coefficient, ϕ, is 0.78, and the spacing between blades, B_x, is 0.5. The LSRR grid contains 228 axial, 25 radial, and 41 circumferential points. Each blade row contains 40 axial points distributed along the chord with 26 axial points between each blade row, the inlet and exit.

The results presented required 11 hours of Cray 2 CPU time. They represent but a small fraction of the information obtained from the simulation. They are intended to illustrate the degree to which one can quantitatively predict performance parameters that are of interest to designers and to reveal qualitative information identifying flow phenomena that may have an effect on performance. These results also reflect the current state of model development. The first series of results shows the predicted pressure distribution on the surface of each blade row of the turbine as a function of axial chord length and percent of span height. The span locations measured from the hub are 1.3, 12.5, 50, 87.5, and 98.7 percent, respectively. The experimental measurements taken at these locations are also shown. Experimental data were also available for 25 and 75 percent of span, but were not used, since they provided little additional information relative to the current discussion. The results for the first vane are shown in figure 1. The predicted loading level is in good agreement with the measurements of Dring (1988). The predicted pressure-surface pressure distribution is in excellent agreement with the experimental results. For the suction surface the agreement between measurement and simulation is good for the region forward of the minimum pressure peak. Aft of the peak the agreement between experiment and simulation deteriorates. This deterioration is believed to be related to viscous effects (i.e., turbulence and transition modeling) whose modeling could be improved. Some exploratory calculations suggest that the boundary layer aft of the suction-surface minimum pressure is growing too rapidly and, as a result of the radial pressure gradient, is being transported toward the hub to an extent greater than that suggested by flow visualization studies. Improvements in the agreement between simulation and experiment have been obtained by incorporating a simple transition model in which the flow remains laminar forward of the minimum pressure peak and Baldwin-Lomax turbulence model as implemented by Dawes (1986).

Figure 2 shows the results for the first blade row, which incorporated these changes in the turbulence model. The improvement is obvious. The remaining results for the rotor and second stator incorporated the modified turbulence model. Figure 3 shows the predicted and measured pressure distribution for the rotor. The predicted loading levels appear to be in good agreement with measurements, with the exception of the hub and tip region. The present simulation does not include a clearance region, which should account for some of the discrepancy in the tip region. The pressure distribution along the pressure surface is once more in excellent agreement with the measurements. At the midspan and at 25 and 75 percent (not shown) of span, the predicted pressure distribution along the suction surface is in good agreement with the data. At 1.3 and 12.5 percent of span, the suction-surface pressure coefficient is lower than that measured. As a result, the loading is lower over the forward portion of the rotor than what has been measured. Although the cause of this discrepancy is, at present, unknown, one could speculate that it may be due to an improper estimate of the magnitude and extent of the low momentum fluid exiting the first vane.

The pressure distribution for the last vane is shown in figure 4. Once again, the loading level is well predicted, with the exception of the 1.3 percent of span location. The underpredicted suction-surface pressure coefficient at 1.3 and 12.5 percent of span suggests that the flow incidence to these sections is underestimated. There also appears to be a shift of the predicted pressure distribution relative to the measured distribution. This shift is believed to be caused by an overestimate of the loss generated by the first two blade rows. With the exception of this discrepancy, the pressure distribution on the pressure surface is in good agreement with measurements. Similarly, the predicted suction-surface distribution at midspan agrees well with the experimental distribution.

Currently, the results of this simulation are being reduced to a format which will allow for the comparison with measurements of total pressure level and flow angle. This comparison should provide additional information for judging the accuracy of the simulation.

SUMMARY AND CONCLUSION

Given the early state of the average passage model development, the results presented in this report are very encouraging. The amount of empirical information used in the stage-and-one-half turbine simulation is considerably less than that required to achieve comparable results using today's quasi-three-dimensional flow models.

FIRST BLADE PRESSURE DISTRIBUTIONS

FIRST VANE

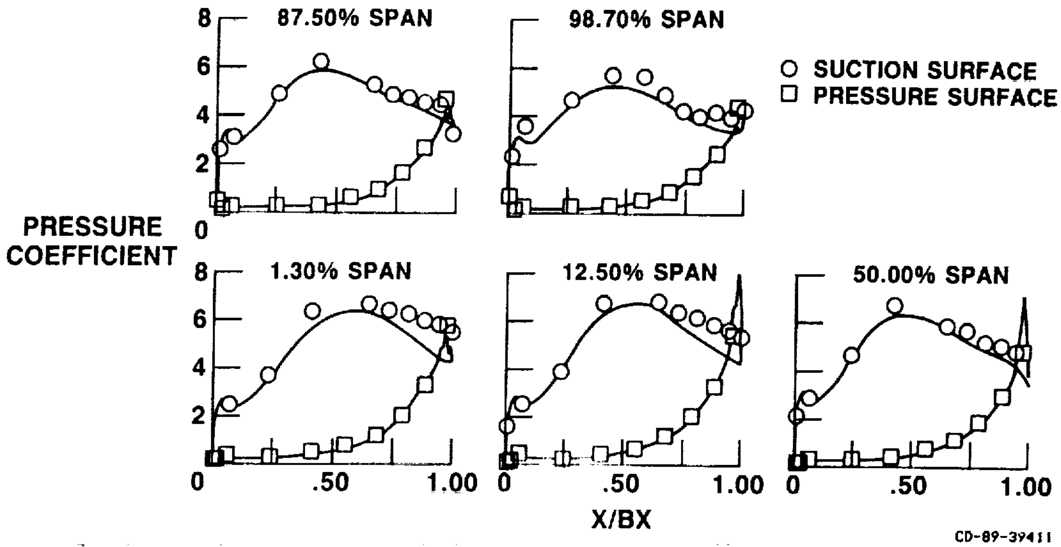

Figure 1

BLADE PRESSURE DISTRIBUTIONS

FIRST BLADE ROW

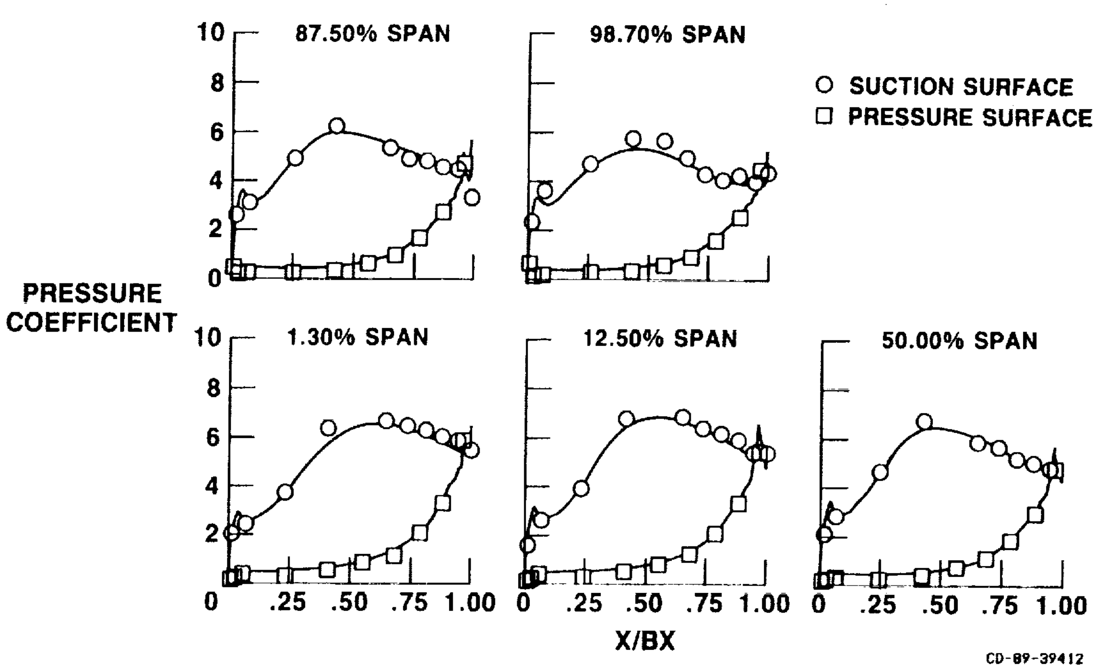

Figure 2

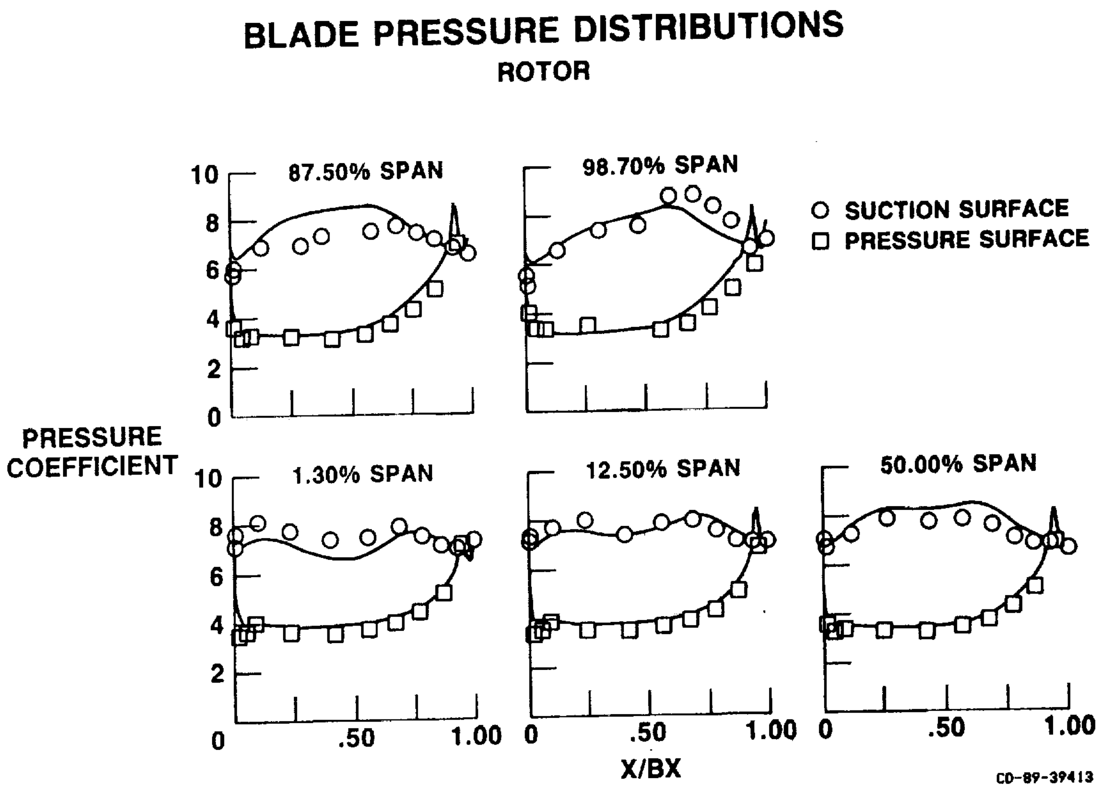

Figure 3

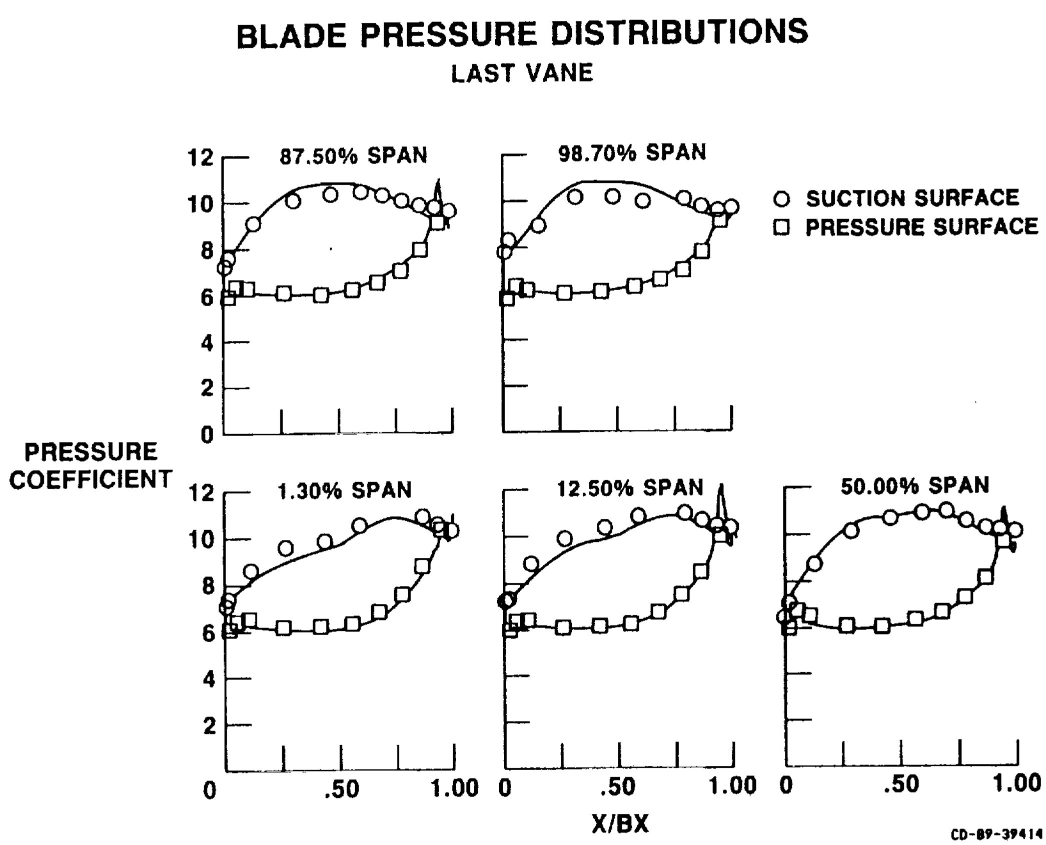

Figure 4