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Analysis of the SSME HPOTP Bearing Inlet Cavity

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Analysis of the flow in the Space Shuttle Main Engine (SSME) high pressure oxygen turbopump (HPOTP) bearing #1 inlet cavity has been completed in support of return-to-flight. With the incorporation of several design changes in the Phase II turbopump, rotordynamic stability of the pumps has been enhanced, but the durability and life of the LOX-cooled bearings has decreased. During the post-Challenger SSME recertification, the MSFC bearing team investigated the causes of limited bearing durability. One topic addressed by this team was the flow environment upstream of the pump-end bearing and the effect of seal exit swirl (Phase I labyrinth seal vs. Phase II damping seal) and a cavity anti-vortex rib on the bearing environment and life. The objective of the present work was to define the hydrodynamic environment upstream of the pump-end bearing and determine the effect of seal exit swirl and the anti-vortex rib on bearing inlet swirl.

The problem was posed as an axisymmetric cavity flow with the computational domain extending from the seal exit to the bearing inlet. This domain was discretized with 22800 grid points. Boundary conditions were obtained from a 1-D model of the SSME coolant path. These resulted in an axial Reynolds number of 297000 and with a seal tip speed of 29,200 rpm. The inlet Mach number was 0.19 and the problem was solved with the CMINT code utilizing the Briley-McDonald/Beam-Warming algorithm with preconditioning to speed convergence at low Mach numbers. Three parametric cases with inlet swirl of 50% shaft speed (labyrinth seal), 20% shaft speed (damping seal) and no inlet swirl were considered. Total CPU time for all analyses was 9 hours on a Cray X-MP with memory requirements of 1.7 million words.

Computational results indicate large vortical flow structures in the cavity, with the labyrinth, damping, and no-swirl cases yielding bearing inlet swirl rates of 14, 10, and 9 percent of shaft speed, respectively. These small differences are due to fluid spin-up on the shaft and inner race and indicate that upstream influences (either inlet swirl or anti-vortex ribs) have little effect on bearing inlet conditions. When these results were used as input to the SHABRETH bearing model, limited durability could not be explained by these small differences in swirl. Also, based on these results, a proposed design change for the cavity anti-vortex rib was not implemented by the SSME chief engineer.

BEARING INLET CAVITY ANALYSIS

OVERVIEW

- OBJECTIVE
- JUSTIFICATION
- APPROACH
- RESULTS
- SUMMARY AND CONCLUSIONS
- PROGRAM IMPACT

OBJECTIVES (IN SUPPORT OF RETURN-TO-FLIGHT)

- DEFINE THE HYDRODYNAMIC ENVIRONMENT FOR THE LOX BEARING #1 INLET CAVITY
  - UNDERSTAND THE SEAL EXIT/CAVITY/BEARING INLET FLOW PATH
  - QUANTIFY THE PRESSURE DROP IN THE CAVITY

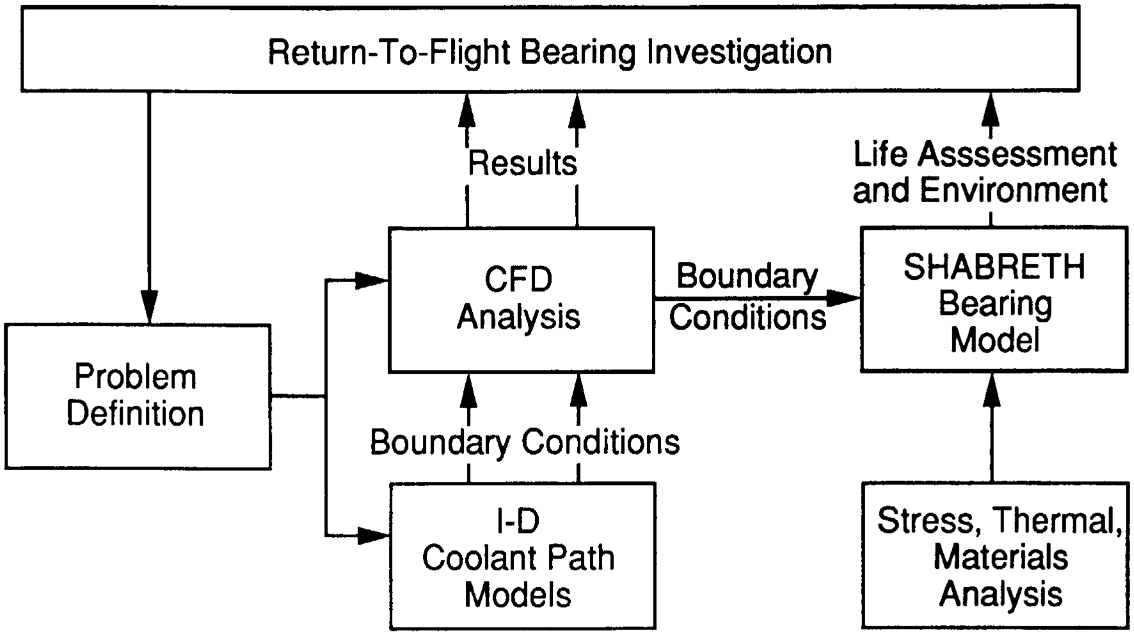
- EVALUATE THE EFFECT OF SEAL EXIT SWIRL ON BEARING INLET SWIRL
  - INLET SWIRL AFFECTS VISCOUS HEAT GENERATION IN BEARING, CAGE DRAG AND PRESSURE DROP ACROSS BEARINGS

- EVALUATE EFFICACY OF THE BEARING CAVITY ANTI-VORTEX RIB

BEARING INLET CAVITY ANALYSIS

JUSTIFICATION

- DURABILITY OF HPOTP PUMP-END BEARINGS (2000 SECOND LIMIT)
  - LOWER LIFE IN PHASE II DESIGN RELATIVE TO PHASE I DESIGN
  - CONFIGURATION CHANGES
    - DAMPING SEALS (PHASE II) VS. LABYRINTH SEALS (PHASE I)
    - INCREASED DEADBAND, INTERNAL CLEARENCES
    - ELONGATED CAGE POCKETS
- PROPOSED DESIGN CHANGE TO REMOVE ANTI-VORTEX RIB IN CAVITY



Return-To-Flight Bearing Investigation

Results

Life Asssessment
and Environment

Problem
Definition

CFD
Analysis

Boundary
Conditions

SHABRETH
Bearing
Model

Boundary Conditions

I-D
Coolant Path
Models

Stress, Thermal,
Materials
Analysis

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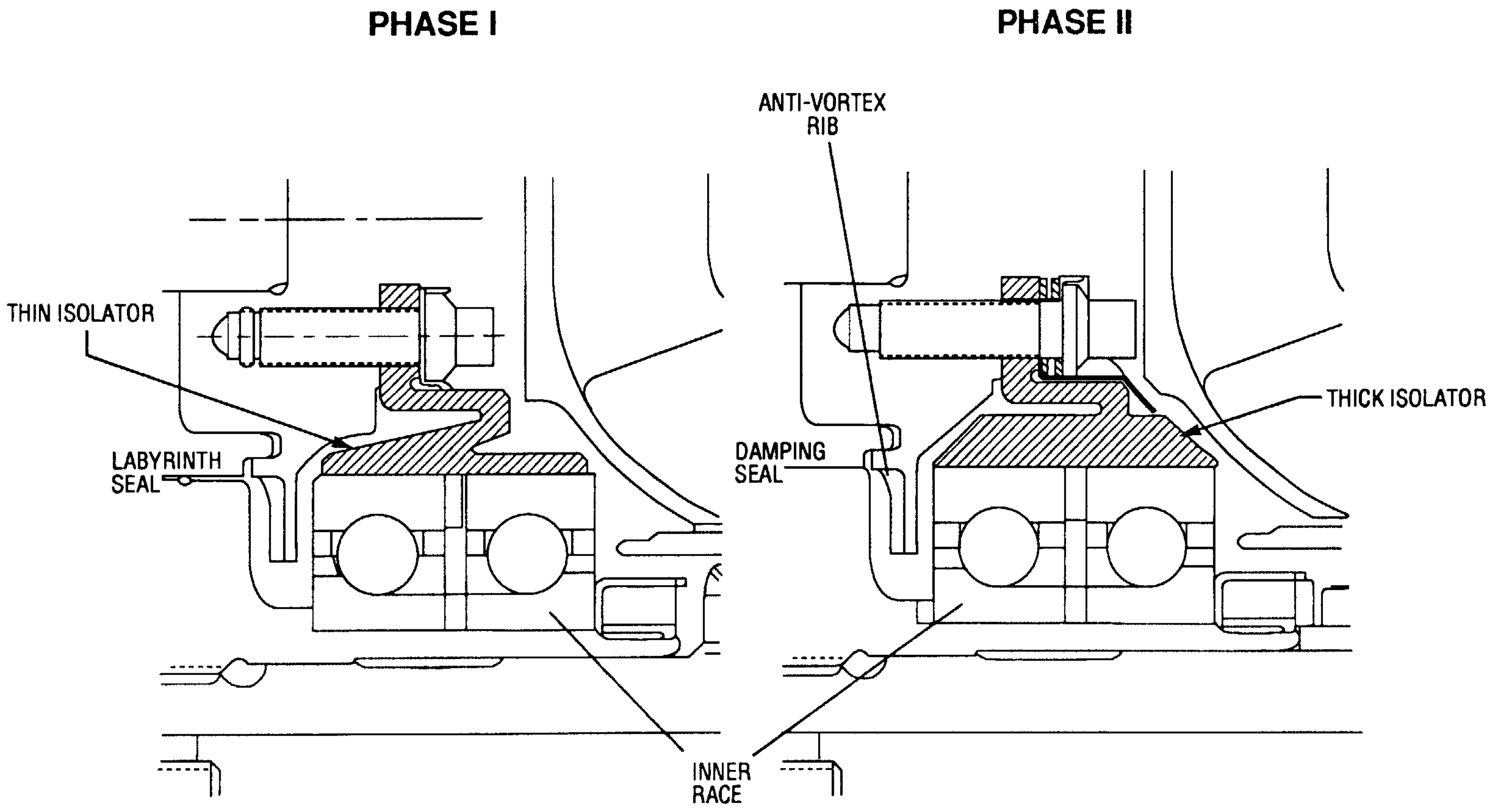
BEARING INLET CAVITY ANALYSIS



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BEARING INLET CAVITY ANALYSIS

APPROACH

PROBLEM DEFINITION

- DOMAIN FROM SEAL EXIT TO BEARING INLET
  - AXISYMMETRIC ANALYSIS (NO ANTI-VORTEX RIB)
  - LEAKAGE PATH IGNORED (1% OF FLOW)
  - ALL FLOW TO BEARING GOES BETWEEN INNER RACE AND CAGE
- $Re_{ax} = 297000$, $\Omega = 29200$ rpm, $M_{in} = 0.19$ (109% POWER LEVEL)

METHOD OF ANALYSIS

- COMPRESSIBLE NAVIER-STOKES EQUATIONS (2-D AXISYMMETRIC WITH SWIRL)
- BRILEY-McDONALD/BEAM-WARMING WITH PRECONDITIONING
- CMINT CODE
- LOW, Re K- ε TURBULENCE MODEL
- 22800 GRID POINTS
- SOFT-START ON DOWNSTREAM STATIC PRESSURE
- 9 HOURS, 1.7×10^6 WORDS ON MSFC CRAY X-MP

VALIDATION OF DISK CAVITY ANALYSES

- OWEN AND PINCOMBE (JFM, 1980)
- DAILY AND NECE (1960)

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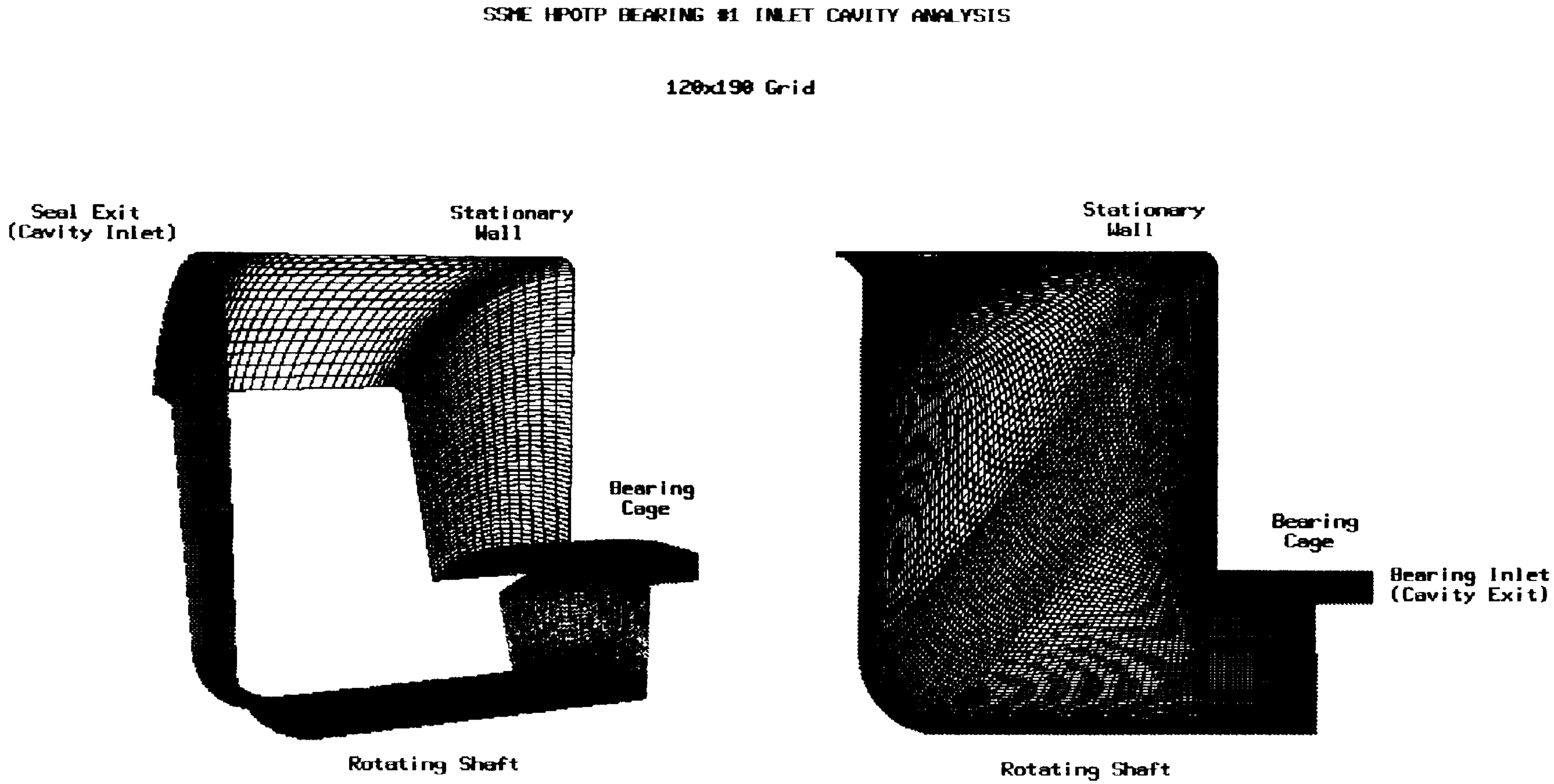
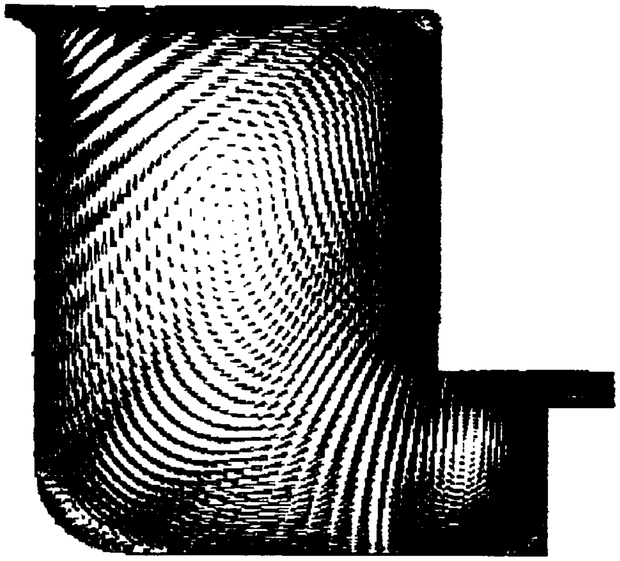

SSME HPOTP BEARING #1 INLET CAVITY ANALYSIS
120x190 Grid
Seal Exit
(Cavity Inlet)
Stationary
Wall
Bearing
Cage
Rotating Shaft
Stationary
Wall
Bearing
Cage
Bearing Inlet
(Cavity Exit)
Rotating Shaft

SSME HPOTP BEARING #1 INLET CAVITY ANALYSIS

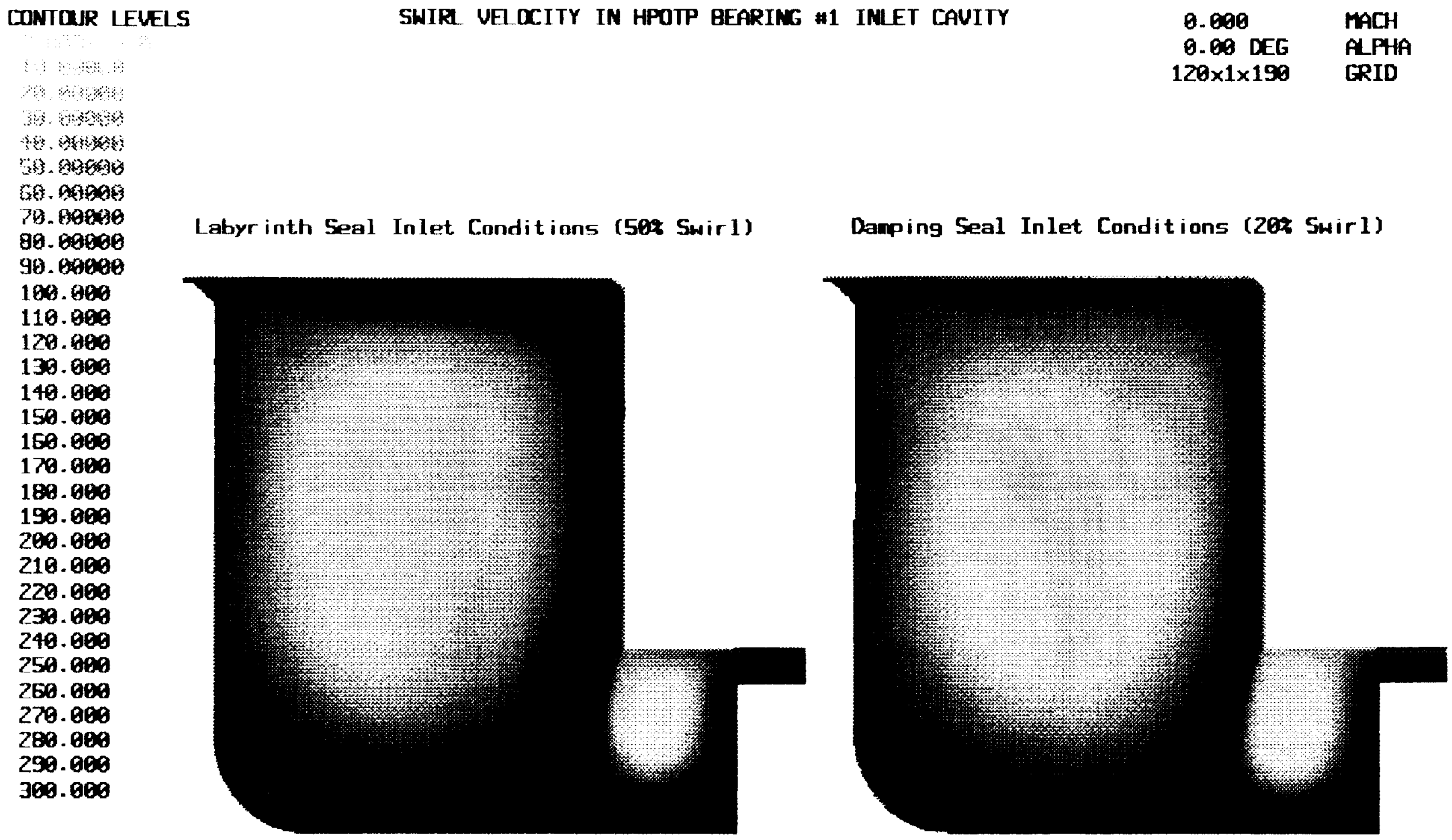
120x190 Grid



Velocity Vectors Colored
by Velocity Magnitude

Particle Traces

SWIRL VELOCITY IN HPOTP BEARING #1 INLET CAVITY



Computational Fluid Dynamics Branch, ED32

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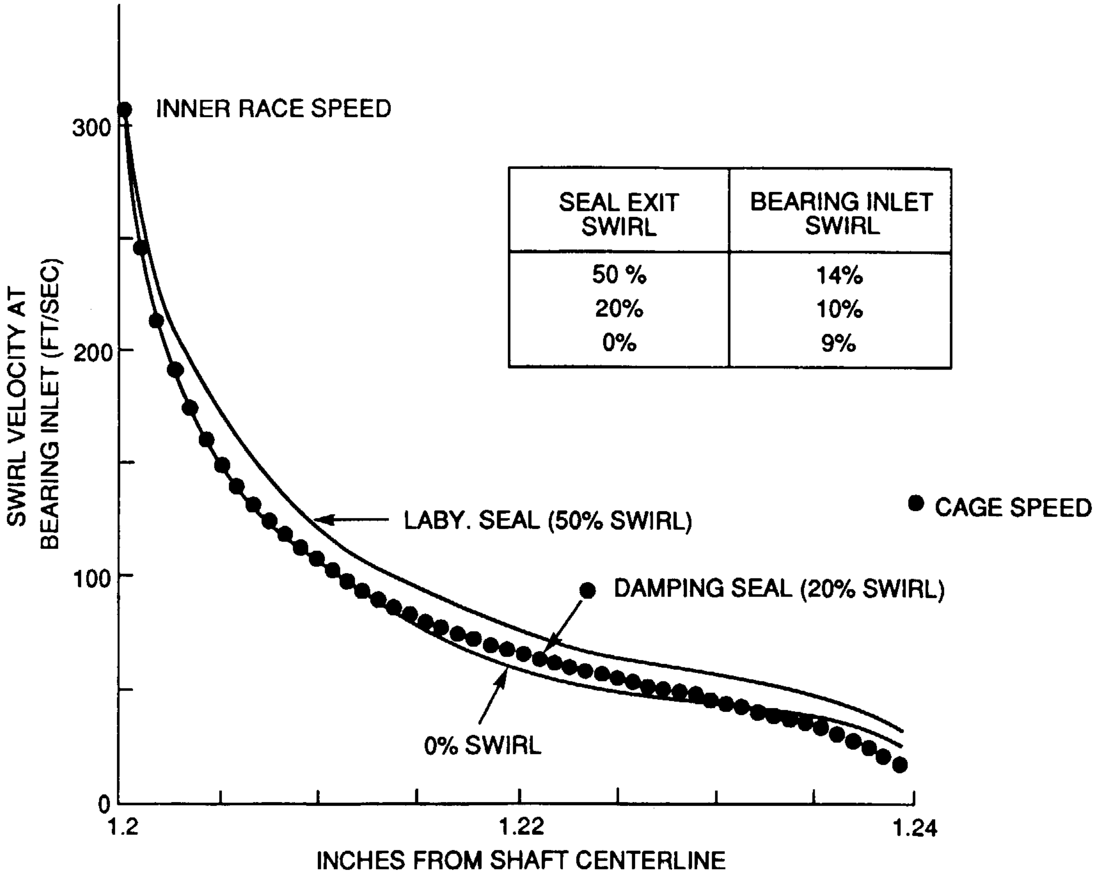
BEARING INLET CAVITY ANALYSIS

LOX SWIRL PROFILES AT BEARING CAGE INLET



SEAL EXIT SWIRL	BEARING INLET SWIRL
50 %	14%
20%	10%
0%	9%

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BEARING INLET CAVITY ANALYSIS

SUMMARY AND CONCLUSIONS

- HYDRODYNAMIC ENVIRONMENT FOR THE SSME HPOTP BEARING #1 INLET CAVITY HAS BEEN DEFINED FOR PHASE I AND PHASE II DESIGNS
- SMALL DIFFERENCE (4%) IN BEARING INLET SWIRL BETWEEN PHASE I AND PHASE II PUMPS
- CFD RESULTS WERE USED AS INPUT INTO SHABRETH BEARING MODEL IN SUPPORT OF RETURN-TO-FLIGHT

BEARING INLET CAVITY ANALYSIS

PROGRAM IMPACT

- DETERMINED THAT THE LIMITED DURABILITIY OF THE HPOTP PUMP-END BEARINGS IS NOT CAUSED BY CHANGES IN SWIRL ASSOCIATED WITH THE PHASE II DESIGN DAMPING SEALS
- DETERMINED THAT THE PROPOSED MODIFICATION OF THE CAVITY ANTI-VORTEX RIB WOULD HAVE LITTLE EFFECT ON SWIRL ENTERING THE BEARING. PROPOSED DESIGN CHANGE WAS NOT IMPLEMENTED BY CHIEF ENGINEERS OFFICE

o DISK CAVITY ANALYSIS AT NASA-MSFC

			TURNAROUND
	PROBLEM	CODE	TIME
-	HPFTP TURBINE AFT CAVITY	PHOENICS	-
-	HPOTP BEARING # 1 INLET CAVITY	CMINT	3 MOS
-	HPFTP TURBINE FORE CAVITY	CMINT	6 MOS
-	TEST BED ENGINE CABLE CAVITY	INS3D*	3 WKS

* CODE WILL BE SET UP FOR GENERALIZED DISK CAVITY ANALYSIS