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

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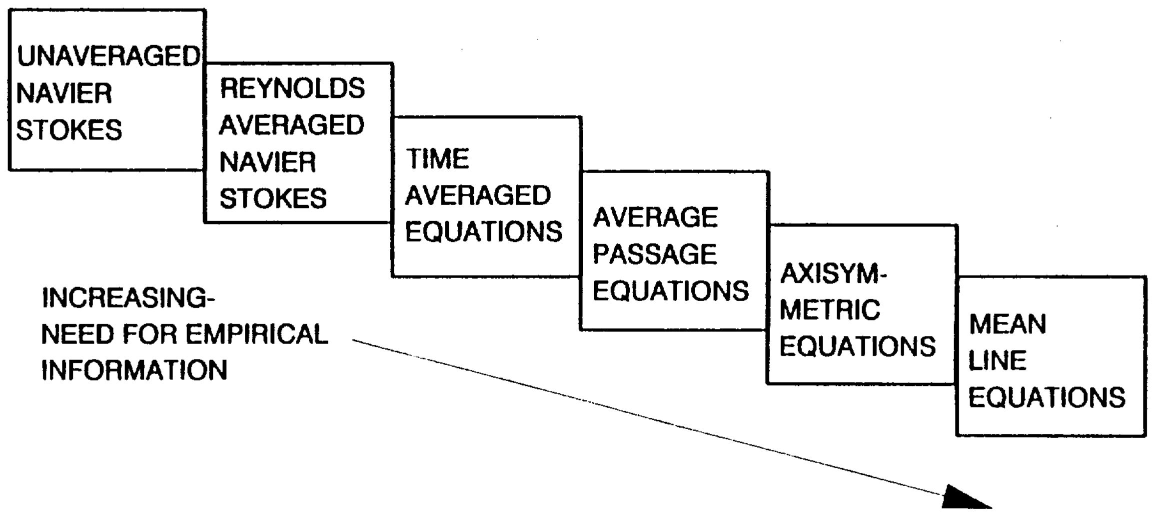
The three-dimensional viscous time-mean flow in the Pratt & Whitney alternate design space shuttle main engine fuel turbine is simulated using the average passage Navier-Stokes equations. The migration of secondary flows generated by upstream blade rows and their effect on the performance of downstream 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



AVERAGE PASSAGE EQUATION SYSTEM

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

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

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

λ = blockage factor < 1 over smeared blade rows
K = source term due to r – θ – z coordinates
S = source term which includes:

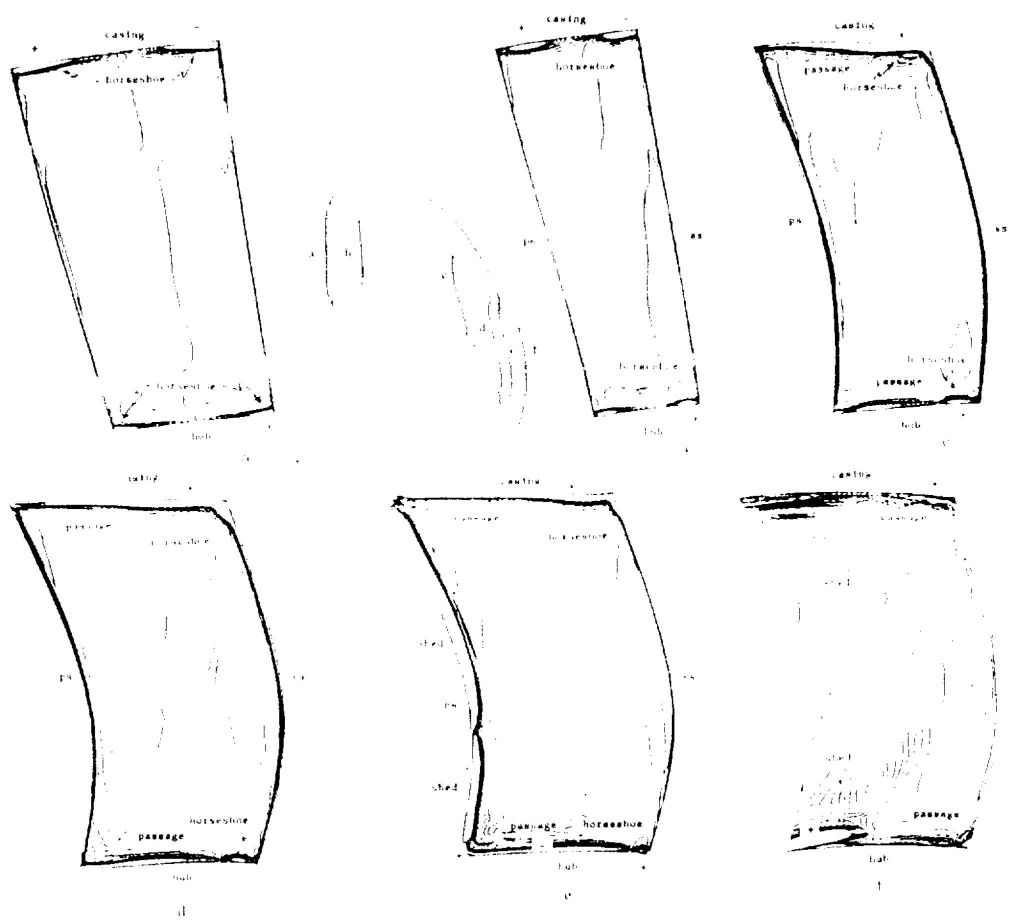
- **body forces**
- **energy sources**
- **momenta/energy temporal correlations**
- **spatial mixing correlations**

PRATT & WHITNEY SSME ALTERNATE TURBOPUMP TURBINE DESIGN

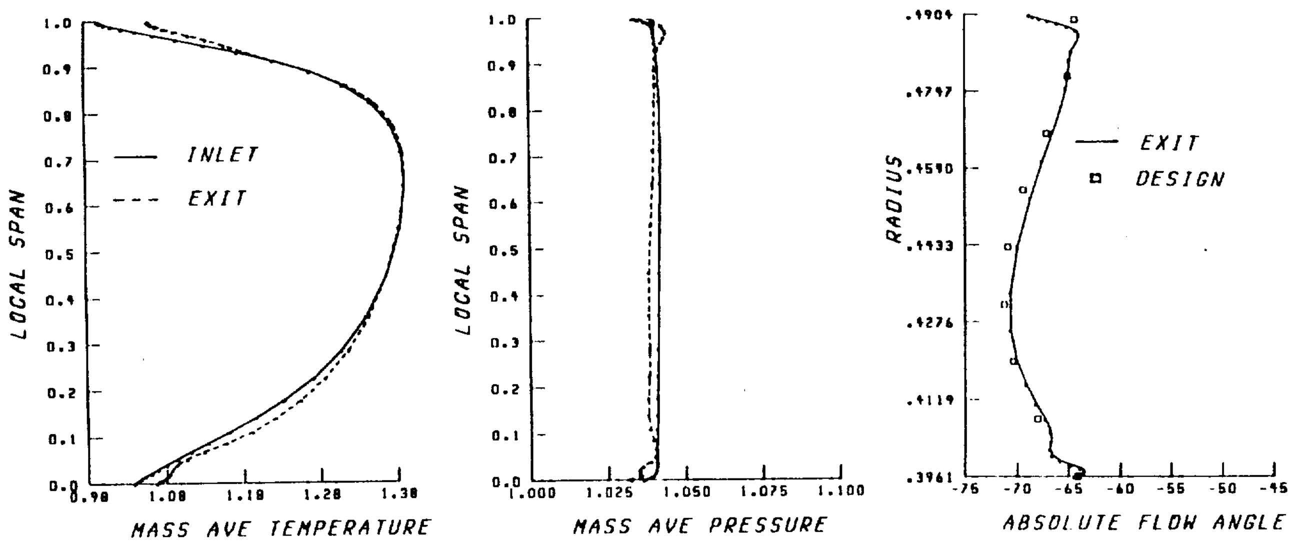
AVERAGE PASSAGE MODEL ANALYSIS

	$\Delta T_0/T_{0_{in}}$		$P_{0_{in}}/P_{0_{out}}$	
	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



VANE 1 AXISYMMETRIC FLOW



BLADE 1 STREAMWISE VORTICITY

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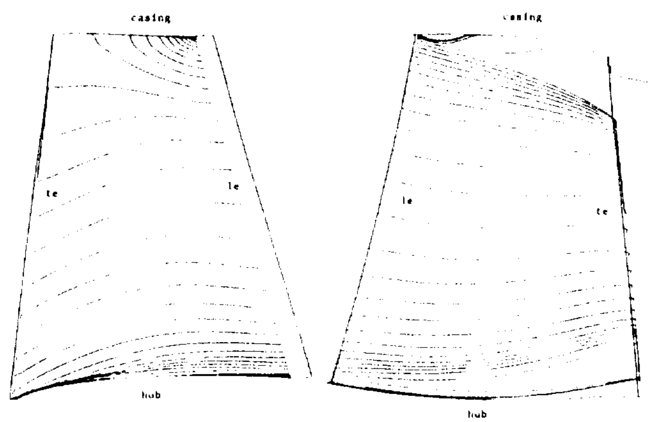
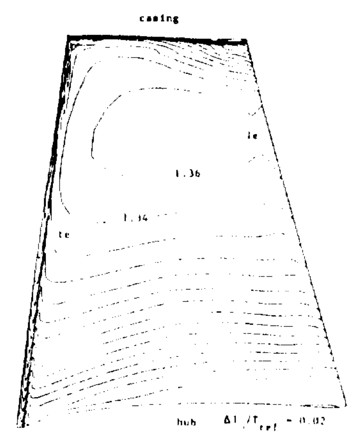
BLADE 1 SURFACE & AXISYMMETRIC FLOW

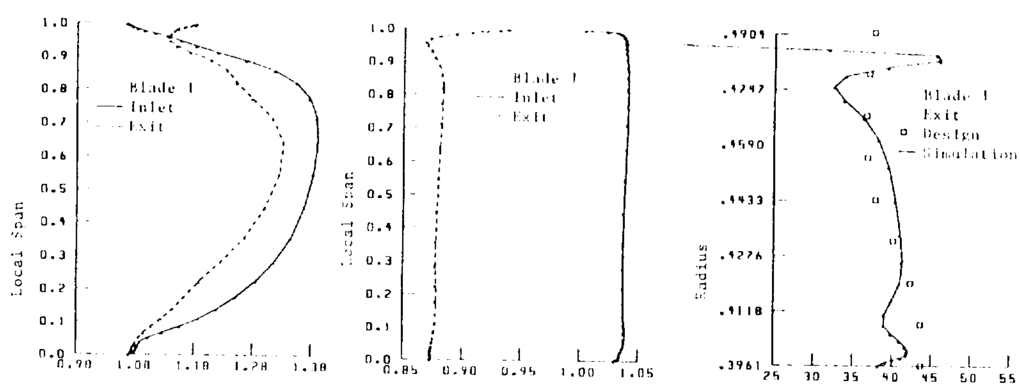


a) pressure side   b) suction side

Streaklines on Blade 1



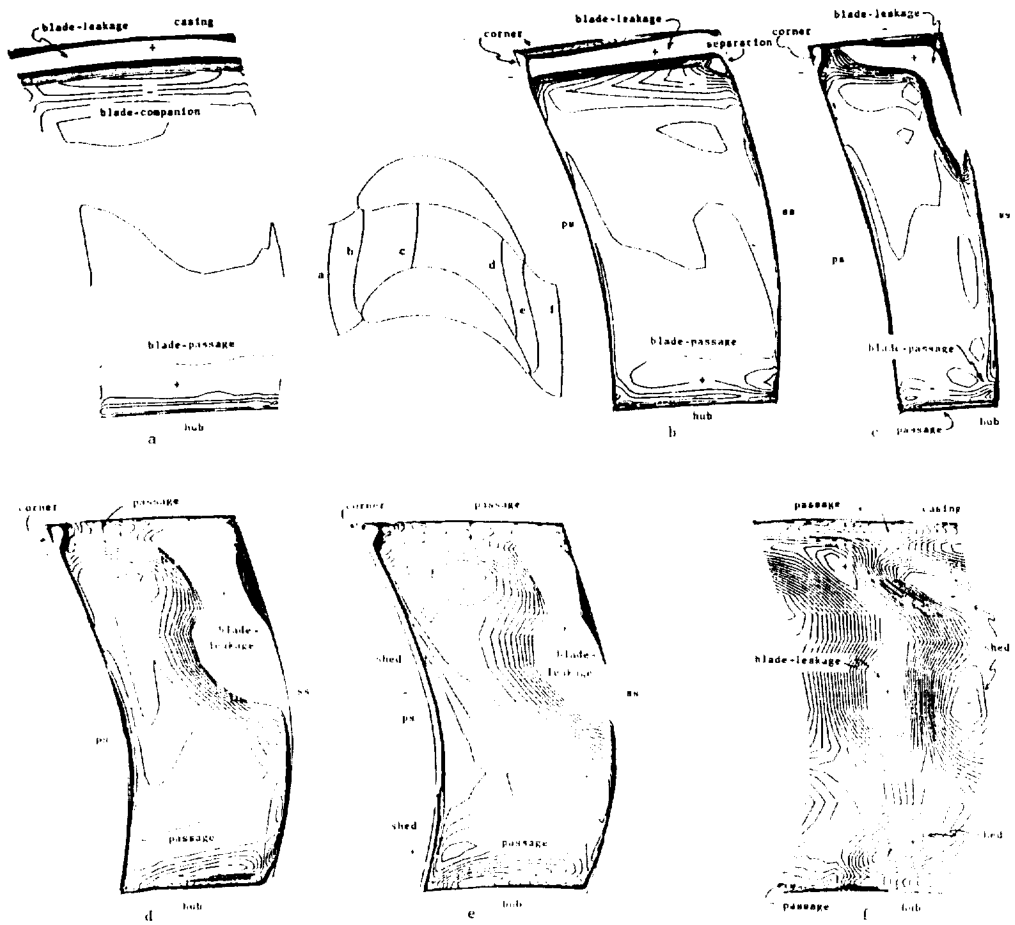
Pressure side T_o/T_{ref}



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



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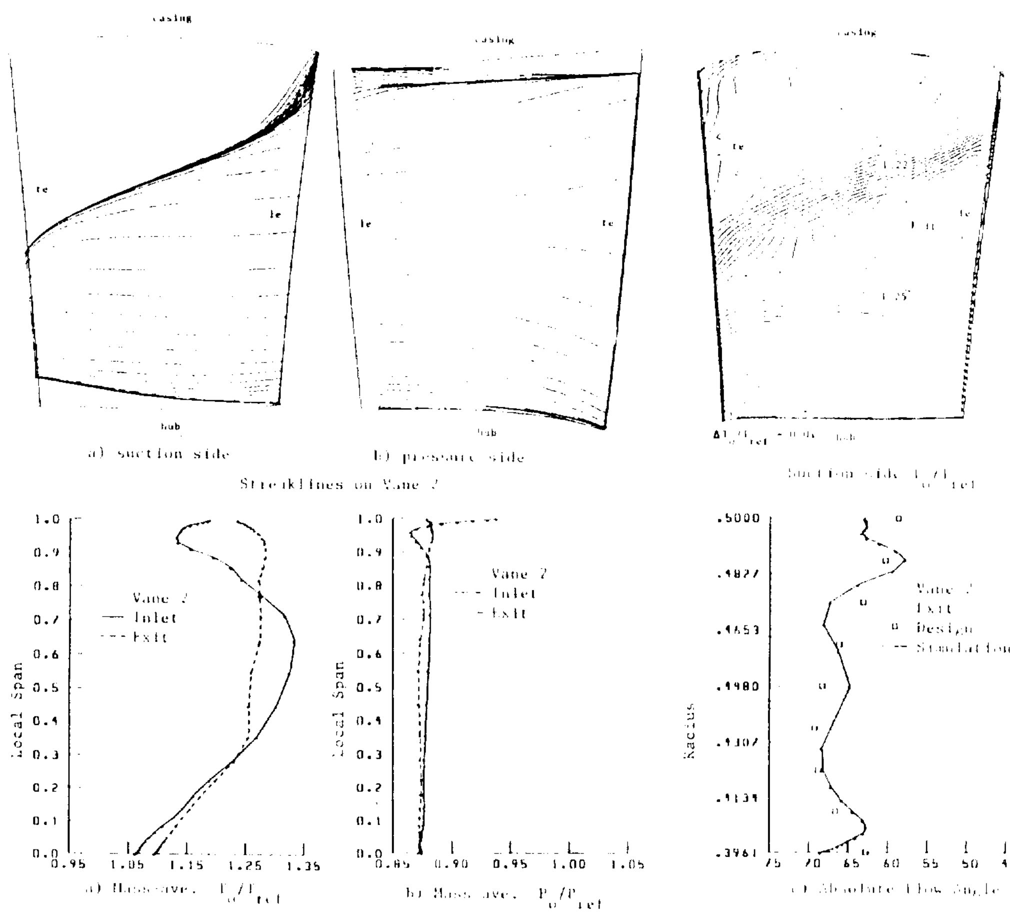
VANE 2 SURFACE & AXISYMMETRIC FLOW



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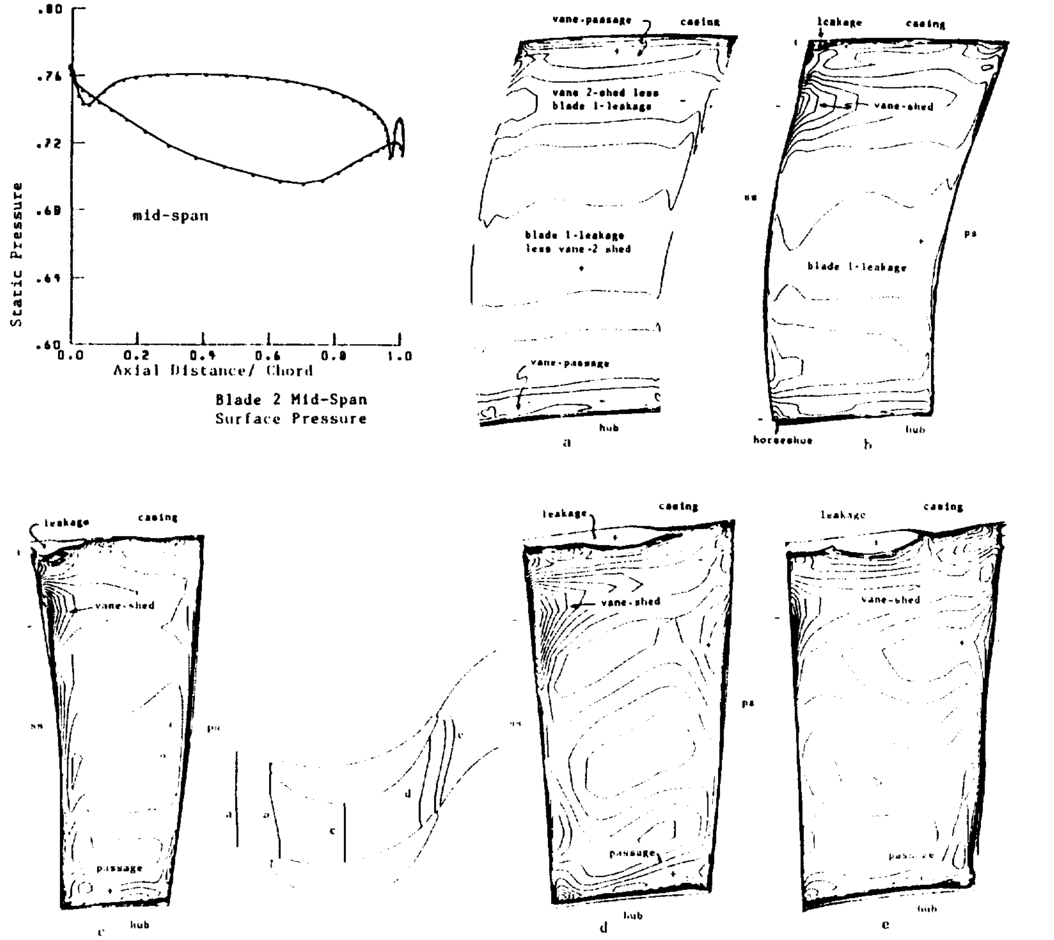
BLADE 2 STREAMWISE VORTICITY



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.