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PREDICTION OF TURBINE ROTOR-STATOR INTERACTION USING NAVIER-STOKES METHODS

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Abstract

Flows in turbomachinery are generally complex and do not easily lend themselves to numerical computation. The flows are three-dimensional and inherently unsteady. The unsteadiness arises from the interaction of the downstream airfoils with the wakes and passage vortices generated upstream, from the motion of the rotors relative to the stators and from vortex shedding at blunt airfoil trailing edges. Complicated blade geometries and flow phenomena such as separation and periodic transition from laminar to turbulent flow add to the numerical complexity. Nevertheless, the accurate numerical analysis of such flows is a problem of considerable interest and practical importance to the turbomachinery community.

Much of the early work in turbomachinery flow prediction focussed on airfoil cascades. While such analyses of flows in isolated airfoil rows have helped improve our understanding of the flow phenomena and have gained widespread acceptance in the industrial community as a design tool, they do not yield any information regarding the unsteady effects arising out of rotor-stator aerodynamic interaction. These interaction effects become increasingly important as the distance between successive stator and rotor rows is decreased. Thus, the need exists for analytical tools that treat the rotor and stator airfoils as a system and provide information regarding the magnitude and the impact of the unsteady effects.

The focus of this presentation is a three-dimensional, time-accurate, thin-layer Navier-Stokes code that has been recently developed to study rotor-stator interaction problems. A system of patched and overlaid grids that move relative to each other is used to discretize the flow field and the governing equations are integrated using a third-order upwind scheme set in an iterative, implicit framework. The code has been used to simulate subsonic flow through an axial turbine configuration for which considerable experimental data exists. Grid refinement studies have also been conducted as part of the code validation process. The current status of the research, along with planned future directions, are also discussed.

INTRODUCTION

- THE PREDICTION OF FLOWS IN TURBOMACHINERY IS A PROBLEM OF CONSIDERABLE INTEREST

- THE FLOWFIELDS ARE INHERENTLY UNSTEADY DUE TO :

  MOTION OF ROTORS RELATIVE TO THE STATORS

  INTERACTION OF DOWNSTREAM AIRFOILS WITH WAKES OF UPSTREAM AIRFOILS

  VORTEX SHEDDING AT BLUNT TRAILING EDGES

- UNSTEADY (OR INTERACTION) EFFECTS PRESENT EVEN FOR AXIAL GAPS USED IN CURRENT DESIGNS (50% TO 25% CHORD)

INTRODUCTION.....CONTD.

- COMPLEX BLADE GEOMETRIES, PERIODIC TRANSITION FROM LAMINAR TO TURBULENT FLOW, FLOW SEPARATION, ETC. PRESENT ADDITIONAL COMPUTATIONAL DIFFICULTIES

- NEED EXISTS FOR A COMPUTATIONAL TOOL THAT TREATS THE COMPLETE TURBINE STAGE AS A SYSTEM AND PROVIDES INFORMATION REGARDING THE UNSTEADY EFFECTS

POSSIBLE GAINS

- IMPROVED PERFORMANCE (LOWER LOSSES, ETC.)
- IMPROVED STRUCTURAL DESIGN (STRUCTURES THAT BETTER WITHSTAND THE DYNAMIC STRESSES ASSOCIATED WITH THE UNSTEADY NATURE OF THE FLOW)
- AN UNDERSTANDING OF THE ACOUSTICS (MINIMIZATION OF ENGINE NOISE)
- PREDICTION OF UNSTEADY HEAT TRANSFER (IMPROVED COOLING TECHNOLOGY)

CURRENT STATUS

- COMPUTER CODES CAPABLE OF PREDICTING UNSTEADY FLOWFIELDS IN SINGLE-STAGE TURBOMACHINERY DEVELOPED

ROTOR-2 .... 2D, NAVIER-STOKES CODE

ROTOR-3 .... 3D, NAVIER-STOKES CODE

CURRENT STATUS.....CONTD.

- CODE CAPABILITIES DEMONSTRATED BY SIMULATING AN EXPERIMENTAL SINGLE–STAGE AXIAL TURBINE CONFIGURATION

    2D COMPUTATIONS

    3D COMPUTATIONS FULLY ACCOUNTING FOR HUB, CASING AND ROTOR TIP CLEARANCE EFFECTS

    GRID–REFINEMENT STUDIES IN 3D

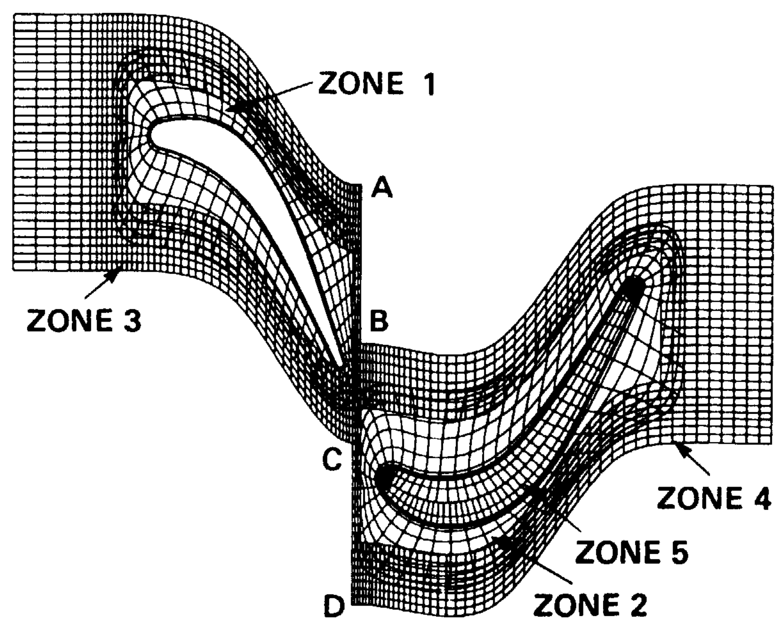
- STATE–OF–THE–ART COMPUTER GRAPHICS TECHNIQUES USED FOR VISUALIZATION OF COMPUTED RESULTS

    ''STEREO ANIMATION'' TECHNIQUES

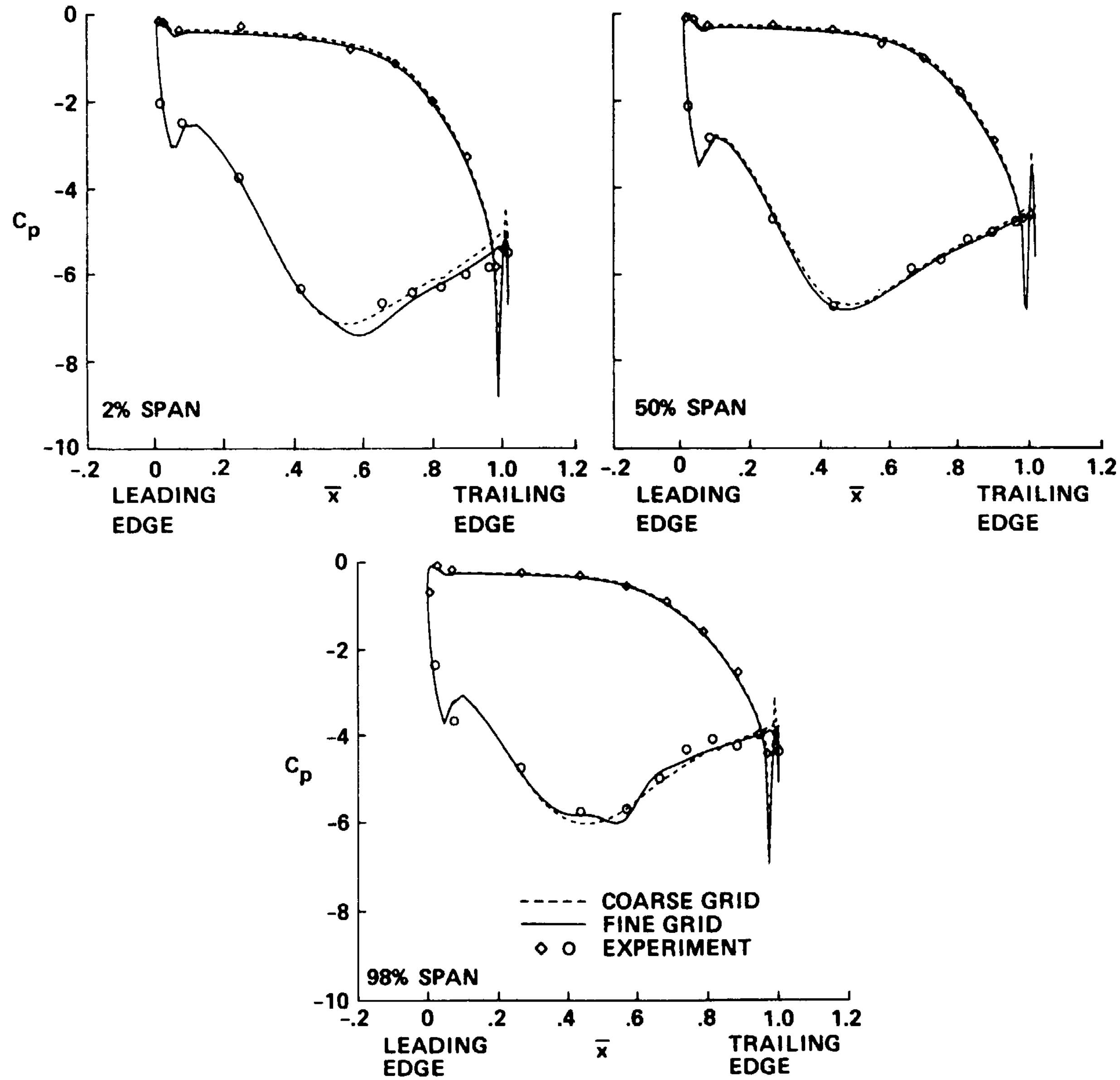
COMPUTATIONAL DETAILS

- HIGH—ORDER UPWIND FINITE—DIFFERENCE ALGORITHM FOR TIME—ACCURATE SOLUTION OF THE THIN—LAYER NAVIER—STOKES EQUATIONS
- ALGORITHM SET IN AN ITERATIVE, FACTORED AND IMPLICIT FRAMEWORK
- SYSTEM OF PATCHED AND OVERLAID GRIDS FOR FLOWFIELD DISCRETIZATION
- ROTOR GRIDS MOVE RELATIVE TO THE STATOR GRIDS
- BALDWIN—LOMAX TYPE TURBULENCE MODEL USED

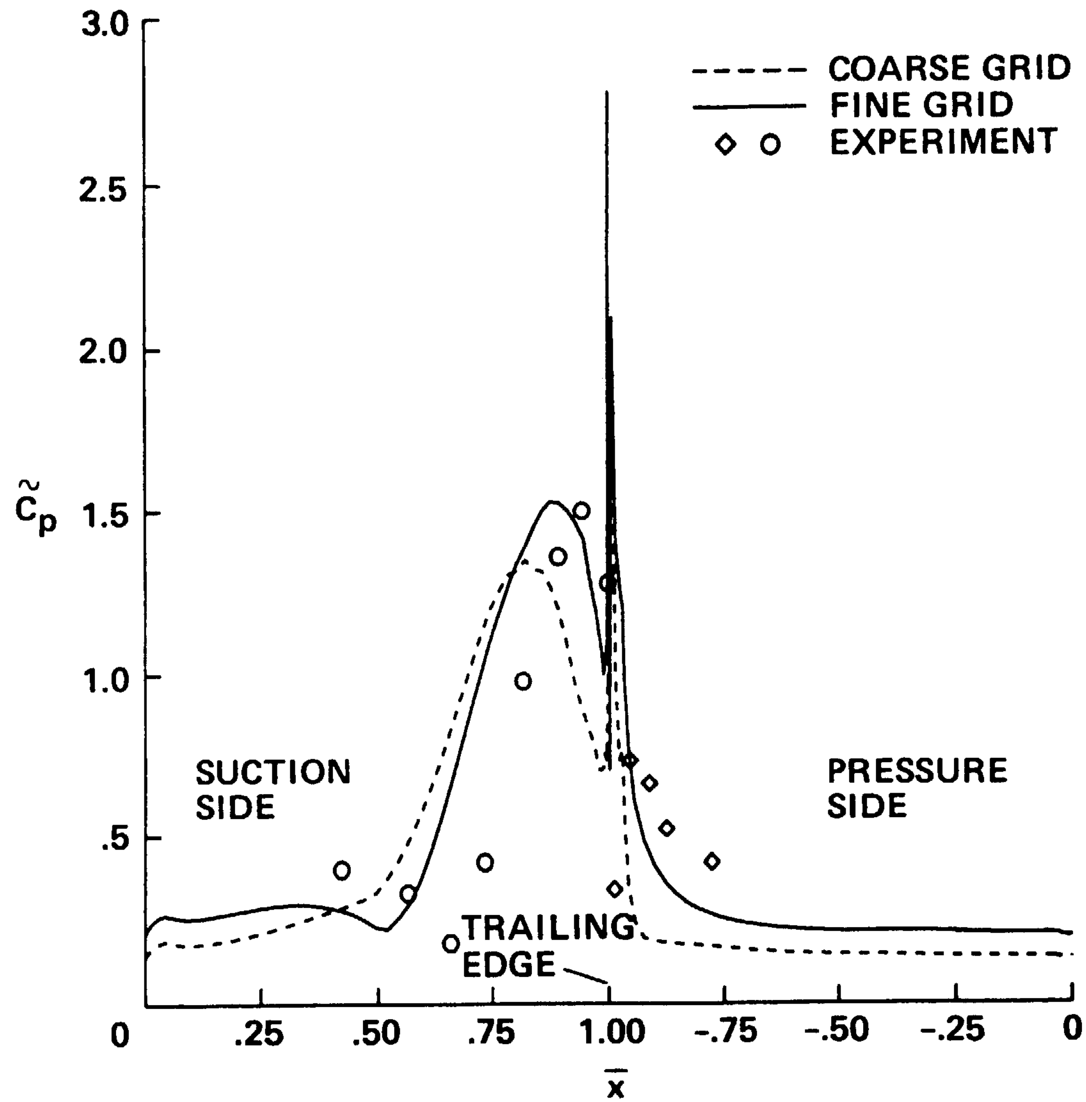
COMPUTATIONAL GRID



SPANWISE VARIATION OF STATOR TIME-AVERAGED PRESSURE

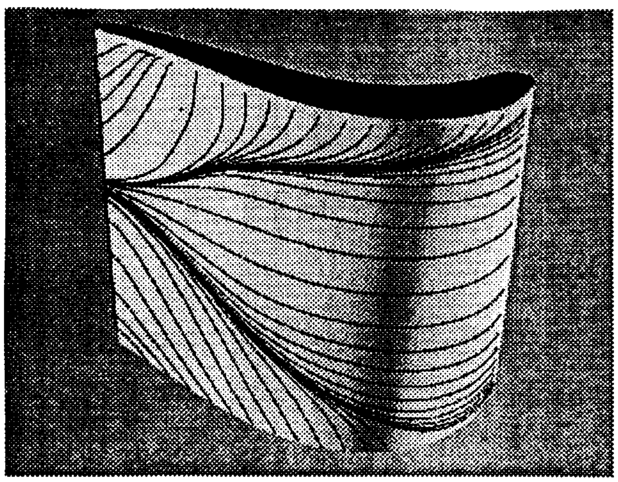


PRESSURE AMPLITUDE DISTRIBUTION ON THE STATOR

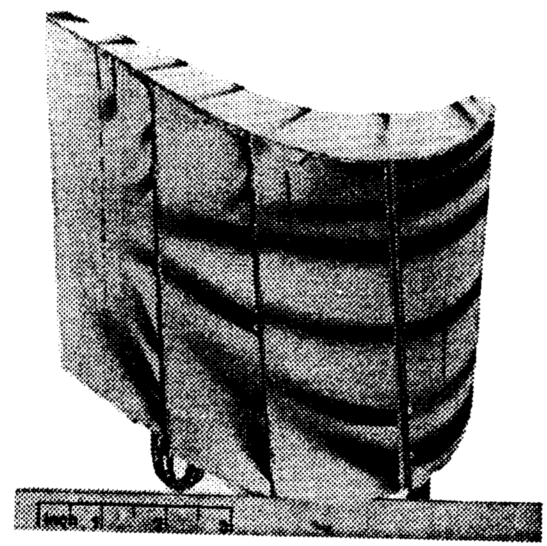


TIME-AVERAGED LIMITING STREAMLINES
ROTOR SUCTION SURFACE

FINE GRID



EXPERIMENTAL VISUALIZATION



SUMMARY AND FUTURE DIRECTIONS

- 2D AND 3D UNSTEADY, THIN–LAYER NAVIER–STOKES CODES DEVELOPED TO SIMULATE ROTOR/STATOR INTERACTION IN TURBOMACHINERY

- CURRENT RESEARCH EFFORTS AND FUTURE DIRECTIONS INCLUDE :

    MULTI–BLADE COMPUTATIONS

    MULTI–STAGE COMPUTATIONS

    BOUNDARY CONDITIONS

    TURBULENCE MODELING

    CODE ACCELERATION TECHNIQUES

    GRAPHICS