# THREE-DIMENSIONAL ANALYSIS OF THE PRATT & WHITNEY ALTERNATE DESIGN SSME FUEL TURBINE

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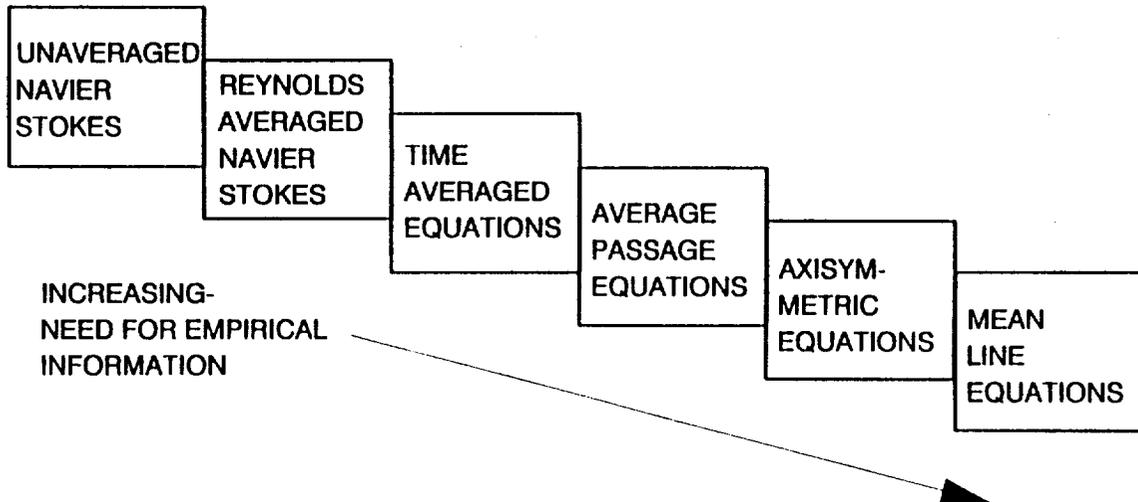Lewis Research Center Group
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The three-dimensional viscous time-mean flow in the Pratt & Whitney alternate design space shuttle main engine fuel turbine is simulated using the average passage Navier-Stokes equations. The migration of secondary flows generated by upstream blade rows and their effect on the performance of downstream blade rows is studied. The present simulation confirms that the flow in this low aspect ratio two stage turbine is highly three-dimensional and dominated by the tip leakage flow. The tip leakage vortex generated by the first blade persists through the second vane and influences the loading of the second blade and adversely affects its performance. The greatest mixing of the inlet total temperature distortion occurs in the second vane and is due to the large leakage vortex generated by the upstream rotor. It is asserted that the predominant spanwise mixing mechanism in this low aspect ratio tubine is the radial transport due to the deterministically unsteady vortical flow generated by upstream blade rows. A by-product of the analysis is accurate pressure and heat loads for all blade rows under the influence of neighboring blade rows. These aero loads are useful for advanced structural analysis of the vanes and blades.

# EQUATIONS HIERARCHY

| UNAVERAGED NAVIER STOKES |
| --- |

| REYNOLDS AVERAGED NAVIER STOKES |
| --- |

| TIME AVERAGED EQUATIONS |
| --- |

| AVERAGE PASSAGE EQUATIONS |
| --- |

| AXISYM-METRIC EQUATIONS |
| --- |

| MEAN LINE EQUATIONS |
| --- |

INCREASING-NEED FOR EMPIRICAL INFORMATION

## AVERAGE PASSAGE EQUATION SYSTEM

$$\int \frac{\delta}{\delta t} (\lambda q)\, dV + L(\lambda q) = \int \lambda S\, dV + \int \lambda K\, dV$$

$$q = [\rho, \rho u_z, \rho u_r, \rho r u_\theta, \rho e_0]^T$$

$$L = \int_{dA} [\lambda F\, dA_z + \lambda G\, dA_r + \lambda H\, dA_\theta]$$

$\lambda$ = blockage factor ‹ 1 over smeared blade rows

K = source term due to r -θ- z coordinates

S = source term which includes:

☐ body forces

☐ energy sources

☐ momenta/energy temporal correlations

☐ spatial mixing correlations

# PRATT & WHITNEY SSME ALTERNATE TURBOPUMP TURBINE DESIGN
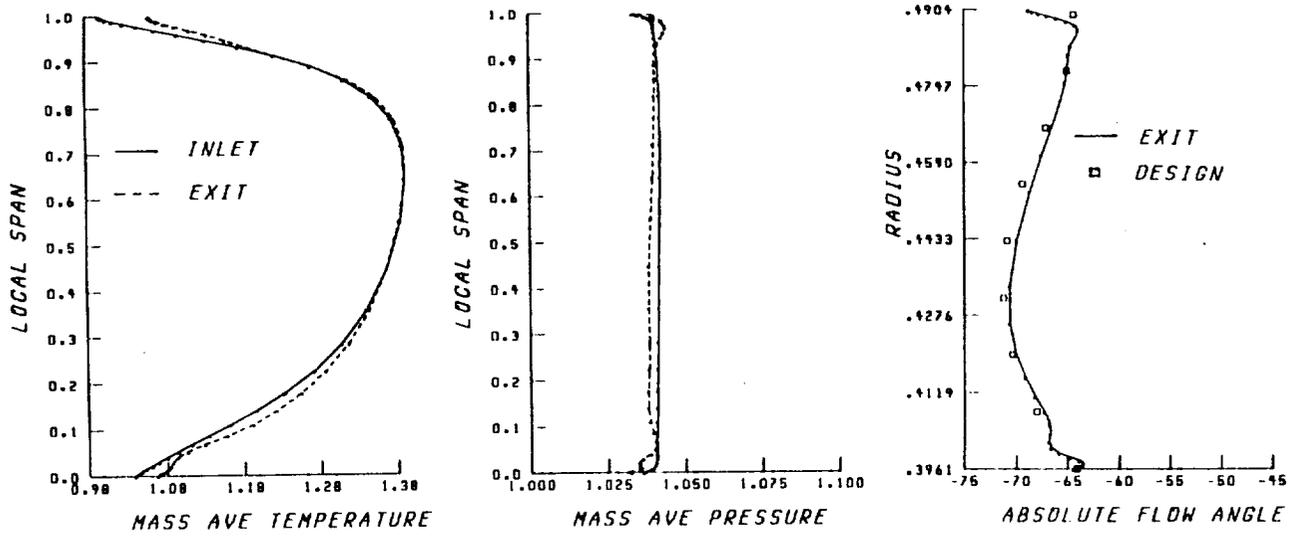
## AVERAGE PASSAGE MODEL ANALYSIS



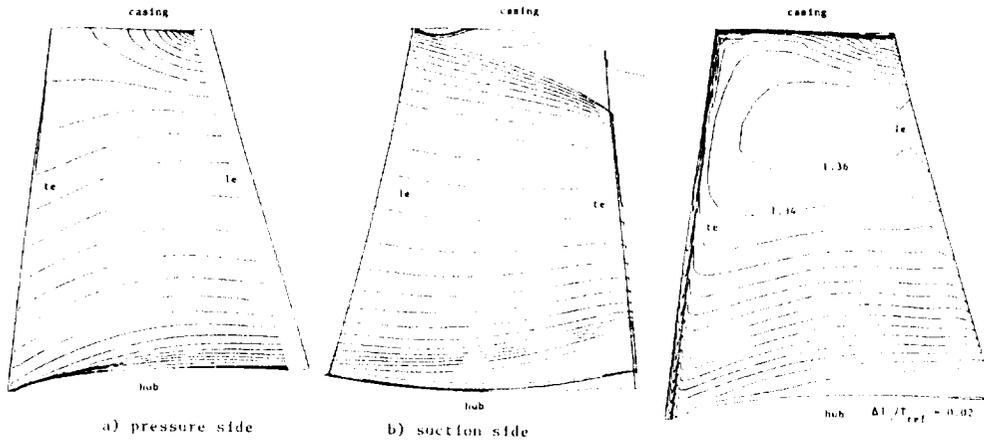|  | $\Delta T_0/T_{0_{in}}$ | | $P_{0_{in}}/P_{0_{out}}$ | |
|---|---|---|---|---|
|  | MEANLINE | AVE. PASS | MEANLINE | AVE. PASS |
| VANE 1 | 0 | 0 | 1.0044 | 1.0032 |
| BLADE 1 | 0.0411 | 0.0429 | 1.2052 | 1.1870 |
| VANE 2 | 0 | 0 | 1.0202 | 1.0085 |
| BLADE 2 | 0.0335 | 0.0286 | 1.1360 | 1.1250 |
| TOTAL | 0.0753 | 0.0711 | 1.4030 | 1.3530 |

# VANE 1 STREAMWISE VORTICITY



257
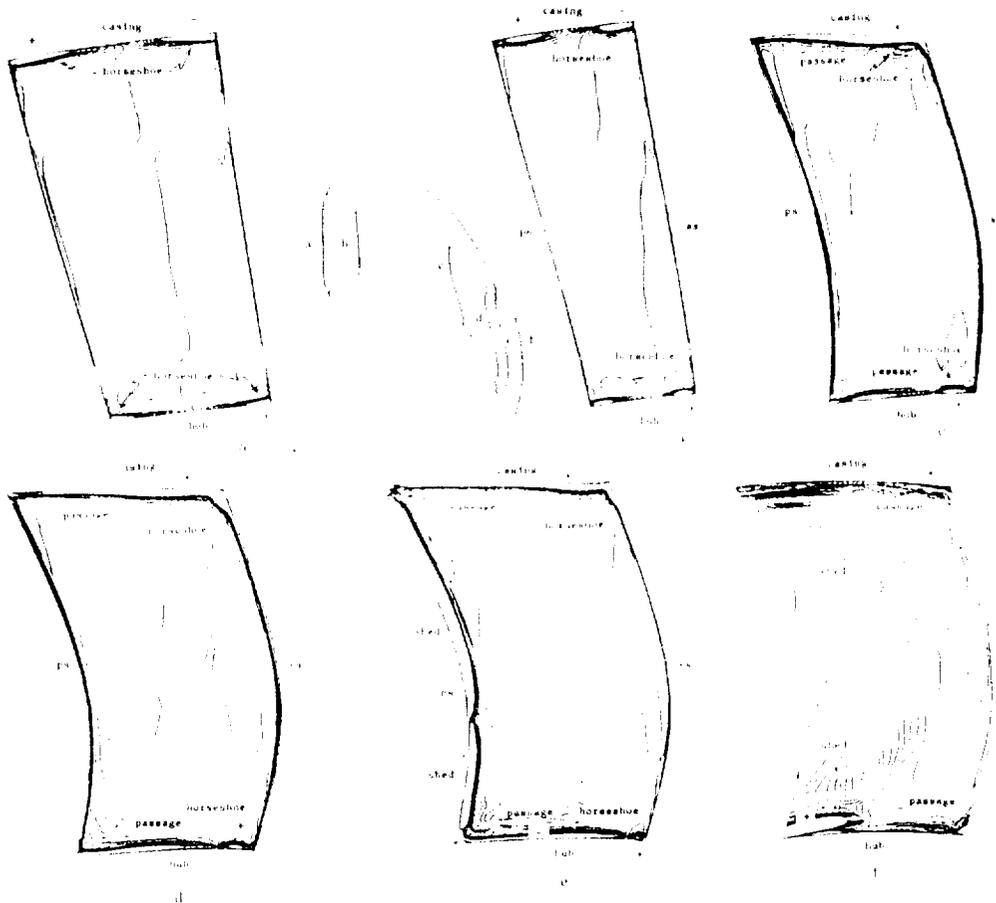
# VANE 1 AXISYMMETRIC FLOW



# BLADE 1 STREAMWISE VORTICITY
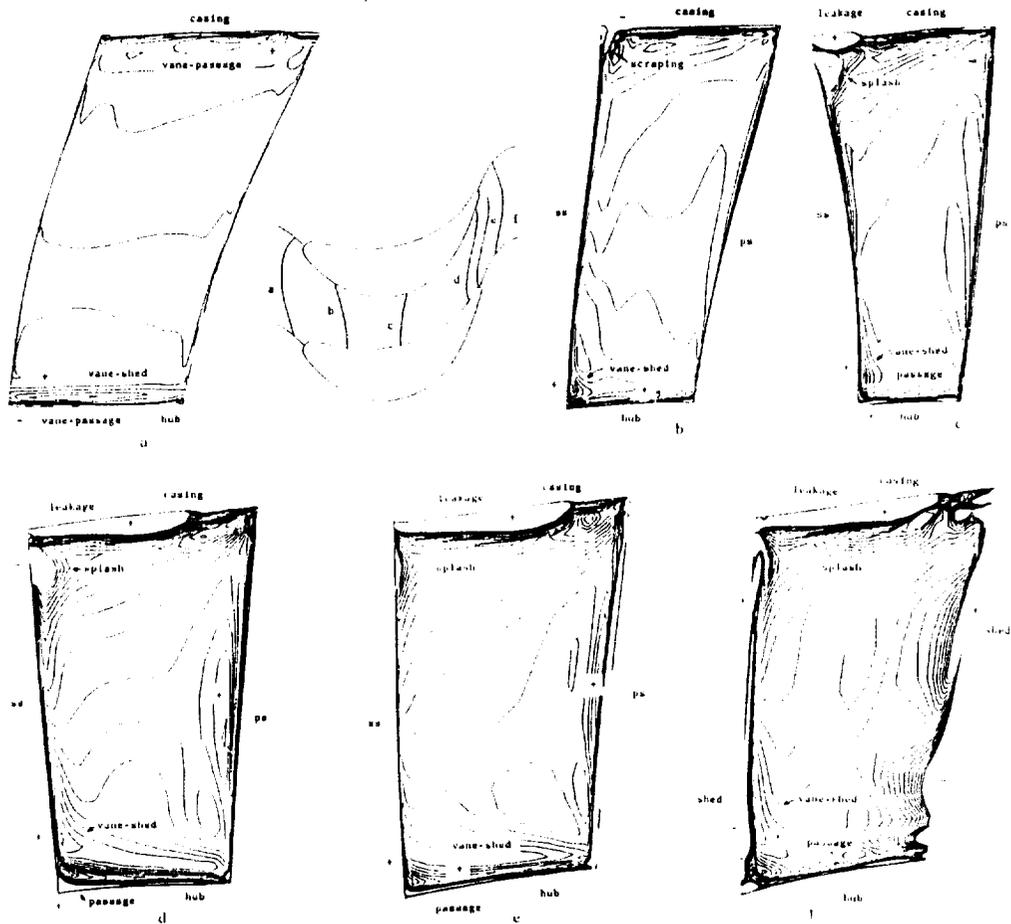
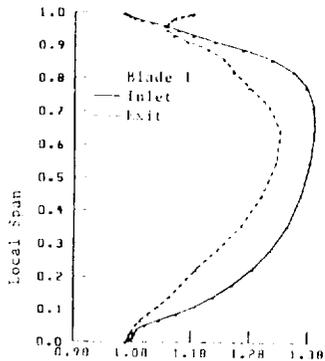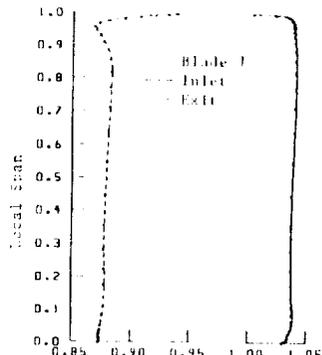# BLADE 1 SURFACE & AXISYMMETRIC FLOW



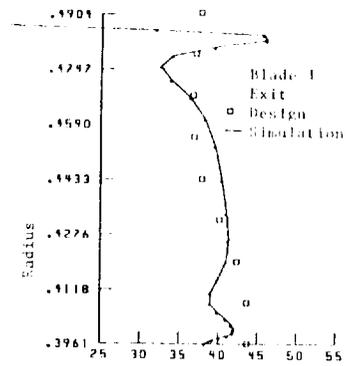a) pressure side   b) suction side

Streaklines on Blade 1

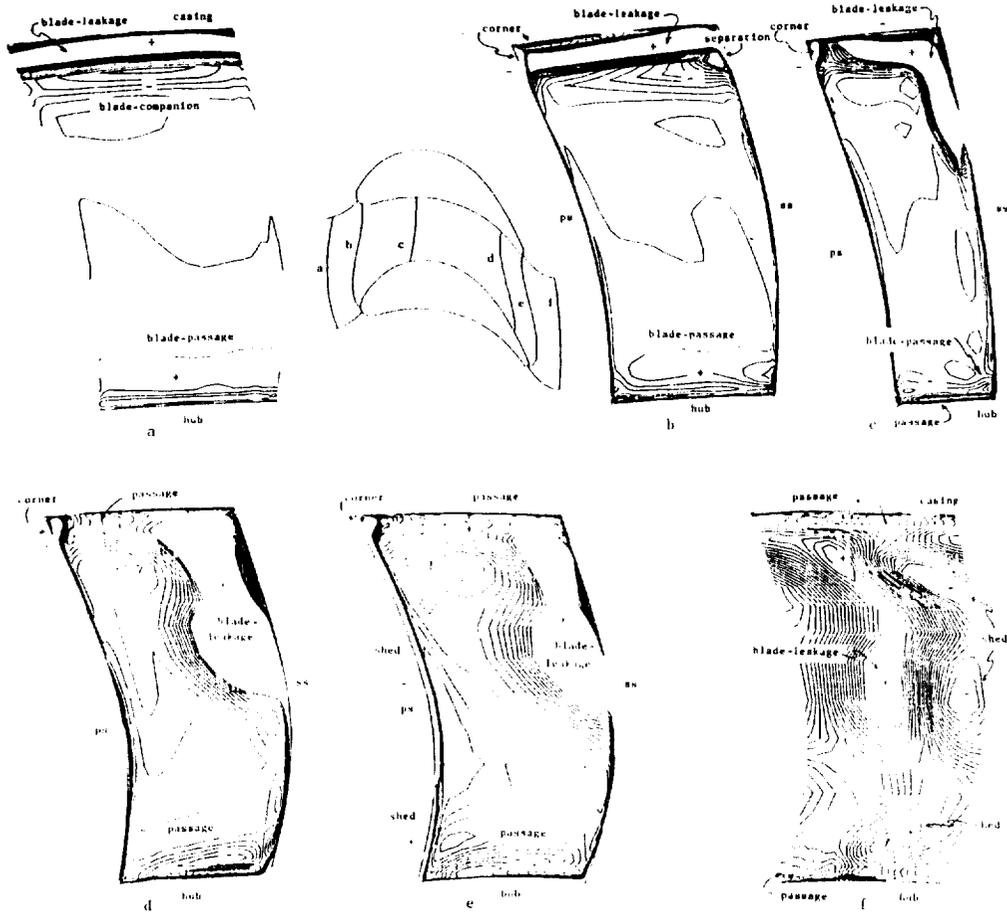Pressure side $T_o/T_{ref}$
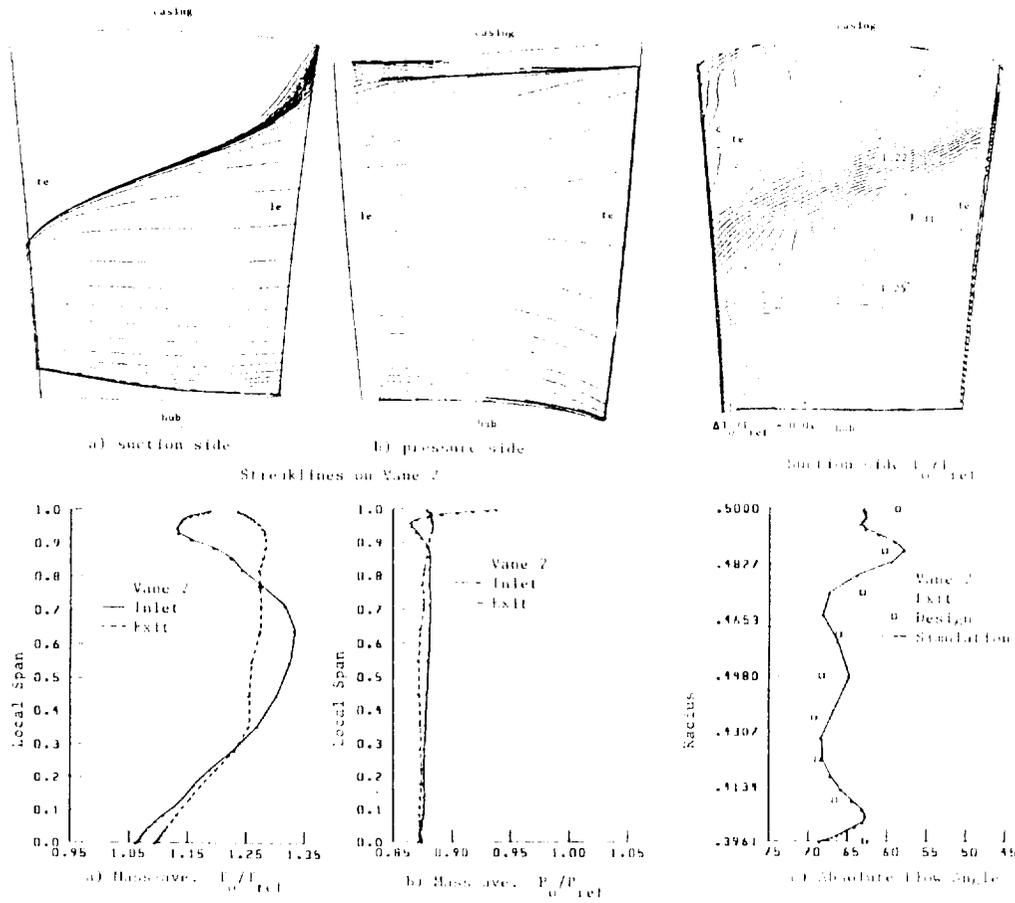


a) Mass-ave. $T_o/T_{ref}$   b) Mass-ave. $P_o/P_{ref}$   c) Absolute Flow angle
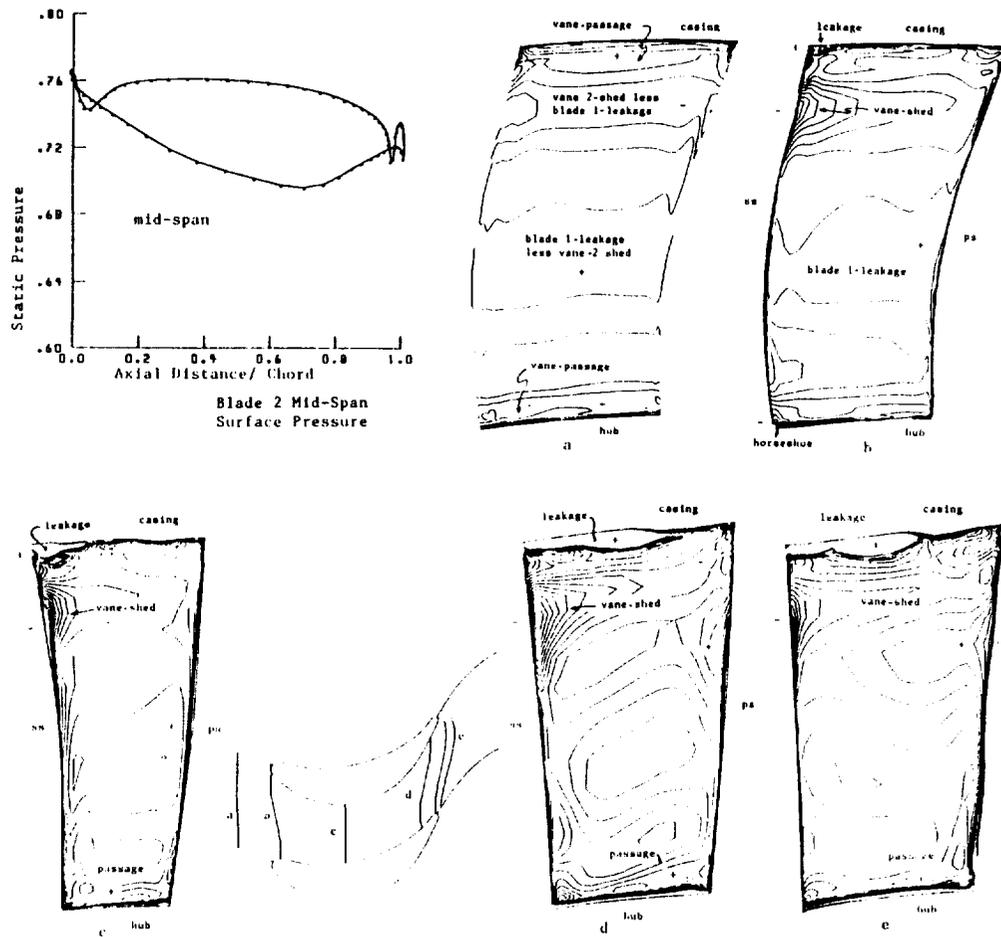
Blade 1 Axisymmetric Flow

# VANE 2 STREAMWISE VORTICITY

# VANE 2 SURFACE & AXISYMMETRIC FLOW



a) suction side      b) pressure side      Suction side, $\Delta T_o/T_{o\ ref}$

Streaklines on Vane 2

a) Mass ave. $T_o/T_{o\ ref}$      b) Mass ave. $P_o/P_{o\ ref}$      c) Absolute Flow Angle

# BLADE 2 STREAMWISE VORTICITY



Blade 2 Mid-Span
Surface Pressure

## CONCLUSIONS

Flow in the Pratt & Whitney ATD SSME HPFTP is highly 3-D and dominated by the leakage flow.

The tip leakage vortex from the first rotor blade persists through the second vane and alters the second blade's loading.

The predominant spanwise mixing mechanism in this low aspect ratio turbine is convection due to deterministic unsteady vortical flows.

262