# REDISTRIBUTION OF THE INLET TEMPERATURE PROFILE THROUGH THE SSME FUEL TURBINE

John R. Schwab
Turbine Aerodynamics Section
NASA - Lewis Research Center

## ABSTRACT

A three-dimensional Euler code was used to predict radial inlet temperature profile redistribution through the two-stage fuel turbopump turbine. The calculation was made at the FPL condition using a turbine inlet radial temperature profile supplied by Rocketdyne. This same calculation was made earlier on an inhouse-designed, single-stage turbine. In that case there was a redistribution of the temperature profile such that the hotter gas that originated at the midspan region at the turbine inlet was shifted to the hub and tip regions on the blade pressure surface at the rotor exit. However, for the SSME fuel turbine, there was no redistribution of the inlet temperature profile. No strong secondary flow patterns were identified. Preliminary assessment of the analytical results indicated that this trend was attributed to the high solidity SSME blading.

## INTRODUCTION

The life and durability of the SSME fuel turbine blading can be largely affected by redistribution of the inlet radial temperature profile due to secondary flow effects. This temperature redistribution can cause a convection of hot gas from the midspan region to the hub and tip endwalls, causing local hotspots and possible failure. To assess this redistribution effect for the SSME fuel turbine, a calculation was made using a three-dimensional Euler code (DENTON code) at the design operating condition for a prescribed inlet radial temperature profile.

## OBJECTIVE

ANALYZE POSSIBLE REDISTRIBUTION OF
INLET RADIAL TEMPERATURE PROFILE DUE TO
SECONDARY FLOW IN FUEL TURBINE

## RATIONALE

CONVECTION OF HOTTER GAS FROM THE MIDSPAN REGION
TO THE HUB AND TIP ENDWALLS COULD INFLUENCE THE
DEVELOPMENT OF HOTSPOTS

A three-dimensional Euler code (ref. 1) developed by J. D. Denton of Cambridge University was found to be useful in predicting redistribution of a nonuniform inlet radial temperature profile through an axial turbine stage (ref. 2). This code is an explicit time-marching solution of the Euler equations in finite-volume form for fixed or rotating turbomachinery blade rows. A two-level multigrid scheme was used to reduce computation time. For the 21 pitchwise x 21 spanwise x 75 streamwise grid used in these computations, the CPU time required was approximately 250 to 350 seconds on a CRAY-1. A uniform transverse grid was used to assure good resolution over the entire transverse flow plane. The blade and endwall surfaces were assumed to be adiabatic.

## METHOD

DENTON 3-D EULER CODE

- EXPLICIT TIME-MARCHING SOLUTION
- FINITE-VOLUME FORMULATION
- 2-LEVEL MULTIGRID SCHEME
- UNIFORM GRID SPACING
- 21 PITCHWISE X 21 SPANWISE X 70 STREAMWISE

In order to circumvent the problems involved in calculating flow properties for the actual fuel mixture of superheated steam and hydrogen, the computations were performed for air at the same mean inlet temperature. The mean inlet pressure was calculated from equivalent conditions to match the mean radius Reynolds number at full power level (FPL) conditions.

## METHOD

### AIR CONDITIONS CALCULATED TO MATCH FPL INLET TEMPERATURE AND REYNOLDS NUMBER

| | |
|---|---|
| REYNOLDS NUMBER (MEAN RADIUS) | 21 830 000 |
| MEAN INLET TEMPERATURE, DEG R | 1 990 |
| MEAN INLET PRESSURE, PSIA | 3 234 |
| MASS FLOW, LBM/SEC | 274 |
| SPEED, RPM | 13 890 |

The inlet total pressure profile was calculated from a specified displacement thickness assuming a turbulent 1/7 power velocity profile in the boundary layer. Since the inviscid code could not accommodate no-slip conditions at the walls, a slip velocity of 50 percent of the free-stream velocity was used. Inlet radial profiles for each succeeding blade row were obtained by circumferentially averaging the outlet flow properties of the preceeding blade row using mass flow averaging.

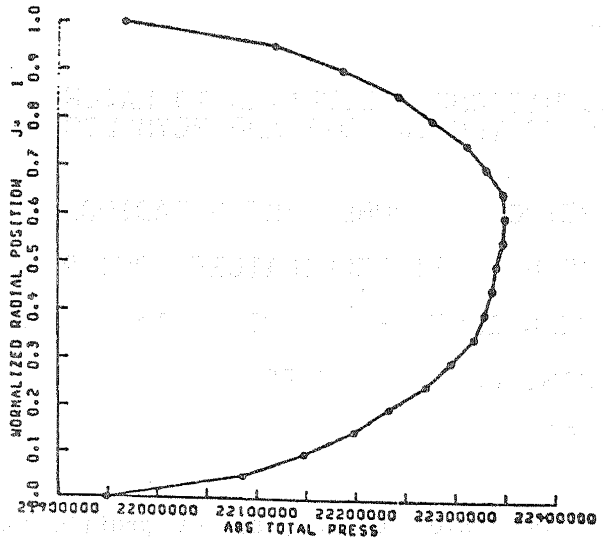
## METHOD

INLET PRESSURE PROFILE CALCULATED FROM INLET DISPLACEMENT THICKNESS ASSUMING TURBULENT 1/7 POWER VELOCITY PROFILE

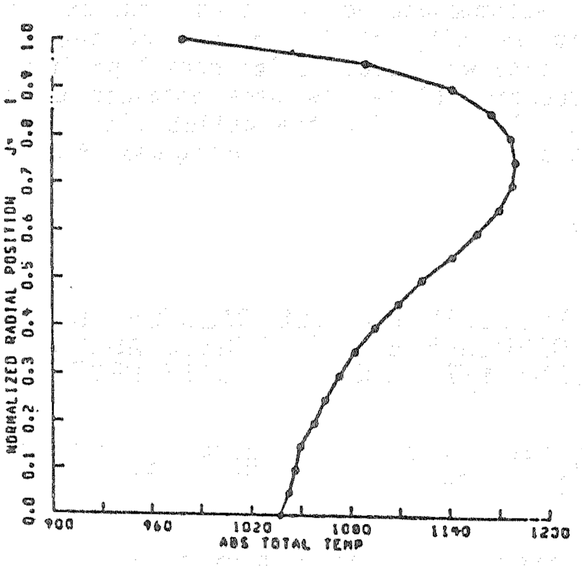
SLIP VELOCITY AT THE ENDWALLS SPECIFIED AS 50 % OF THE FREE-STREAM VELOCITY

INLET RADIAL PROFILES FOR SUCCEEDING BLADE ROWS OBTAINED BY CIRCUMFERENTIALLY AVERAGING THE OUTLET FLOW PROPERTIES OF THE PRECEEDING BLADE ROW

Total pressure and total temperature radial profiles are shown for the first stage stator inlet. The normalized radial coordinate ranges from 0.0 for the hub to 1.0 for the tip. The total pressure is given in newtons per square meter, while the temperature is given in degrees kelvin. The temperature profile was obtained from Rocketdyne.

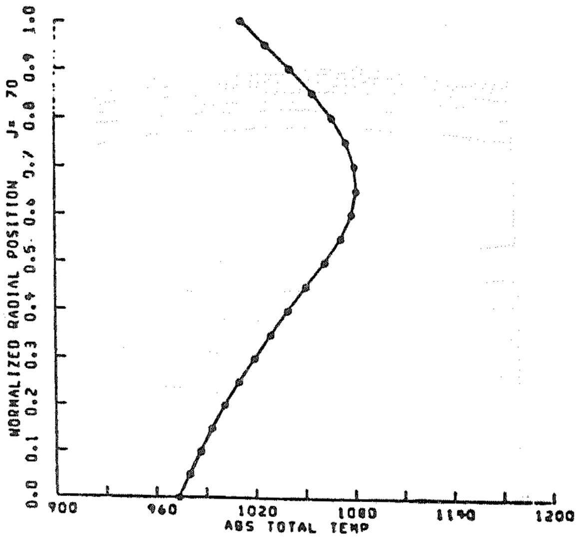


STATOR 1 INLET

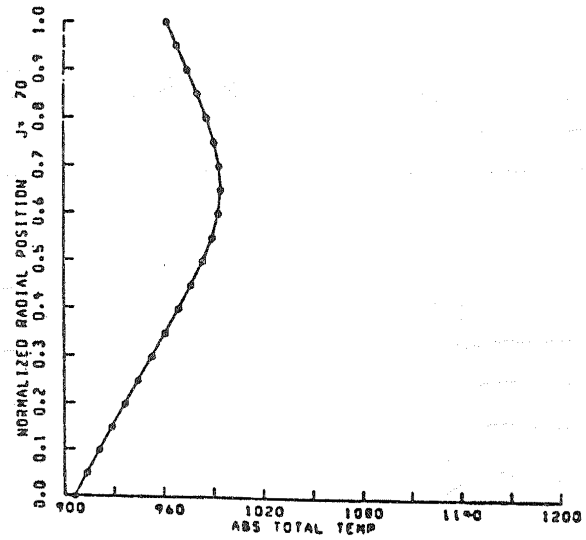


STATOR 1 INLET

Circumferentially averaged total temperature profiles are shown for the first and second stage rotor outlets. Some attenuation has occurred due to smoothing and numerical diffusion as well as the extraction of work across the rotors, but the profile persists through both stages.

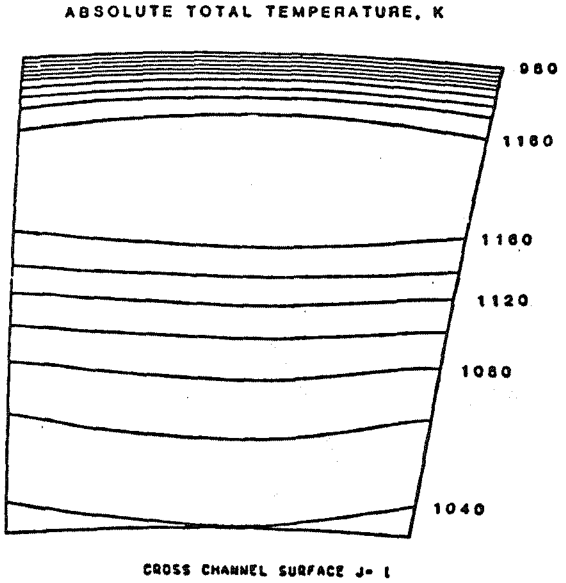


ROTOR 1 OUTLET

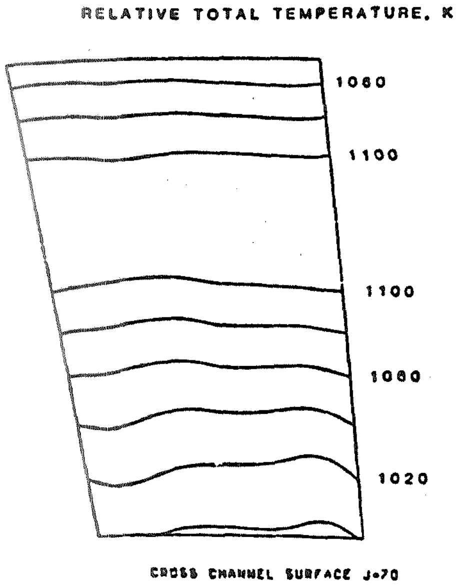


ROTOR 2 OUTLET

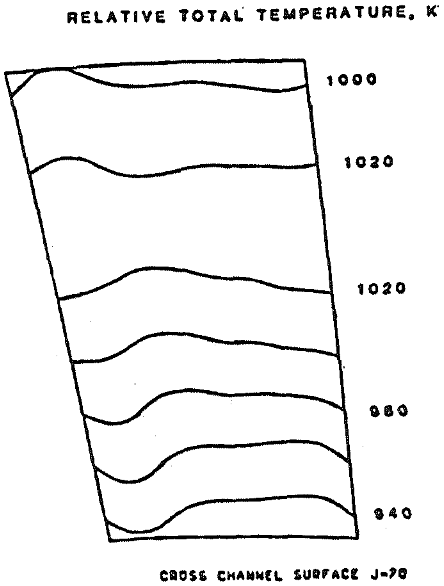
Contour plots of total temperature are shown in transverse planes at the first stage stator inlet and first and second stage rotor outlets. The absolute total temperature is shown for the stator, while the relative total temperature is shown for the rotors. The pressure surface is on the left side of the plot and the suction surface is on the right. There is no evidence of rotation of the temperature profiles due to secondary flow.



STATOR 1 INLET



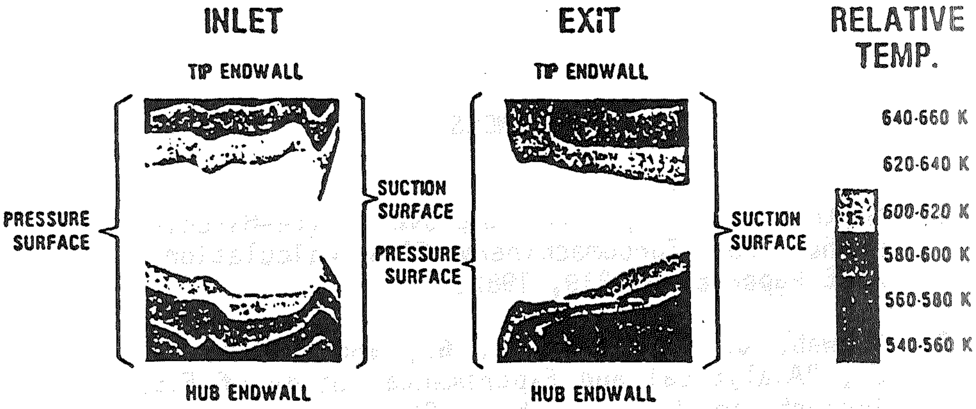
ROTOR 1 OUTLET



ROTOR 2 OUTLET

Color contour plots of relative total temperature are shown at the inlet and exit of a core turbine rotor. Definite rotation of the profile can be discerned. Hotter gas from the midspan region has been convected by secondary flow into the hub and tip regions near the pressure surface. This rotor had solidity of 1.079 and turning of 112.7 degrees. The solidity and turning of the SSME fuel turbine rotors were 1.452 and 101.1 degrees for the first stage rotor and 1.412 and 96.1 degrees for the second stage rotor.

## REDISTRIBUTION OF INLET RADIAL TEMPERATURE PROFILE THROUGH AN AXIAL TURBINE ROTOR



- UNCOOLED 75° RESEARCH CORE TURBINE STAGE
- DENTON 3-D EULER CODE
- REALISTIC STATOR INLET RADIAL TEMPERATURE PROFILE
- MODERATE ROTATION OF RELATIVE TEMPERATURE PROFILE BY SECONDARY FLOW
- 60 K GAS TEMPERATURE RISE ON PRESSURE SURFACE AT HUB AND TIP FOR 670 K MEAN STATOR INLET TEMPERATURE

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## CONCLUSIONS

CIRCUMFERENTIALLY AVERAGED RADIAL TEMPERATURE PROFILES SHOW MODERATE ATTENUATION DUE TO SMOOTHING AND NUMERICAL DIFFUSION AS WELL AS WORK EXTRACTION ACROSS THE ROTORS

NO EVIDENCE OF TEMPERATURE PROFILE ROTATION DUE TO SECONDARY FLOW

PRELIMINARY ASSESSMENT INDICATES THAT HIGHER SOLIDITY AND LOWER TURNING BLADE DESIGN PREVENTS TEMPERATURE PROFILE ROTATION

## REFERENCES

1. Denton, J. D., "An Improved Time-Marching Method for Turbomachinery Flow Calculation," ASME Paper 82-GT-239, 1982.

2. Schwab, J. R., Stabe, R. G., and Whitney, W. J., "Analytical and Experimental Study of Flow Through an Axial Turbine Stage with a Non-uniform Inlet Radial Temperature Profile," NASA TM 83431, 1983.