Stator/Rotor Interaction in a Transonic Turbine

Michael B. Giles*
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

This paper presents calculations of a stator/rotor interaction in a highly loaded transonic first turbine stage. Of particular interest is the propagation and reflection of shocks which originate at the trailing edge of the upstream stator. These produce a 40% variation in the lift on the rotor, which would cause structural vibrations and increased losses. Also, the unsteady shocks would cause temporary boundary-layer separation near the leading edge of the suction surface. The numerical procedure solves the inviscid unsteady Euler equations, including quasi-three-dimensional terms. The use of a conservative treatment guarantees the correct treatment of the moving shocks. A simple technique is used to couple the calculations on the stator and rotor grids. A key feature of the paper is the use of "time-inclined" computational planes to allow the analysis of cases in which the ratio of stator and rotor pitches is not equal to unity or the ratio of two small integers.

Introduction

IN the last few years, an increasing amount of attention has been devoted to the calculation of unsteady flow in turbomachinery. Hodson[1] and Giles[2] have performed calculations of wake/rotor interaction in which incoming wakes were specified at inflow boundaries, and the resulting interaction was modeled using the inviscid Euler equations. Koya and Kotake,[3] Fourmaux,[4] and Lewis et al.[5] have calculated inviscid stator/rotor interactions in three dimensions, two dimensions, and quasi-three dimensions respectively. Finally, Rai has performed Navier-Stokes calculations of stator-rotor interaction in two dimensions[6] and three dimensions.[7]

The purpose of this paper is to add to this previous body of research in three areas. The first is an extremely simple method for handling the unsteady stator/rotor interface using two separate stator and rotor grids with a gap, which is bridged by a set of shearing computational cells. The treatment is fully conservative and therefore is suitable for applications in which shocks pass across the interface.

The second area of interest is the use of time-inclined computational planes to treat the difficulties encountered when the stator/rotor pitch ratio is not a small integer ratio, which is what has been assumed by most researchers. Hodson[1] and Koya[3] used a technique due to Erdos,[8] which involves a large amount of computer storage and a critical assumption that the flow is temporally periodic as well as spatially periodic. In Ref. 2 it was explained why this assumption is invalid for viscous flows, and an alternative approach was introduced. This involves "inclining" the computational plane such that different nodes at a given time-level are actually at different physical times. This technique was used for wake/rotor calculations, and in this paper it is shown that the technique can be extended to stator/rotor calculations.

The final part of this paper presents an application to a stator/rotor interaction in a highly loaded transonic first turbine stage. An interesting feature in this highly unsteady flow is the oblique shock wave, which extends from the trailing edge of the stator. This shock impinges on the rotor blade, reflects upstream, and then reflects again off the stator blade suction surface. The calculation clearly captures the complicated shock motion and shows the large unsteadiness in the lift on the rotor blade.

Basic Numerical Method

The flowfield is modeled by the unsteady Euler equations. These are inviscid equations that in a conservative formulation correctly model the formation and motion of shocks as well as the entropy and vorticity generated by the shocks.

$$h\frac{\partial U}{\partial t}+\frac{\partial (hF)}{\partial x}+\frac{\partial (hG)}{\partial y}=S \tag{1}$$

where U, F, G and, S are four component vectors given by

$$U=\begin{bmatrix}\rho\\ \rho u\\ \rho v\\ \rho E\end{bmatrix} \tag{2}$$

$$F=\begin{bmatrix}\rho u\\ \rho u^2+p\\ \rho uv\\ \rho uH\end{bmatrix} \tag{3}$$

$$G=\begin{bmatrix}\rho v\\ \rho uv\\ \rho v^2+p\\ \rho vH\end{bmatrix} \tag{4}$$

$$S=\begin{bmatrix}0\\ p\,\dfrac{\partial h}{\partial x}\\ p\,\dfrac{\partial h}{\partial y}\\ 0\end{bmatrix} \tag{5}$$

Although these are two-dimensional equations, they include three-dimensional effects through the specification of the streamtube thickness h in the third dimension, which produces the source term on the right side of the equation. The pressure

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*Harold R. Edgerton Assistant Professor, Department of Aeronautics and Astronautics. Member AIAA.