TURBINE DISK CAVITY AERODYNAMICS AND HEAT TRANSFER

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Experiments were conducted to define the nature of the aerodynamics and heat transfer for the flow within the disk cavities and blade attachments of a large-scale model, simulating the SSME turbopump drive turbines. These experiments of the aerodynamic driving mechanisms explored the following: (1) flow between the main gas path and the disk cavities, (2) coolant flow injected into the disk cavities, (3) coolant density, (4) leakage flows through the seal between blades, and (5) the role that each of these various flows has in determining the adiabatic recovery temperature at all of the critical locations within the cavities. The model and the test apparatus provide close geometrical and aerodynamic simulation of all the two-stage cavity flow regions for the SSME High Pressure Fuel Turbopump and the ability to simulate the sources and sinks for each cavity flow.

Carbon dioxide was used as a trace gas for constant density experiments or as the simulated "heavy gas" coolant. Gas samples were withdrawn at selected locations on the rotating and stationary surfaces in the fore and aft cavity and the interstage seal regions of the two stage system. The gas samples were used to determine the fraction of gas at a location which originates from each of three coolant injection locations or four gas path locations. Samples were also withdrawn at selected locations in the blade shank regions.

A parametric series of experiments was conducted with constant density fluids and an exploratory series of experiments was conducted with CO₂ as the simulated coolant. Experimental results showed (1) the variation of coolant distribution on the cavity and disk surfaces as a function of coolant flow ratio, (2) the effects on the coolant distribution for changes in the coolant inlet distributions, and (3) increased mixing of coolant with the ingested gas when a heavy gas (density ratio equal 1.5) was used as the coolant.
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ACTUAL AND MODEL DISK/CAVITY SYSTEMS

4.0 in. radius full scale SSME

8.0 in. radius large scale model IFSF

195
GAS SOURCES AND EXITS
MODEL INSTRUMENTATION

- Thermocouples
- Pressure/CO₂ taps in passages
- Pressure/CO₂ taps on rotating components
- Pressure/CO₂ taps on stationary components
SSME TURBINE DISK CAVITY MODEL
MODEL IN INTERNAL FLOW FACILITY
MODEL SEAL REGION AND GAS SOURCE/EXIT LOCATIONS

REGION VI
Rotor 2 Blade Shanks

REGION V
Rotor 1 Blade Shanks

REGION IV
Aft Cavity & Rotor 2

REGION III
Center Cavity & Rotor 2

REGION II
Center Cavity & Rotor 1

REGION I
Forward Cavity & Rotor 1
COOLANT CONCENTRATION ON ROTOR AND STATIONARY WALLS

Variables:
- Radius
- Coolant flow rate

Region IV: Aft Cavity & Rotor 2
Coolant: Air

Rotor Wall

Stationary Wall

Dimensionless coolant flow rate, \( \frac{m_c/2\pi\mu_0R_0}{(\rho_0\Omega R_0^2/\mu_0)^{0.8}} \)
COOLANT CONCENTRATION ON ROTOR AND STATIONARY WALLS

Variables:
- Radius
- Coolant flow rate

Region IV: Aft Cavity & Rotor 2
Coolant: CO$_2$

Rotor Wall

Stationary Wall

Dimensionless coolant flow rate, \( \frac{\dot{m}_c / 2\pi \mu_a R_0}{(\rho_a \Omega R_0^2 / \mu_a)^{0.8}} \)
EFFECT OF COOLANT DENSITY ON DISTRIBUTION

Variables:
- Radius
- Coolant flow rate
- Coolant density

Region IV: Aft Cavity & Rotor 2

Rotor Wall

Stationary Wall

Dimensionless coolant flow rate, \( \left( \frac{m_c}{2 \pi \mu_a R_0} \right) / \left( \frac{\rho_a \Omega R_0^2}{\mu_a} \right)^{0.8} \)
COOLANT DISTRIBUTION ON ROTOR

Region IV: Aft Cavity & Rotor 2
Coolant: Air

Local free disk entrainment flow rate

Dimensionless coolant flow rate, \( \frac{\dot{m}_c}{2\pi \mu_a R_0}/(\rho_a \Omega R_o^2/\mu_a)^{0.8} \)
COOLANT DISTRIBUTION ON STATIONARY WALL

Region IV: Aft Cavity & Rotor 2

Coolant: Air

Dimensionless coolant flow rate, \( \frac{\dot{m}_c/2\pi \mu a R_0}{\rho_a \Omega R_0^2/ \mu_a}^{0.8} \)

Local free disk entrainment flow rate
COOLANT DISTRIBUTION ON ROTOR

Region IV: Aft Cavity & Rotor 2
Coolant: CO₂

Dimensionless coolant flow rate, \( \frac{m_c}{2 \pi \mu_a R_0} \| \frac{\rho_a \Omega R_0^2}{\mu_a} \)^{0.8} 

Local free disk entrainment flow rate

\[ \Phi_{14} 50 60 70 80 90 \]
COOLANT DISTRIBUTION ON STATIONARY WALL

Region IV: Aft Cavity & Rotor 2
Coolant: CO₂

Local free disk entrainment flow rate

Dimensionless coolant flow rate, \( \frac{m_c}{2 \pi \mu R_0} / (\rho \Omega R_o^2 / \mu)^{0.8} \)
RESULTS/CONCLUSIONS

Constant Density

- Coolant flows approximately one-half free disk entrainment rate provide full purge of cavity ($\phi > 80\%$ below blade shanks)

- Coolant concentration on rotor surface high ($\phi > 90\%$) for coolant flows 1/4 design flow rate

- Cavity walls have largest variation of $\phi$ with coolant flow rate
RESULTS/SPECULATION

Variable Density (Exploratory Experiments with CO₂)

- Density ratio has strong effect
  - Coolant concentration on rotor decreased from constant density results at comparable weight flow or volume flow rates.
  - Coolant concentration on aft cavity wall decrease significantly from constant density results at comparable flow rates.

- Decreased coolant concentration attributed to increased mixing and probable instability of rotating flow with higher gas densities at low radii.