Computation of Transonic Flows in Turbomachines Using the Runge-Kutta Integration Scheme

S. V. Subramanian* and R. Bozzola†
AVCO—Lycoming Textron, Stratford, Connecticut

Abstract

A COMPUTER code for solving the Euler equations using the four-stage Runge-Kutta integration scheme has been developed for turbomachinery flowfield calculation. The program has been successfully applied to predict blade-to-blade flows for many cascades with different geometries and flow conditions. Numerical results indicate that the present method can be applied to yield fast results with good accuracy for a wide variety of cascade configurations and flow conditions. The C-type grids produce the best overall results for any particular test case from the standpoint of accuracy, simplicity of implementation, and boundary condition treatments. The present code, which could be used in conjunction with any type of user-opted computational grids, is simple, efficient, and accurate enough to be used for cost-effective preliminary and advanced aerodynamic design studies.

Contents

A broad spectrum of flow conditions are encountered at various stages of a modern gas-turbine engine operational cycle. Development of analytical tools closely representing the important flow features is a necessary step for efficient design, operation, and performance improvements. The purpose of the present study is to develop a fast and accurate Euler cascade computer flow code that can be used for the design and performance improvements of critical gas-turbine engine components such as compressors and turbines. Development of the solution procedure is based on the Jameson's fourth-order Runge-Kutta numerical integration scheme.[1]

Numerical solutions were obtained for a variety of cascade test cases using the present code. At the inflow, the total pressure, total temperature and flow angle are specified. For subsonic axial inflow, the upstream running Riemann invariant is extrapolated from the interior point for the one numerical boundary condition required. For supersonic conditions, the inflow Mach number is also specified, in addition to the three physical conditions described above. At the outflow boundary, the one physical condition specified is the static pressure corresponding to the desired subsonic axial exit Mach number. The three numerical conditions come from extrapolating the downstream running Riemann invarient, the y-velocity component v, and the total energy E. On the blade surface, the "zero flux" conditions are imposed. For estimating the pressure at the wall, the same procedure described in Ref. 1 is adapted in the study. The periodic boundaries are treated as interior points in the computation.

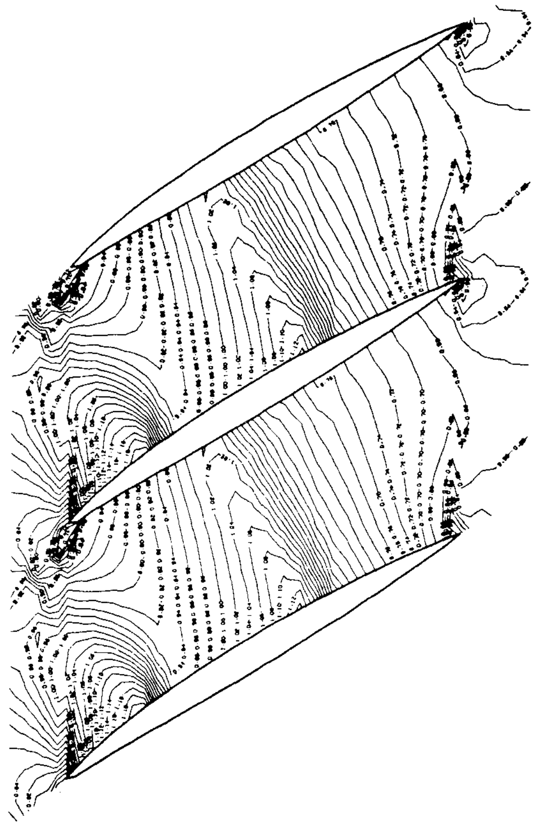

Fig. 1 Contour plots of Mach numbers for the compressor cascade.

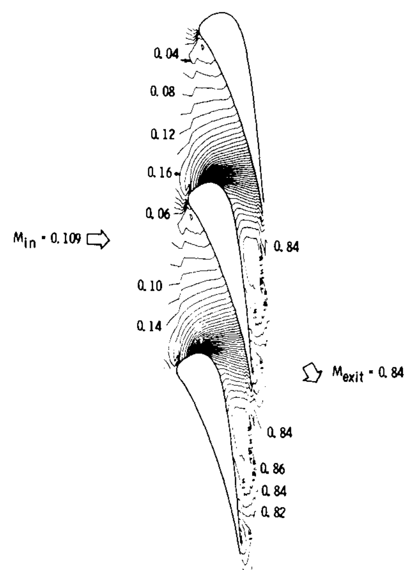

Fig. 2 Mach number contours for the inlet guide vane.

Presented as Paper 85-1332 at the AIAA/SAE/ASME/ASEE 21st Joint Propulsion Conference, Monterey, CA, July 8-10, 1985; received Sept. 24, 1985; synoptic received May 6, 1986. Full paper available from AIAA Library, 555 W. 57th Street, New York, NY 10019. Price: microfiche, $4.00; hard copy, $9.00. **Remittance must accompany order.**

*Senior Research Engineer, Aerodynamic Design Group.
†Manager, Turbine Design and Development Group.

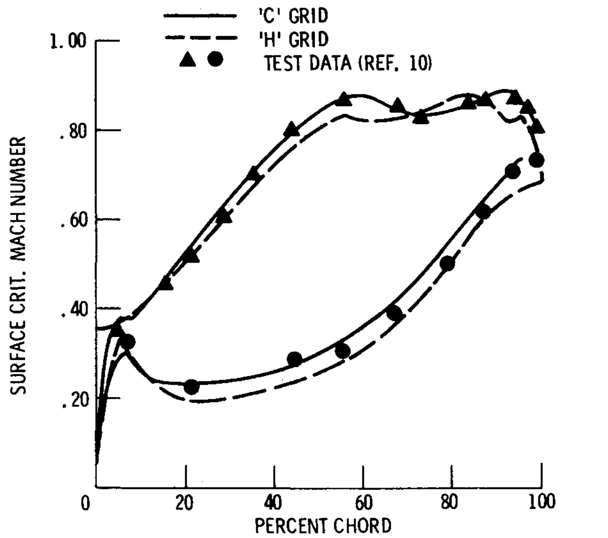

Fig. 3 Surface Mach number distribution for the NASA turbine stator.

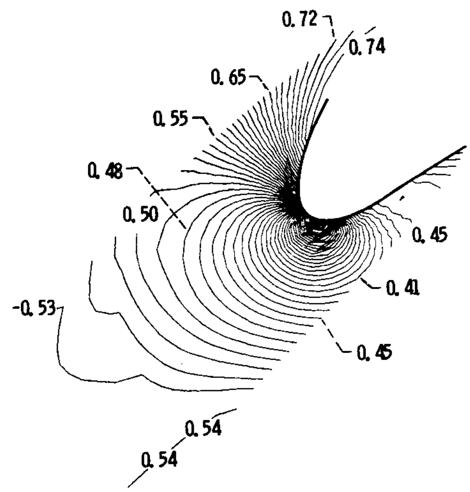

Fig. 4 Mach number contours near the leading edge of the cascade.

The Mach number contours calculated for a transonic flow through a compressor cascade are illustrated in Fig. 1. The computed surface Mach numbers agree very well with the predictions of other numerical methods. However, there are no experimental data available for this case. The computed Mach number contours for a high work inlet guide vane are shown in Fig. 2. The flow accelerates from an inflow Mach number of 0.11 to an exit value of 0.84 in a very short distance. The computed surface static pressure values show good agreement with the test data.[2,3] Figure 3 shows the calculated critical velocity ratio for a fully subsonic NASA turbine stator[4] using the H-type and C-type grids. The results obtained on a C mesh shows excellent agreement with the test data[4] and are far improved near the leading as well as trailing edges of the blade compared to H-grid results. Figure 4 illustrates this point further where the Mach number contours near the blade leading edge obtained using

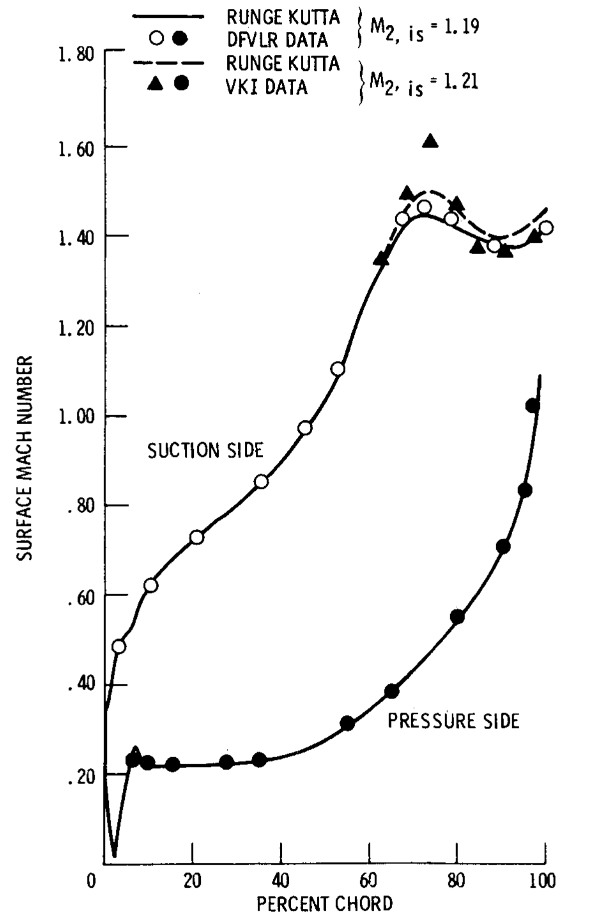

Fig. 5 Surface Mach number distribution for the VKI turbine rotor.

a C grid are plotted, showing excellent flow resolution. Finally, Fig. 5 compares the predicted surface Mach numbers with test data obtained from two different cascade tunnels and two different exit flow conditions for a transonic turbine rotor.[5] The agreement between the present computations and the two sets of test data is excellent, especially for the case corresponding to exit Mach number of 1.19.

References

[1]Jameson, A., Schmidt, W., and Turkel, E., "Numerical Solution of Euler Equations by Finite Volume Methods Using Runge-Kutta Time-Stepping Schemes," AIAA Paper 81-1259, June 1981.

[2]Subramanian, S. V. and Bozzola, R., "Application of Runge-Kutta Time Marching Scheme for Computation of Transonic Flows in Turbomachines," AIAA Paper 85-1332, July 1985.

[3]Kopper, F. C., Milano, R., Davis, R. L., Dring, R. P., and Stoeffler, R. C., "Energy Efficient Engine High Pressure Turbine Supersonic Cascade," NASA CR-165567, Nov. 1981.

[4]Whitney, W. J., Szanca, E. M., Moffitt, T. P., and Monroe, D. E., "Cold-Air Investigation of a Turbine for High Tempeature-Engine Application," NASA TN-D 3751, Jan. 1967.

[5]Sieverding, C. H., "The Base Pressure Problem in Transonic Turbine Cascades," *Transonic Flows in Axial Turbomachinery*, Vol. 2, von Kármán Institute for Fluid Dynamics, Rhode-Saint-Genese, Belgium, 1976.