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TURBINE STATOR FLOW FIELD SIMULATIONS*

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INTRODUCTION

The increased capability and accessibility of modern computers, coupled with increasingly sophisticated and accurate numerical and physical modeling, has led to a marked impact of numerical simulations upon current turbine design and research problems. The turbine section represents a considerable challenge as it contains significant regions of complex three-dimensional flow, including both aerodynamic and heat transfer phenomena. In particular, the turbine flow field contains several features which make its analysis a formidable problem. These include complex geometry, multiple length scales, three-dimensional effects, possible strong secondary flows, possible flow separation at off-design operation, possible transonic effects and possibly important unsteady effects.

As a result of the particularly difficult nature of the turbine cascade flow field, not nearly as much effort has been focused upon Navier-Stokes turbine simulations as upon many simpler problems. Much of the work performed to date has focused upon two-dimensional simulations. Although these can yield valuable information and insight, the actual problem is a three-dimensional one, and a three-dimensional approach is required to capture many of the important flow field properties.

The focus of the present effort is development of an efficient and accurate three-dimensional Navier-Stokes calculation procedure for application to the turbine stator and rotor problems. In particular, an effective procedure is sought which (i) adequately represents the flow physics, (ii) allows for sufficient resolution in regions of small length scale, and (iii) has sufficiently good convergence properties so as to allow use on a regular basis.

APPROACH AND BACKGROUND

The present approach solves the ensemble-averaged Navier-Stokes equations via the Linearized Block Implicit (LBI) technique of Briley and McDonald (Ref. 1). Boundary conditions for subsonic inflow and outflow (the usual case) set upstream stagnation pressure, upstream stagnation temperature, upstream flow angle, and downstream static pressure. Additional conditions used are density derivative on the inflow (upstream boundary), and velocity and temperature second derivatives on the downstream boundary. On the cascade blade no-slip conditions and a zero pressure gradient condition are applied along with either a specified temperature or a specified heat transfer rate. In general, the first grid point off the wall is taken so as to place a point in the viscous sublayer. The governing equations are written in general tensor form and solved in a body-fitted coordinate system. Details of the governing equations, numerical techniques, grid construction, turbulence model, etc. are given in Refs. 2-4.

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Using this approach has allowed simulation of a variety of flow fields. In particular, Refs. 3 and 4 describe work performed under a previous HOST contract showing favorable comparisons with experimental data for heat transfer and surface pressure distribution. More recent and yet unpublished work performed under NASC sponsorship shows favorable comparisons for surface pressure distribution, skin friction coefficient and velocity profiles, both on the blades and in the wake. References 3 and 4 also show demonstration calculations for a three-dimensional case formed by placing the C3X geometry between parallel endwalls. Finally, preliminary convergence studies for a Turner turbine cascade were presented by the present authors at the 1985 HOST meeting.

More recent convergence studies for the C3X cascade are presented in Figs. 1 and 2. Convergence history results for a two-dimensional laminar calculation are given in Fig. 1. The residual is defined as the imbalance of all steady terms and is normalized by the maximum residual in the field at the first time step. As can be seen, the residual drops five orders of magnitude in 150 time steps. It is also of interest to note that doubling the number of grid points did not significantly effect the convergence rate. The convergence rate for the three-dimensional case, is shown in Fig. 2. Again, rapid convergence is obtained; the solution was not continued to assess if the residual would continue to drop.

PRESENT EFFORTS

The focus of the present effort is demonstration of a two-equation turbulence model and demonstration of a three-dimensional turbulent case. In regard to the turbulence model, the code contains both a mixing length model and a $k-\varepsilon$ model, as described in Ref. 4. The C3X turbine cascade was chosen as a demonstration case for this capability. The calculation was run for a case having an inflow Mach number of 0.16, a Reynolds number of 3.4×10^5 and an inflow incidence of 0°. The calculation was initiated as a mixing length calculation and then continued with the two-equation model. Results showing pressure contours and velocity vector field are given in Figs. 3 and 4.

In addition to the turbulence energy calculation, present efforts are focusing upon three-dimensional turbulent calculations, in both stator and rotor configurations. The current problem being pursued is that of the C3X casade between parallel endwalls. A calculation is being made for the same flow conditions as in the two-dimensional case, using both mixing length and turbulence energy formulations.

REFERENCES

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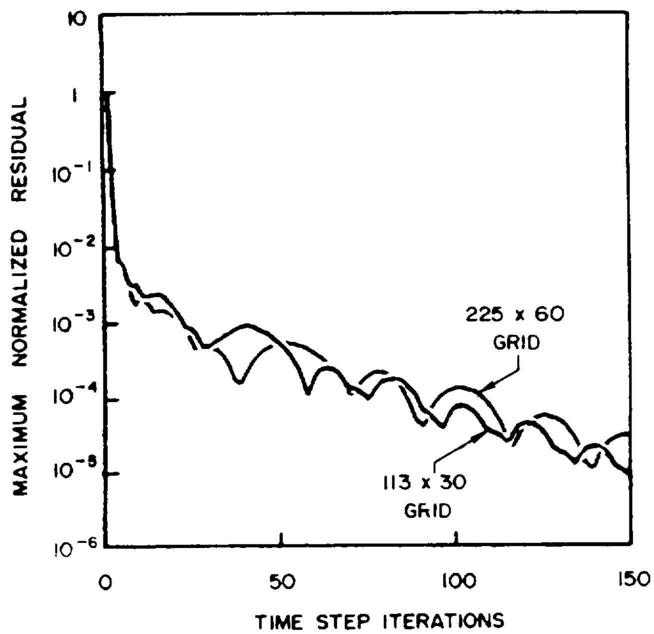

Fig. 1 - Convergence Behavior, C3X Laminar 2-D Cascade.

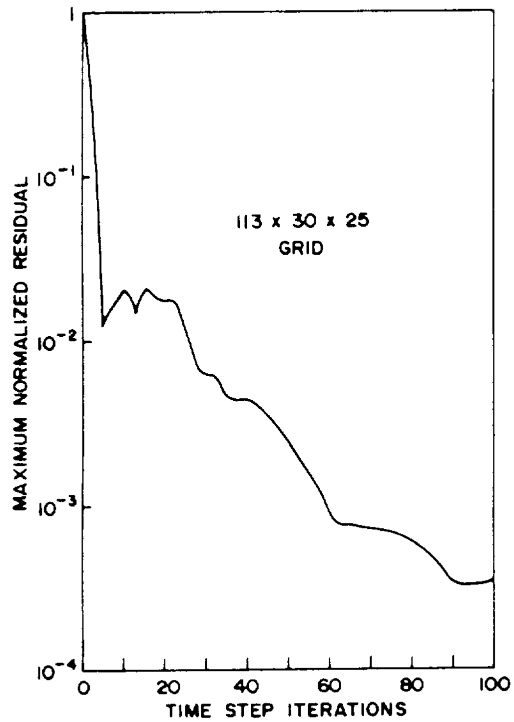

Fig. 2 - Convergence Behavior, C3X Laminar 3-D Cascade.

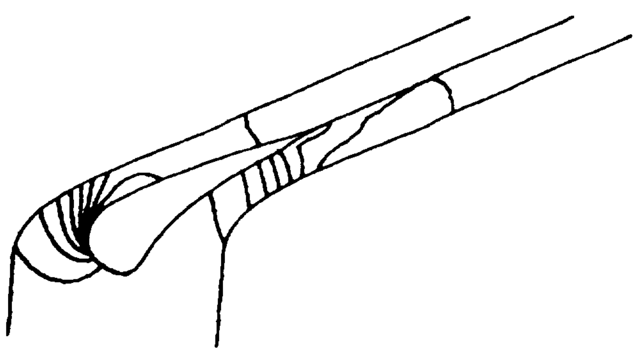

Fig. 3 - Pressure Contours, C3X Cascade, Turbulent Flow, k-ϵ Model.

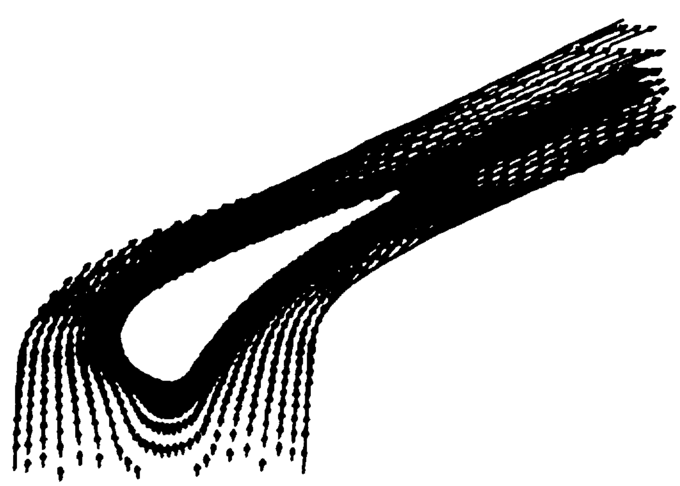

Fig. 4 - Velocity Vectors, C3X Cascade, Turbulent Flow, k-ϵ Model.