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UNSTEADY STATOR/ROTOR INTERACTION

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The major thrust of the computational analysis of turbomachinery to date has been the steady-state solution of isolated blades using mass-averaged inlet and exit conditions. Unsteady flows differ from the steady solution due to interaction of pressure waves and wakes between blade rows. To predict the actual complex flow conditions one must look at the time accurate solution of the entire turbomachine.

ANALYSIS

Many of the numerical tools used in the analysis of isolated blades can be used for time-accurate analysis. Here the quasi-three-dimensional Euler and thin-layer Navier-Stokes equations are solved for unsteady turbomachinery flows. These equations are written in general coordinates for an axisymmetric stream surface, and they account for the effects of blade-row rotation, radius change, and stream-surface thickness (ref. 1).

A four-stage Runge-Kutta scheme based on the work of Jameson (ref. 2) is used to predict time-accurate results. Body-fitted C-type grids were used in this work and were generated using the GRAPE code (GRids about Airfoils using Poisson's Equation) developed by Sorenson (ref. 3).

To predict the interaction between a stator and a rotor in turbomachinery, one must pass flow information to an interface that acts as a moving boundary between the two computational grids. A nonconservative interface formulation is used in this procedure. The solution must be integrated using a constant minimum time step based on the computational domain of two blades. The data management necessary to update the stator and rotor flowfields will be discussed. Currently the code is limited to solving stator/rotor configurations that have equal pitch blades.

RESULTS

The solution procedure has been applied to two test problems. The first is a cascade and the second is a turbine rotor from the space shuttle main engine (SSME). Euler and Navier-Stokes results will be presented.

A model turbine stage made up of two identical cascades of NACA 0012 airfoils was used to develop and test the interface and data management routines. Figure 1 shows the C-grids used in the computation where the second blade row is moving downward. A converged solution can be seen in the periodic loading diagram of the rotor (fig. 2).

The stator inlet Mach number is 1.84. Figure 3 shows relative Mach number contours when the blade rows are aligned. Detached bow shocks form ahead of the stators, interact at mid-passage, and reflect obliquely back to the stator surface. A strong curved shock forms at the stator trailing edge, and the shock curvature generates an entropy layer that convects downstream into the rotor. The stator flowfield is symmetric but the rotor flowfield is asymmetric due to the incidence of the relative flow.

Figure 4 shows relative Mach number contours after the rotor has moved 1/4 pitch downward. The flow between the stator and rotor is subsonic so that pressure waves from the rotor can affect the stator trailing-edge shock, which has moved upstream. The entropy layer from this shock produces a large asymmetry in the rotor flowfield. The flow reaccelerates to supersonic in the rotor passage and produces strong oblique shocks off the rotor trailing edge.

Previous steady-state calculations of the SSME first-stage fuel-side turbine blade (ref. 1) showed a reverse flow region on the pressure surface (fig. 5). Time-accurate results are being generated to determine how that separation is affected by the upstream stator wakes. The grids used for this calculation are shown in figure 6 where the second blade row is the rotor of interest. Euler results are shown in figure 7. There is very little interaction between the blade rows. Viscous results will be shown in the presentation. Currently the numerical procedure works on blade row configurations of equal pitch. The actual SSME stator/rotor blade count is 41:63, which is close to the 2:3 count shown in figure 8. A future goal of this work is to use this solution procedure to solve problems of unequal blade count like the one shown here.

REFERENCES

1. Chima, R.V.: Development of an Explicit Multigrid Algorithm for Quasi-Three-Dimensional Viscous Flows in Turbomachinery. AIAA Paper 86-0032, Jan. 1986. (Also, NASA TM-97128.)

2. Jameson, A., et al.: Numerical Solutions of the Euler Equations by Finite Volume Methods Using Runge-Kutta Time-Stepping Schemes. AIAA Paper 81-1259, June 1981.

3. Sorenson, R.L.: A Computer Program to Generate Two-Dimensional Grids About Airfoils and Other Shapes by the Use of Poisson's Equation. NASA TM-81198, 1980.

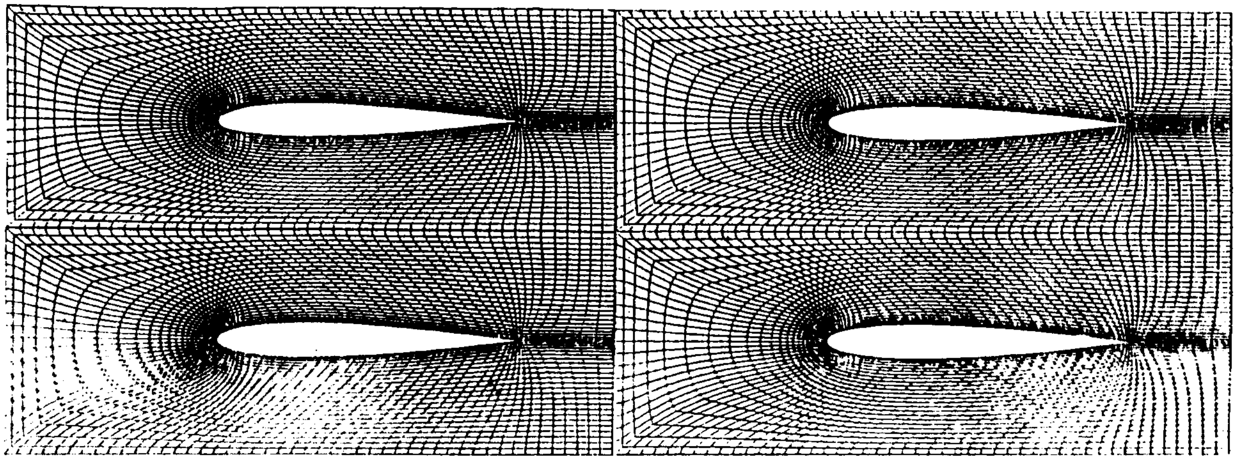

Figure 1.- Computational grids for the NACA 0012 model problem.

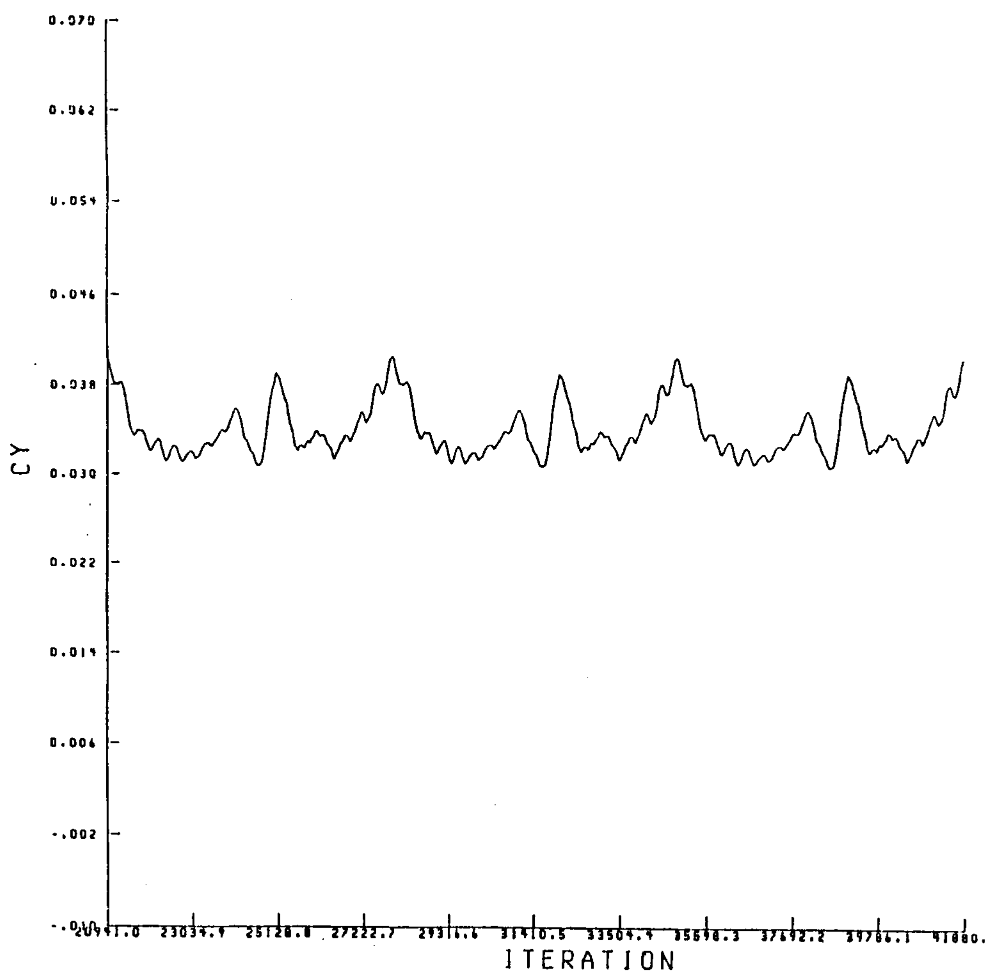

Figure 2. - Loading diagram for the model problem rotor.

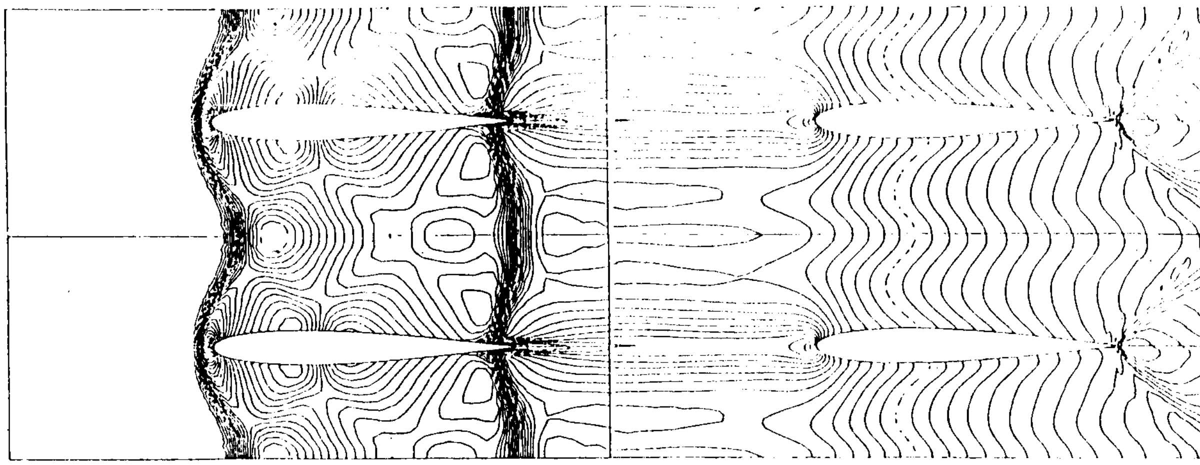

Figure 3.- Mach contours after 1.00 pitch rotation.

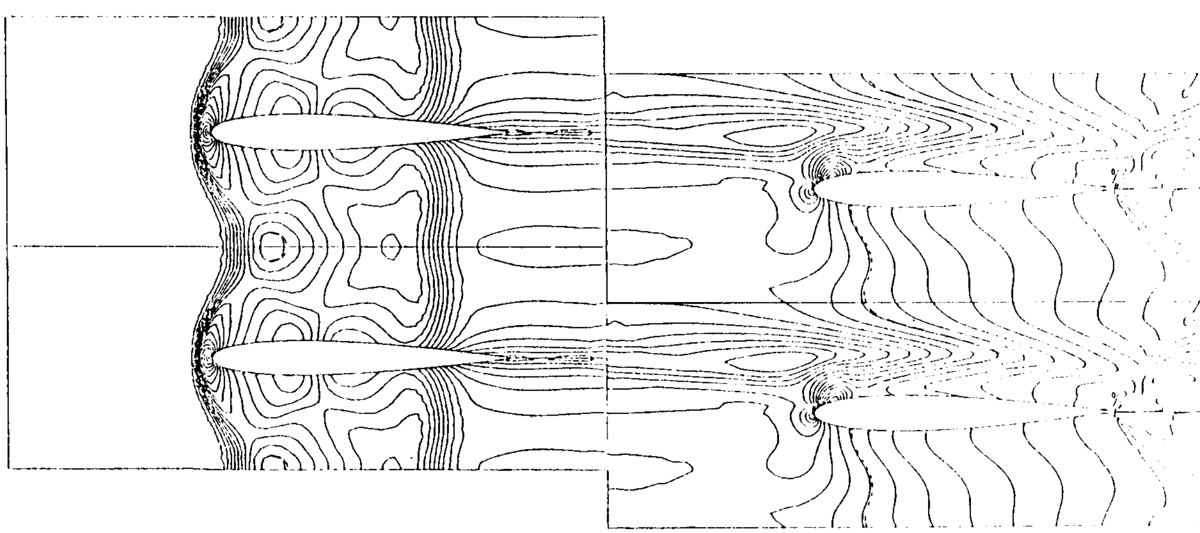

Figure 4.- Mach contours after 1.25 pitch rotations.

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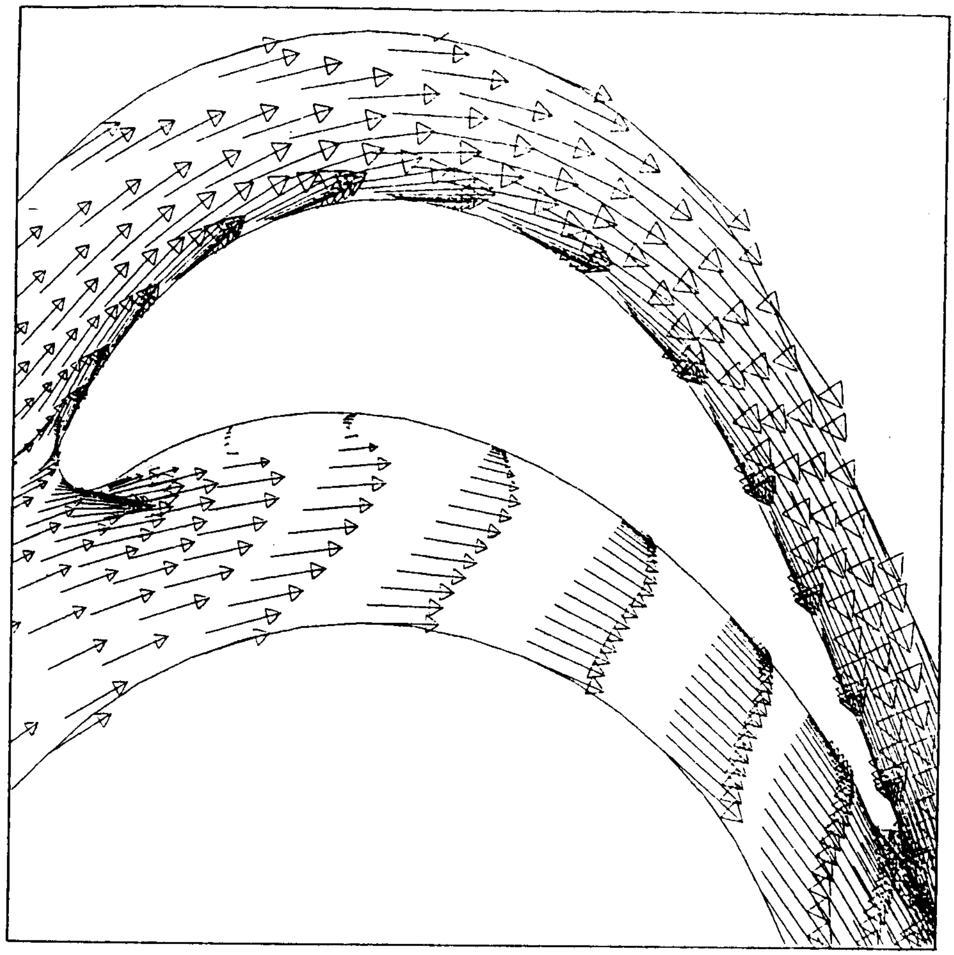

Figure 5. - Steady-state vector plot of SSME turbine rotor.

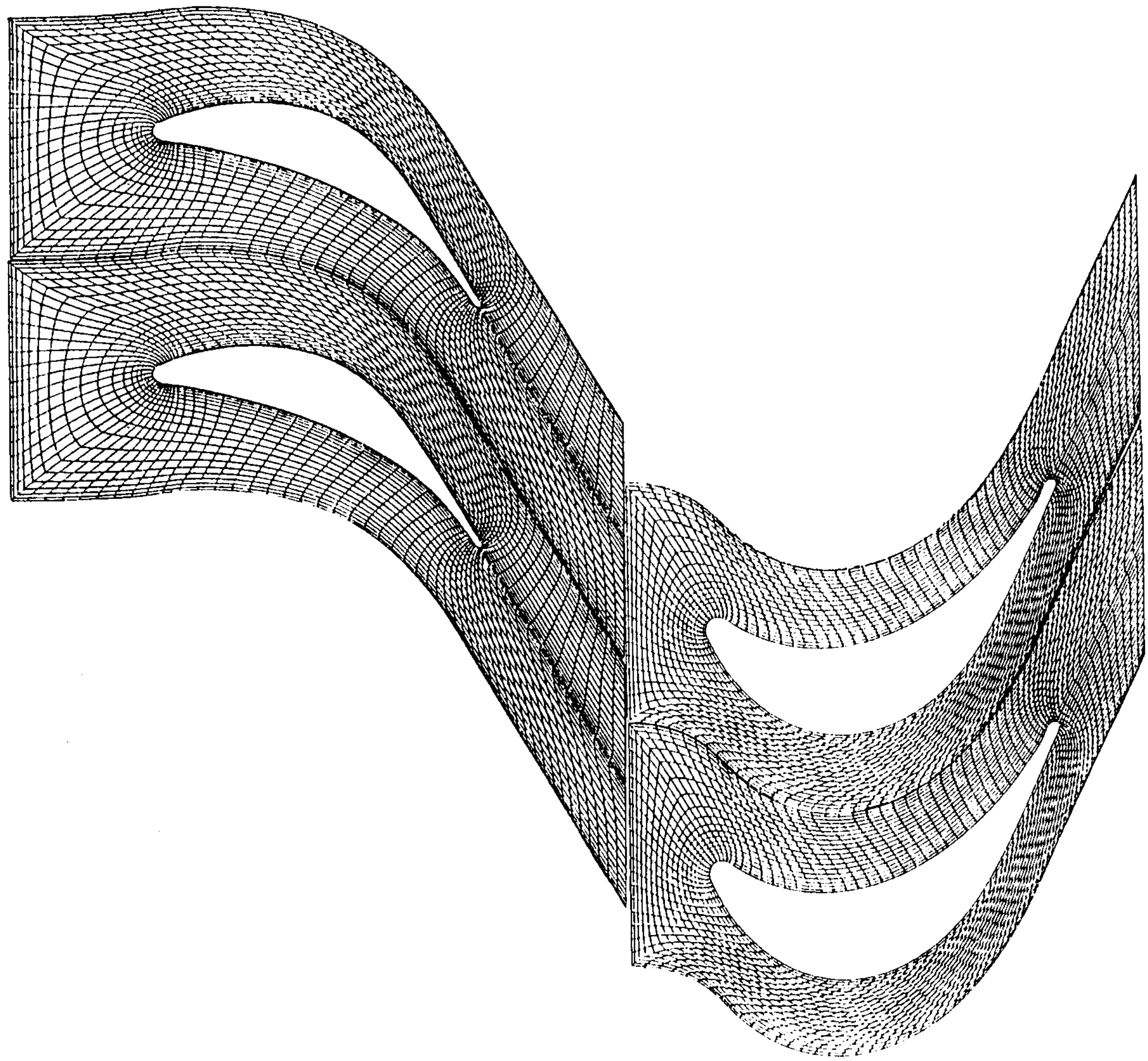

Figure 6. - Computational grids for the time-accurate SSME turbine rotor.

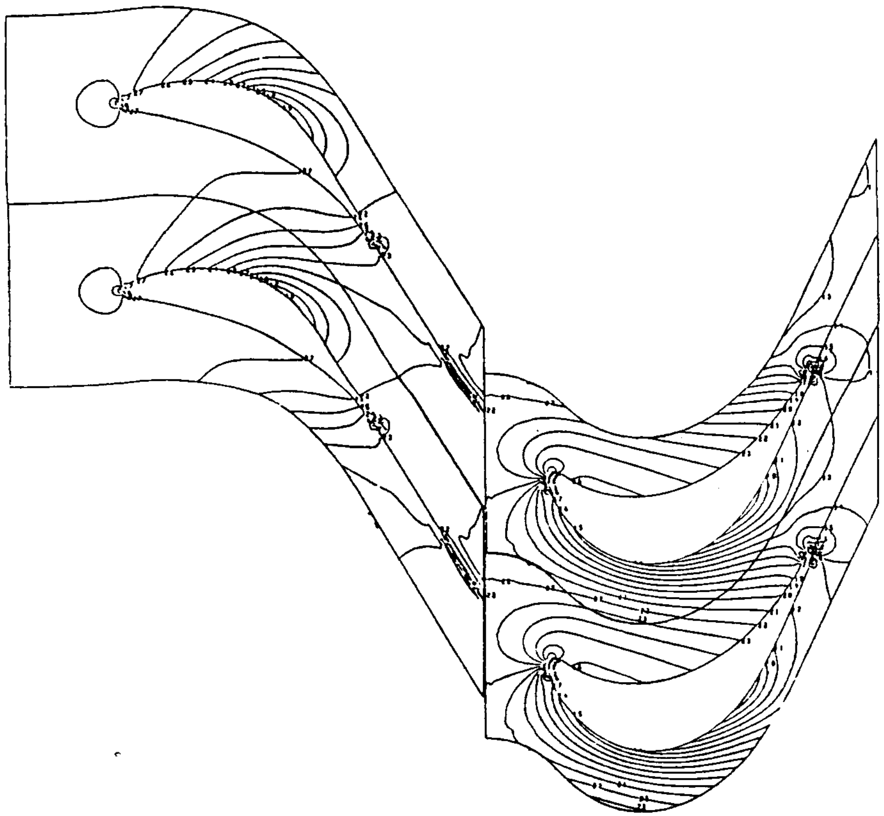

Figure 7. - Static pressure contours for SSME turbine rotor, inviscid.

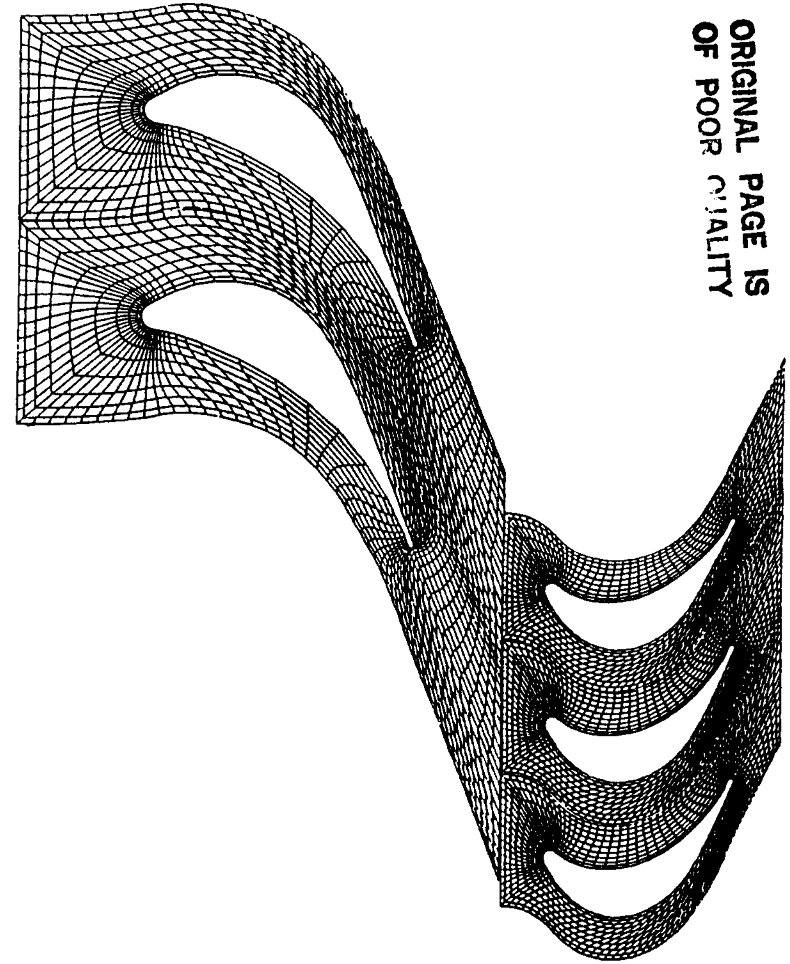

Figure 8. - SSME stator/rotor blade configuration.