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Turbine Stage Aerodynamics And Heat Transfer Prediction

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A numerical study of the aerodynamic and thermal environment associated with axial turbine stages is presented. Computations were performed using a modification of the unsteady NASA Ames viscous code, ROTOR1, and an improved version of the NASA Lewis steady inviscid cascade system MERIDL-TSONIC coupled with boundary layer codes BLAYER and STAN5. Two different turbine stages were analyzed: the first stage of the United Technologies Research Center Large Scale Rotating Rig (LSRR) and the first stage of the Space Shuttle Main Engine (SSME) high pressure fuel turbopump turbine. The time-averaged airfoil midspan pressure and heat transfer profiles were predicted for numerous thermal boundary conditions including adiabatic wall, prescribed surface temperature, and prescribed heat flux. Computed solutions are compared with each other and with experimental data in the case of the LSRR calculations. Modified ROTOR1 predictions of unsteady pressure envelopes and instantaneous contour plots are also presented for the SSME geometry. Relative merits of the two computational approaches are discussed.

OVERVIEW

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- APPROACH
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  - APPLICATIONS
- RESULTS
  - AERODYNAMIC
  - HEAT TRANSFER
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- SUMMARY AND CONCLUSIONS

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OBJECTIVES

- DEFINITION OF STEADY AND UNSTEADY AEROTHERMAL ENVIRONMENTS FOR THE SPACE SHUTTLE MAIN ENGINE (SSME) HIGH PRESSURE FUEL TURBOPUMP (HPFTP) TURBINE
- CALIBRATION OF TURBINE ANALYSIS CODES VIA COMPARISON OF PREDICTED AND EXPERIMENTALLY MEASURED AIRFOIL LOADS IN UNITED TECHNOLOGIES RESEARCH CENTER LARGE SCALE ROTATING RIG (LSRR)

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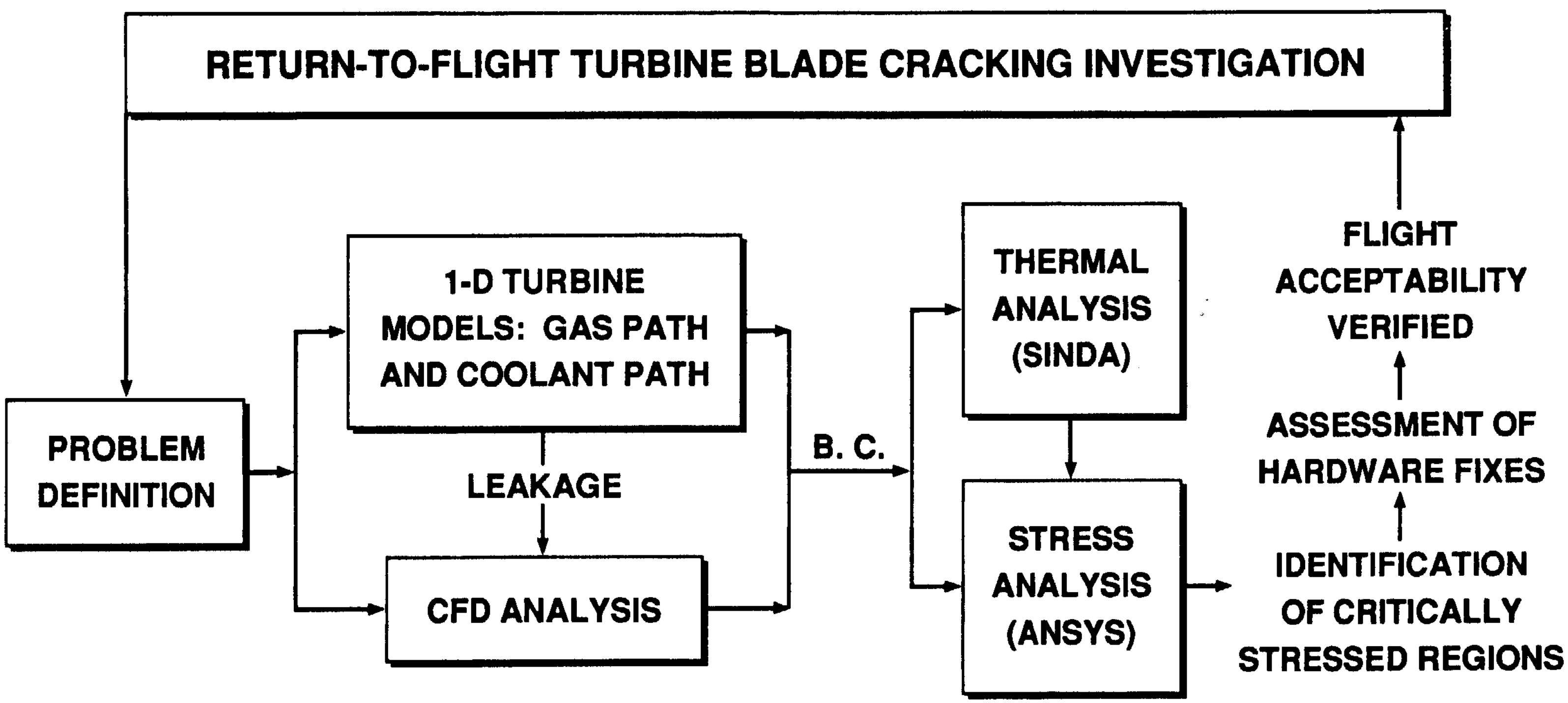
MOTIVATION



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APPROACH

CODES:

- MTSBL-STAN5 – STEADY INVISCID QUASI-3D SYSTEM MERIDL-TSONIC COUPLED WITH BOUNDARY LAYER CODES BLAYER AND STAN5. DEVELOPED AT NASA/LEWIS.
- ROTOR1 – UNSTEADY 2D SINGLE-STAGE CODE DEVELOPED AT NASA/AMES. ASSUMES EQUAL BLADE COUNT. MODIFIED TO INCORPORATE HEAT TRANSFER PREDICTION CAPABILITY

APPLICATIONS:

- LSRR – CODE CALIBRATION
- SSME HPFTP – ENVIRONMENT DEFINITION

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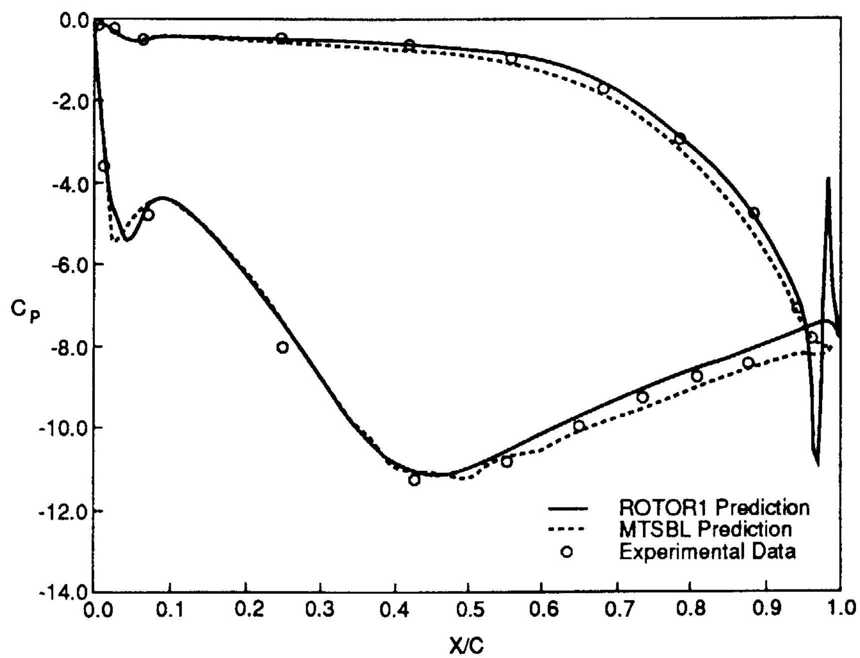
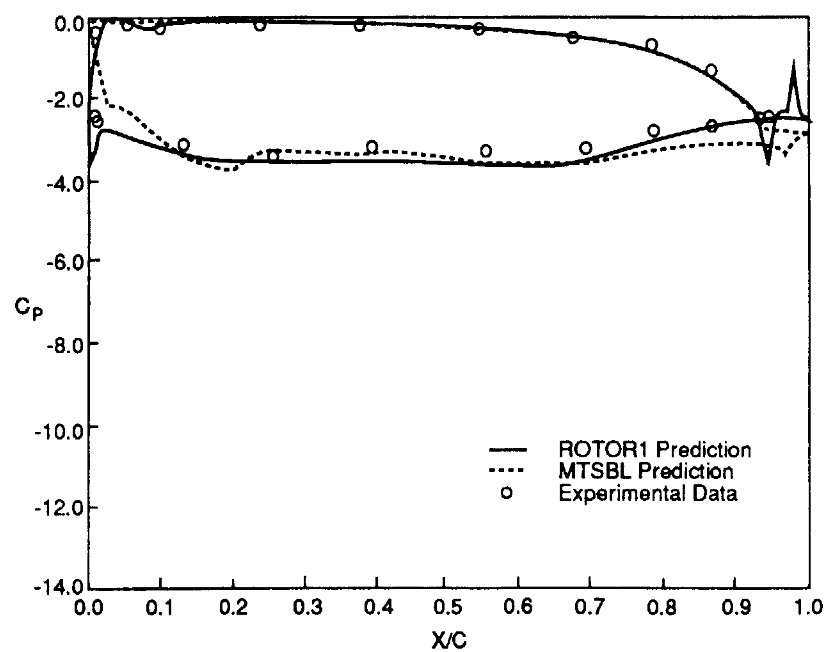
PRESSURE DISTRIBUTIONS FOR THE LSRR



Stator



Rotor

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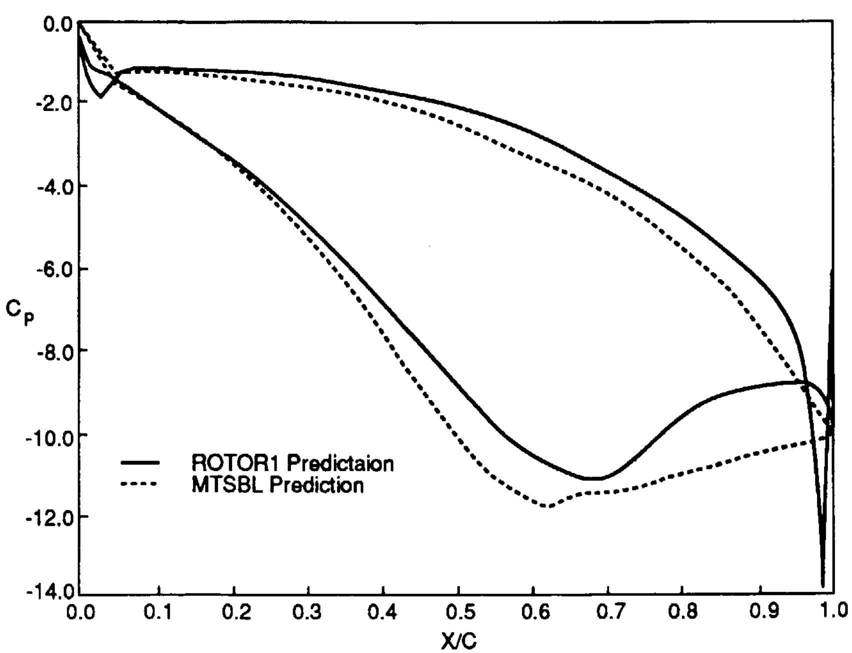
PRESSURE DISTRIBUTIONS FOR THE SSME HPFTP



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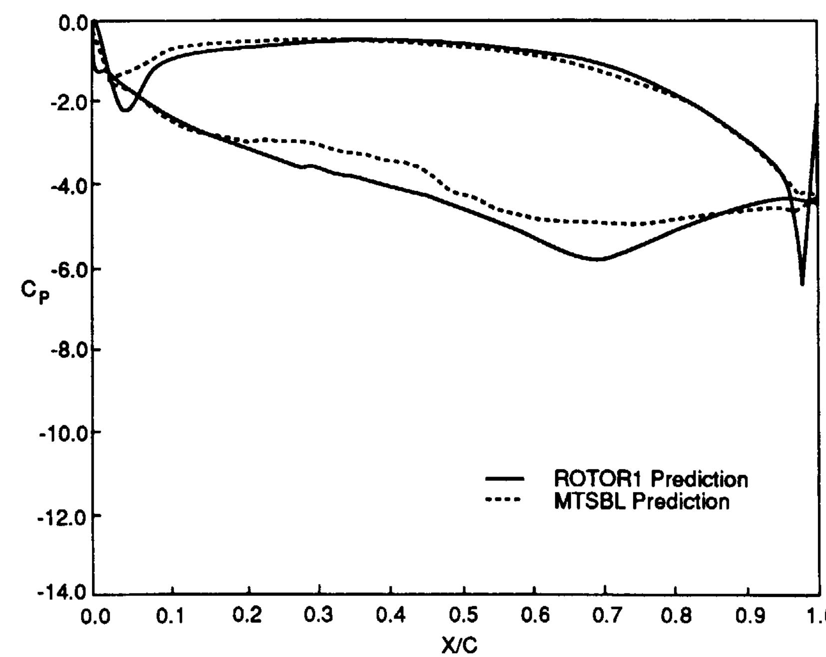

Rotor

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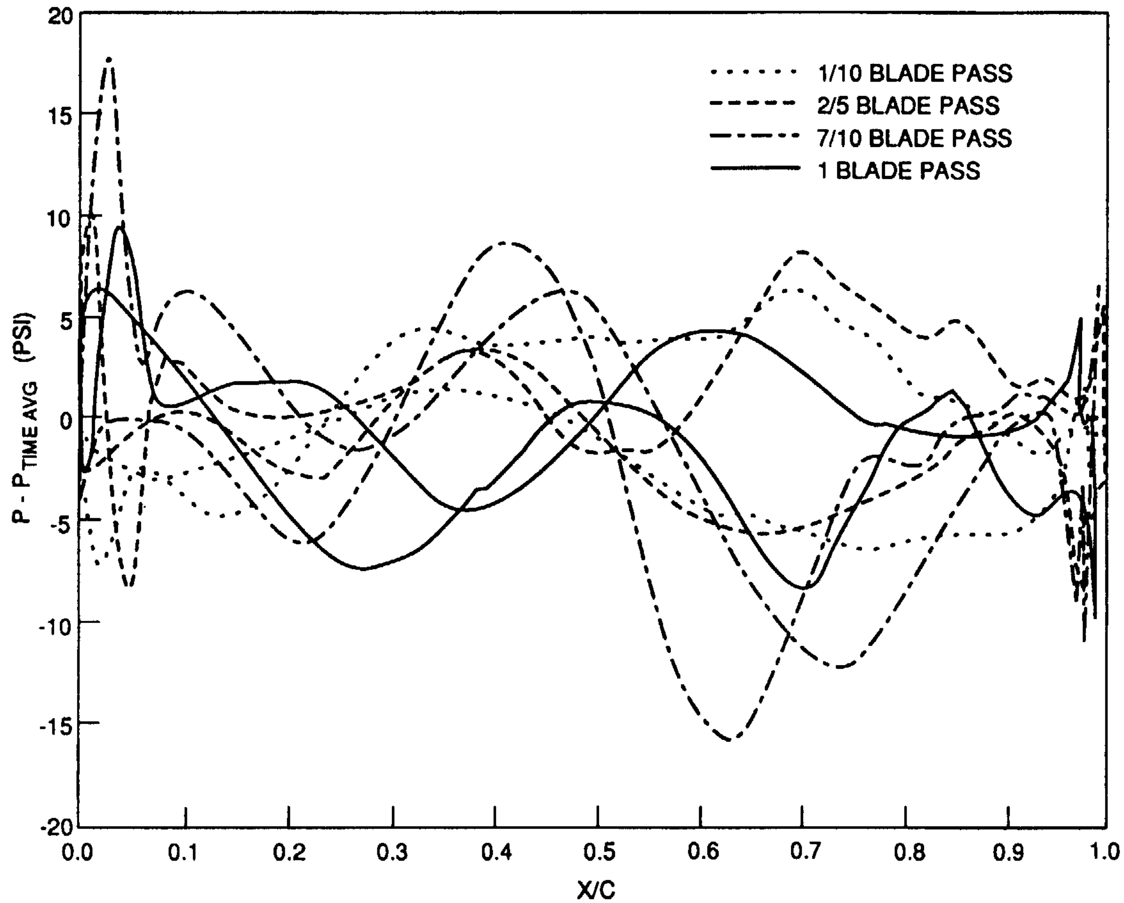
UNSTEADY PRESSURE DISTRIBUTIONS ON THE SSME HPFTP ROTOR



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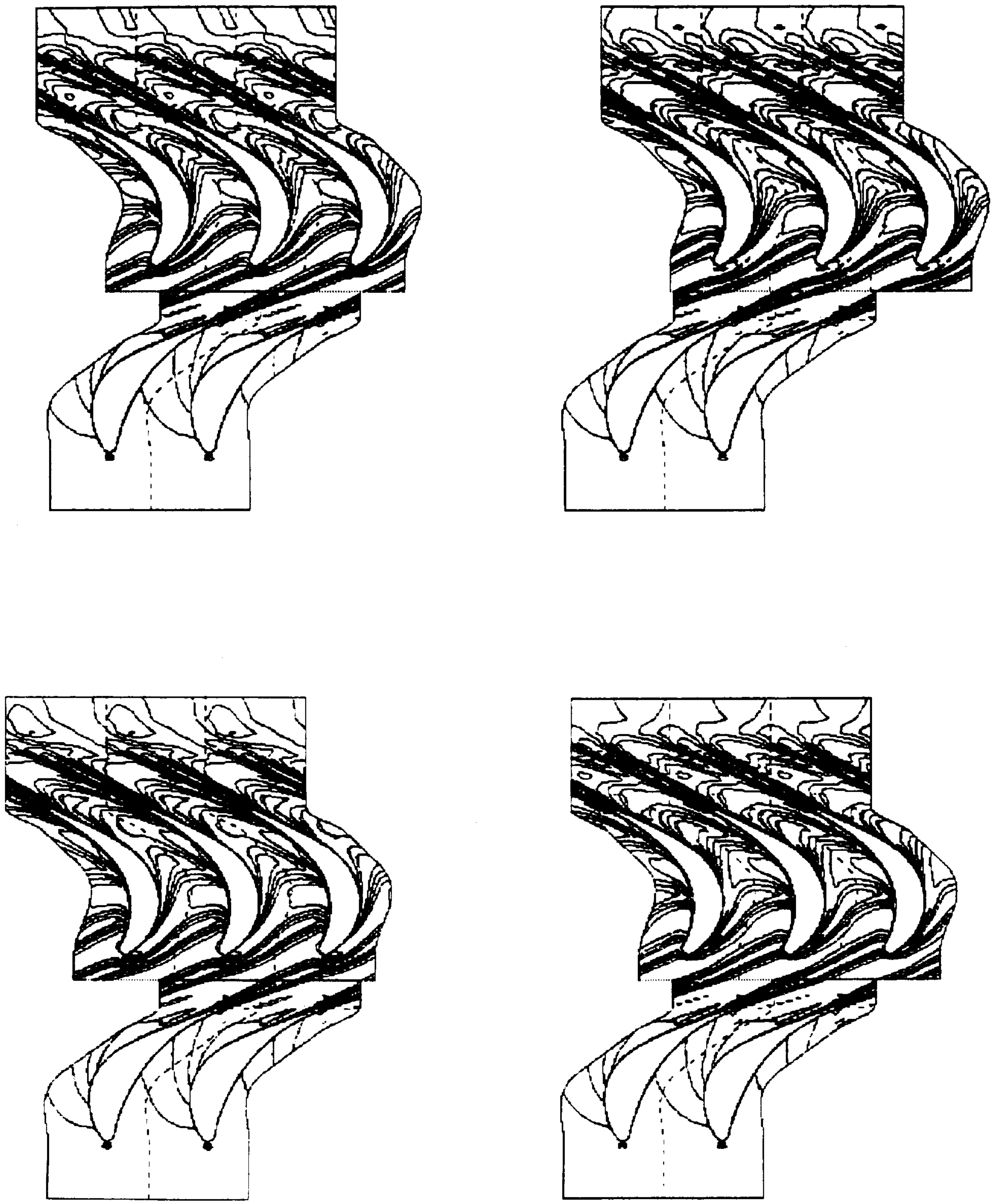
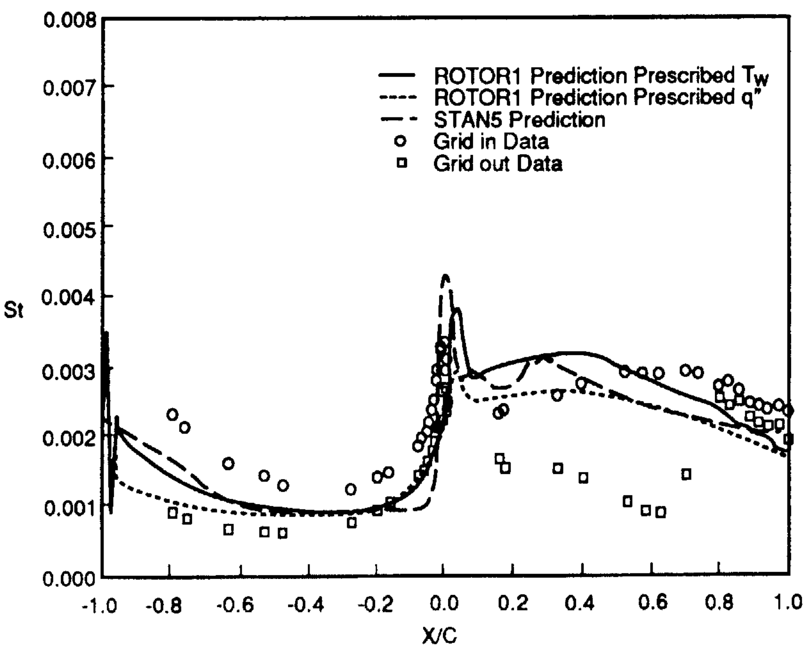
ENTROPY CONTOURS



COMPARISON OF PREDICTED AND EXPERIMENTAL HEAT TRANSFER FOR THE LSRR



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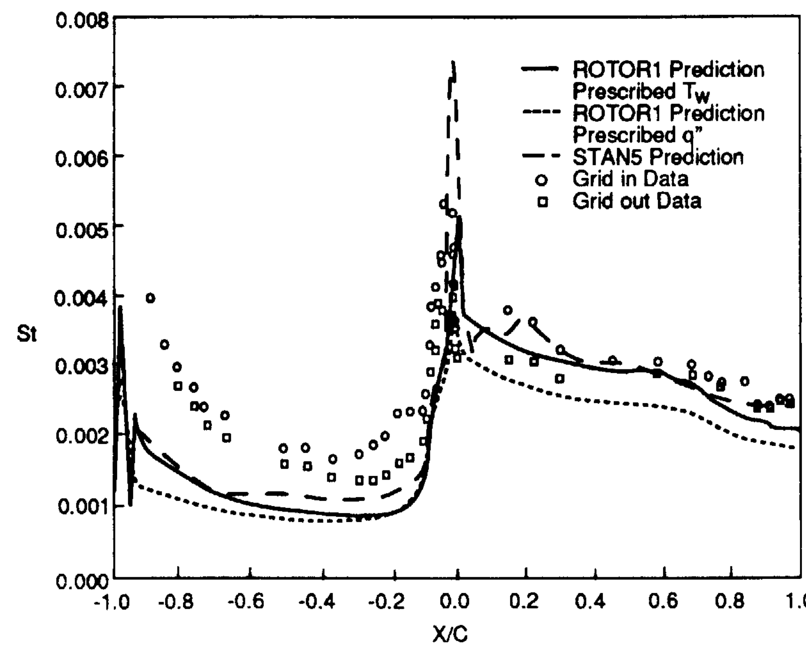

Rotor

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COMPUTER RESOURCES REQUIREMENTS

MTSBL - STAN5 – 6 CPU MINUTES, 0.9 X 10^6 WORDS MEMORY

ROTOR1 – 6 CPU HOURS, 2.1 X 10^6 WORDS MEMORY +
4.1 X 10^6 WORDS SSD

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IMPACT

- MSFC BENCHMARKING OF QUASI-3D TURBINE ANALYSIS SYSTEM AND UNSTEADY STAGE CODE; ASSESSMENT OF RELATIVE MERITS OF THE TWO APPROACHES.
- STEADY 3D FIRST AND SECOND STAGE BLADE LOADS WERE USED IN STRESS ANALYSIS OF HPFTP TURBINE BLADES IN SUPPORT OF <u>RETURN TO FLIGHT</u>; INTEGRATED LOADS PREDICT CORRECT TORQUE WITHIN 1%.
- UNSTEADY MIDSPAN PRESSURES WERE USED IN STRUCTURAL DYNAMICS ANALYSIS OF HPFTP FIRST STAGE BLADES.

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SUMMARY AND CONCLUSION

- SUPPORTED MSFC SSME PROGRAMS THROUGH CHARACTERIZATION OF THE STEADY AND UNSTEADY AEROTHERMAL ENVIRONMENTS OF THE HPFTP.
- BOTH APPROACHES YIELDED COMPARABLE STEADY OR TIME-AVERAGED AERODYNAMIC AND THERMAL RESULTS.
- AERODYNAMIC RESULTS FROM BOTH APPROACHES COMPARE WELL WITH DATA; THERMAL RESULTS EXHIBIT FAIR AGREEMENT WITH DATA.

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