MODELING AND FULL-SCALE TESTING OF AN ASPIRATING FACE SEAL

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A 36" diameter aspirating face seal for aircraft engine application has undergone extensive testing and analysis. Previous testing indicated that the seal tended to seek equilibrium at axial rotor clearances that were larger than expected. Parameter studies were conducted on several seal design parameters to evaluate effect on seal performance. Mixing of air flows from the air dam and air bearing regions of the seal was shown to have a significant impact on the seal's performance. Two methods of minimizing this flow interaction were studied both analytically and experimentally. The first method is to reduce the labyrinth tooth clearance, thereby limiting flow to the air dam itself. The second method involves utilizing a flow deflector between the air dam and air bearing regions of the seal in order to prevent radial flow from the air dam from disrupting the formation of a hydrostatic film at the air bearing. Both methods were shown to be effective design enhancements, allowing seal closure to be achieved. In both cases, the seal seeks an equilibrium position 0.0015" from the rotor surface, with correspondingly low leakage rates.

Description of Slides

1. Title slide
2. Objectives and Motivation for Aspirating Face Seal Modeling and Full Scale Testing
3. Cross-section of the 36" Diameter Aspirating Face Seal, showing seal components
4. Cross-section of the Full Scale Test Rig, in the Fully Assembled and Open Vessel Configurations
5. The Aspirating Seal Test Plan
6. Test Results - Seal/rotor Air Gap and Flow vs. % of Open Air Bearing Orifice Holes for 5 psid
7. Test Results - Seal/rotor Air Gap and Flow vs. Pressure Differential with 50% of Air Bearing Holes blocked
8. Axisymmetric Analytical Model of the Aspirating Seal, showing seal Degrees of Freedom and Forces
9. Wire Frame of the 3-D CFD Model
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13. Analytical Results - Flow fields for Base Design and Modified seal with flow deflector in place between air dam and air bearing; both for measured 0.016" seal/rotor air gap
14. Analytical Results - Pressure profiles for Base Design and Modified labyrinth tooth clearance of 0.035"; both for measured 0.016" seal/rotor air gap
15. Analytical Results - Pressure profiles for Base Design and Modified seal with flow deflector in place between air dam and air bearing; both for measured 0.016" seal/rotor air gap
16. Test Results - Flow vs. Pressure Differential at 0 RPM and Flow vs. Speed at 20 psid for the Aspirating Seal with a modified labyrinth tooth clearance of 0.035". Seal opened at 38 psid and 0 RPM, and at 20 psid and 1000 RPM.
17. Test Results - Flow vs. Pressure Differential at 0 RPM for 0.035" labyrinth tooth clearance and flow deflector in place between air dam and air bearing
18. Test Results - Flow vs. Pressure Differential at 0 RPM for 0.085" labyrinth tooth clearance and flow deflector in place between air dam and air bearing; deflector found to be damaged upon completion of test
19. Conclusions

Aspirating Face Seal Modeling and Full Scale Testing

Objectives

Develop an Aspirating Face Seal design for use in the GE90 aft outer LPT seal location, and other new and existing engines.

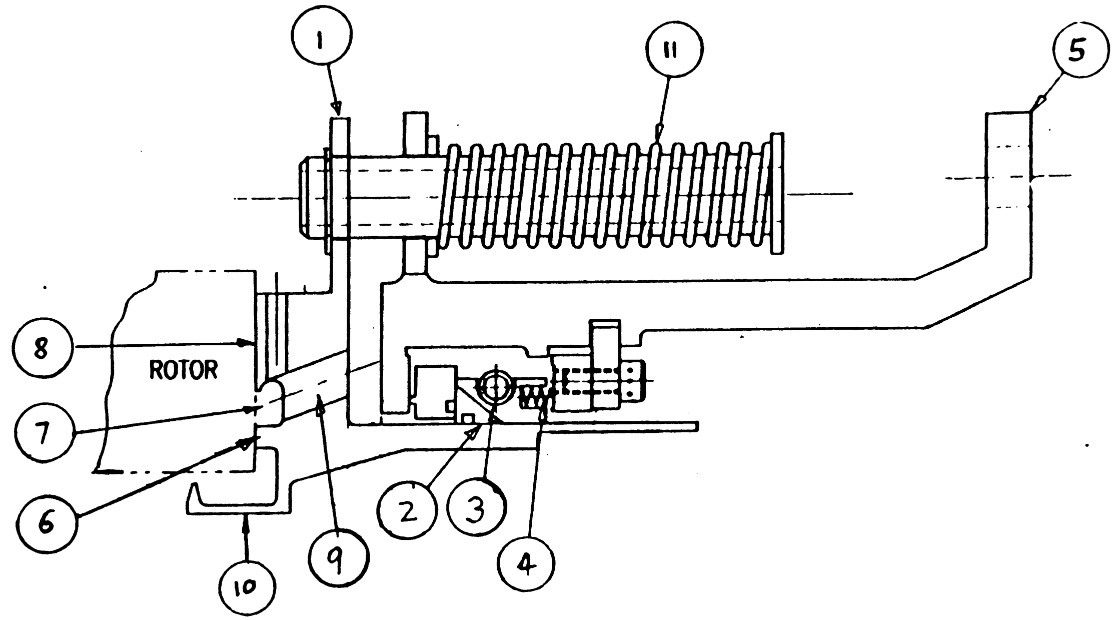
Motivation

Reduced secondary flow leakages result in SFC improvements
Non-contact seal results in longer seal life, no performance degradation

Outline

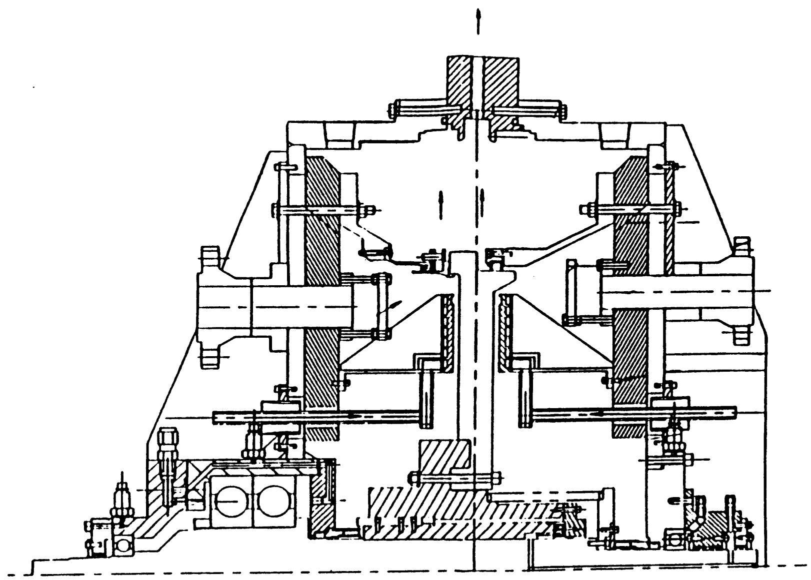
Seal Overview
Full Scale Test Rig
Test Plan
Test Results
Analytical Results
Conclusions

The 36" Diameter Aspirating Face Seal

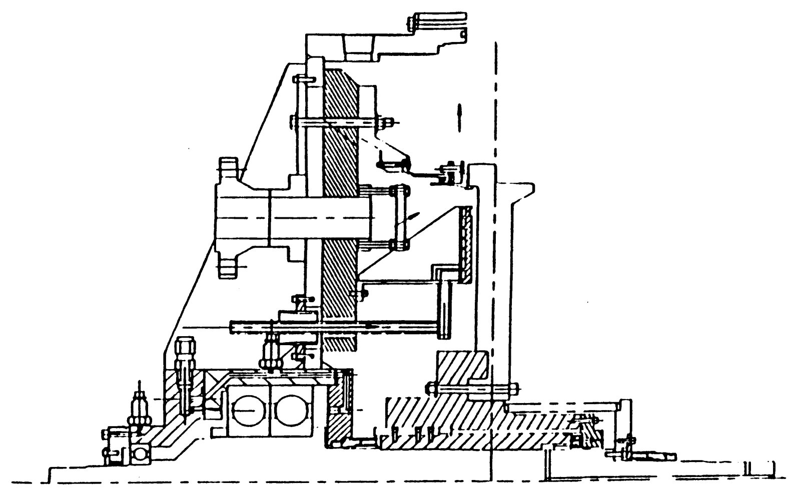


- Hydrostatic gas bearing while closed
- Single tooth labyrinth while retracted
- Seal is normally retracted
- Non-contact
- All metal design
- Designed for 0.002” film thickness at operating pressure

The Full Scale Test Rig



Fully Assembled
Rig Configuration



Open Vessel Test
Configuration

The Test Plan

Plan must address all conditions seal is likely to encounter

1. Dust Ingestion

- 14.7" seal
- 0-10 micron particles at 1/3000 lb/sec

2. Static Leakage

- leakage performance up to 100 psid

3. Tracking

- 0.75" relative axial motion

4. Dynamic Leakage

- leakage performance up to 100 psid, 2400 rpm, 750° F

5. Rotor Runout

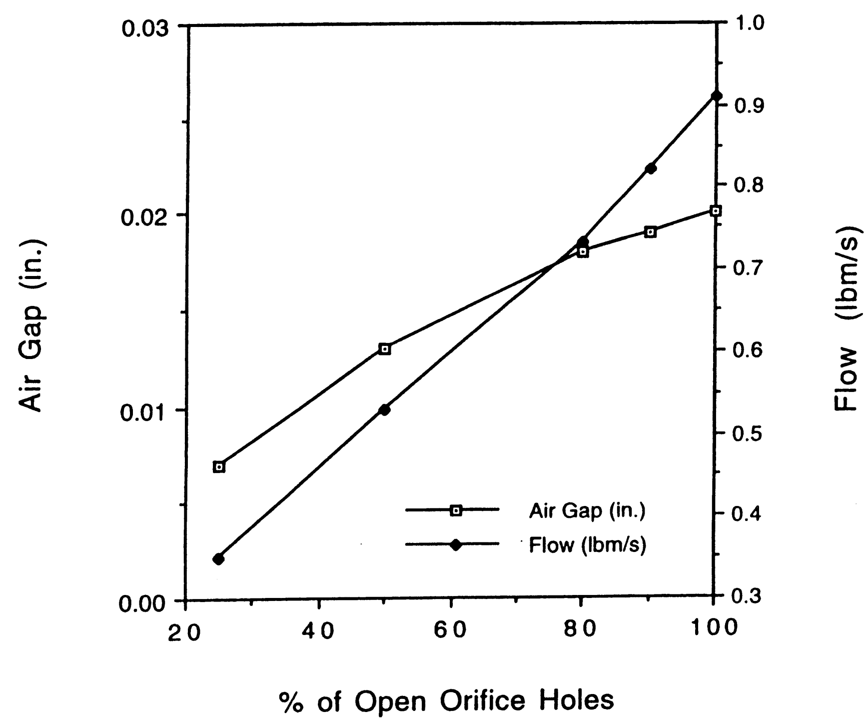
- leakage performance up to 100 psid, 2400 rpm with 0.005 and 0.010" TIR

6. Seal Tilt

- leakage performance up to 100 psid, 2400 rpm with 0.27° tilt

Test Results

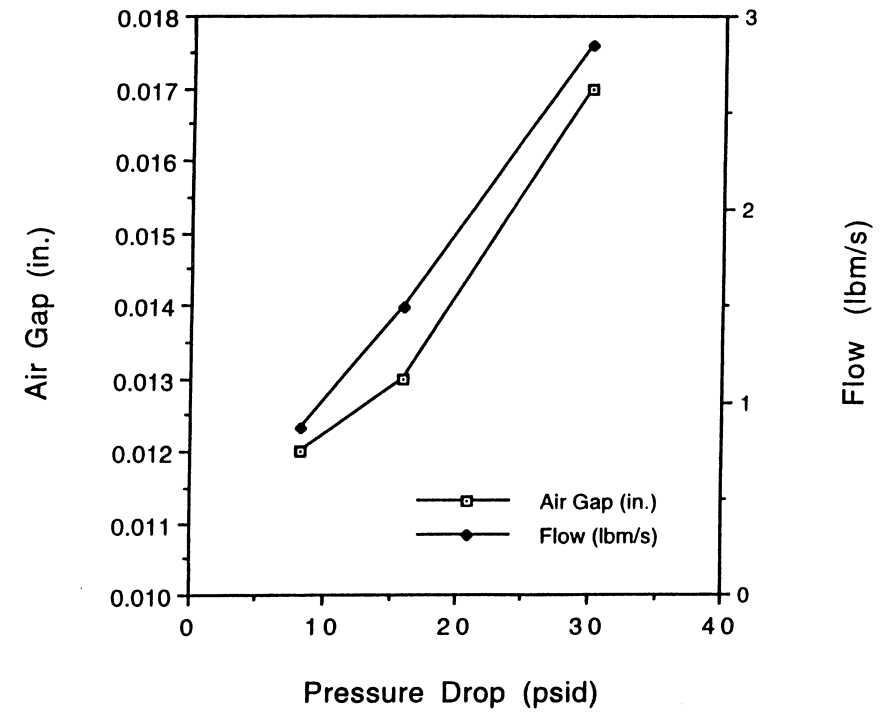
Static leakage with % of open orifice holes varied - 5 psid



- Larger than expected air gap and seal leakage
- Orifice holes strongly influence seal equilibrium position
- Larger number of holes yields larger air gap and leakage

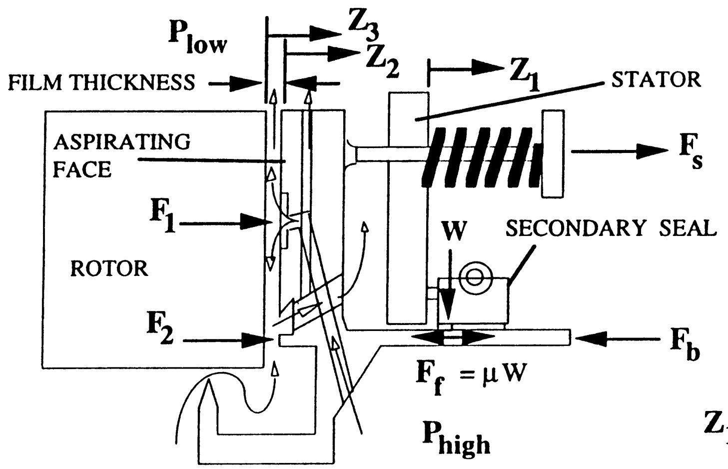
Test Results

Static leakage vs. Pressure differential; 50% of holes blocked



- Air gap increases with increasing seal differential pressure
- Seal observed closing at 3 psid

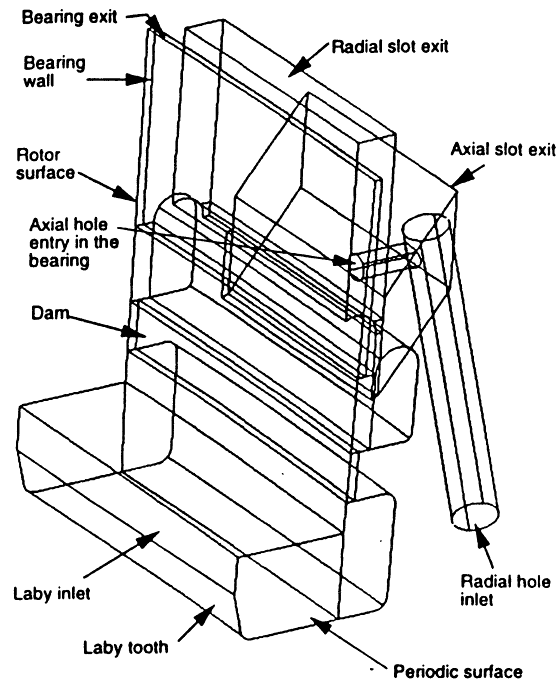
The Axisymmetric Model



F_s	- Retraction Spring Force
W	- Pressure Induced Normal Force
F_b	- Back Pressure
F_f	- Sliding Friction
F_1 F_2	- Film Forces
$Z_1 Z_2 Z_3$	- Degrees of Freedom

- Force balance establishes seal equilibrium position

The CFD Model



- 3-D Pie Sector of seal
- Includes labyrinth tooth, air dam, and hydrostatic air bearing
- Captures effect of discrete orifice holes in air bearing face

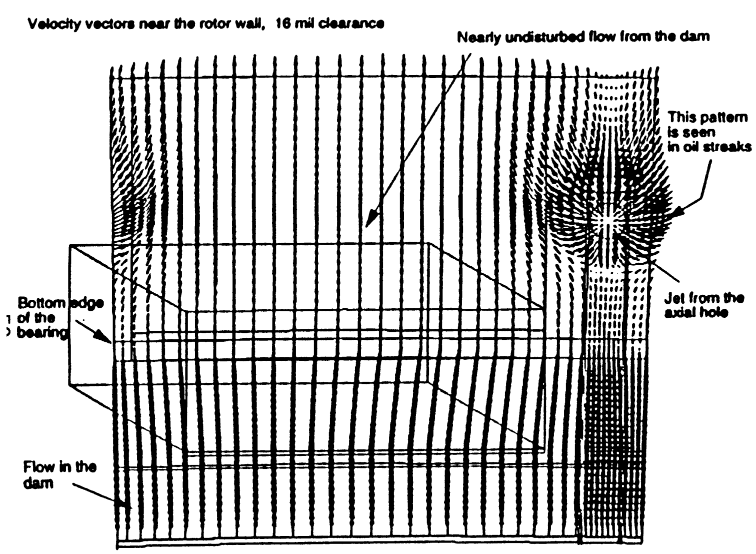
Aspirating Seal Test Results - Static Leakage

Test	Flow Deflector (Y/N)	Labyrinth Tooth Clearance (in.)	Seal/Rotor Air Gap (in.)	Mass Flow (lbm/s)
1	Y	0.035	0.001-0.002	0.15 @ 7.0 psid 0.20 @ 12.3 psid
2	Y	0.085	0.001-0.002	0.16 @ 7.3 psid 0.20 @ 12.3 psid
3	N	0.085	0.015-0.018	0.94 @ 6.2 psid 1.24 @ 10.0 psid
4	N	0.035	0.001-0.002	0.11 @ 4.8 psid 0.20 @ 12.4 psid
5*	N	0.085	0.016-0.020	1.00 @ 7.6 psid 0.93 @ 6.0 psid

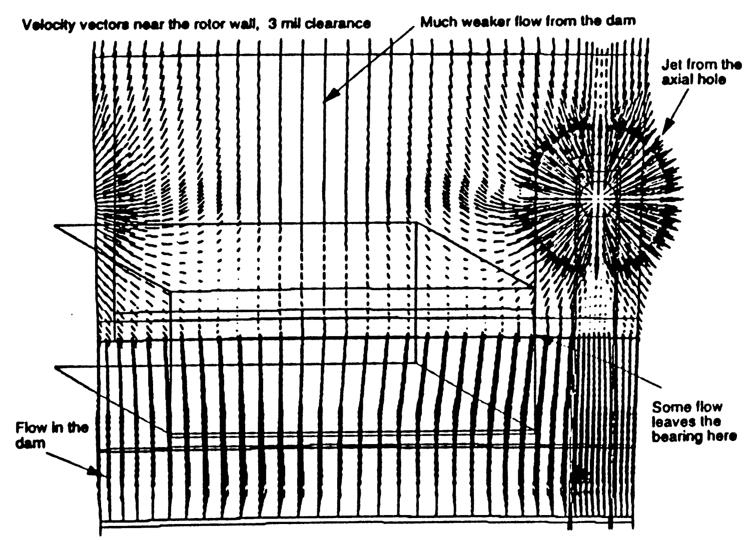
* Test 5 is a repeat of Test 3

Analytical Results

Axial view of flow fields - 0.016" and 0.003" air gaps



0.016" air gap (test case)

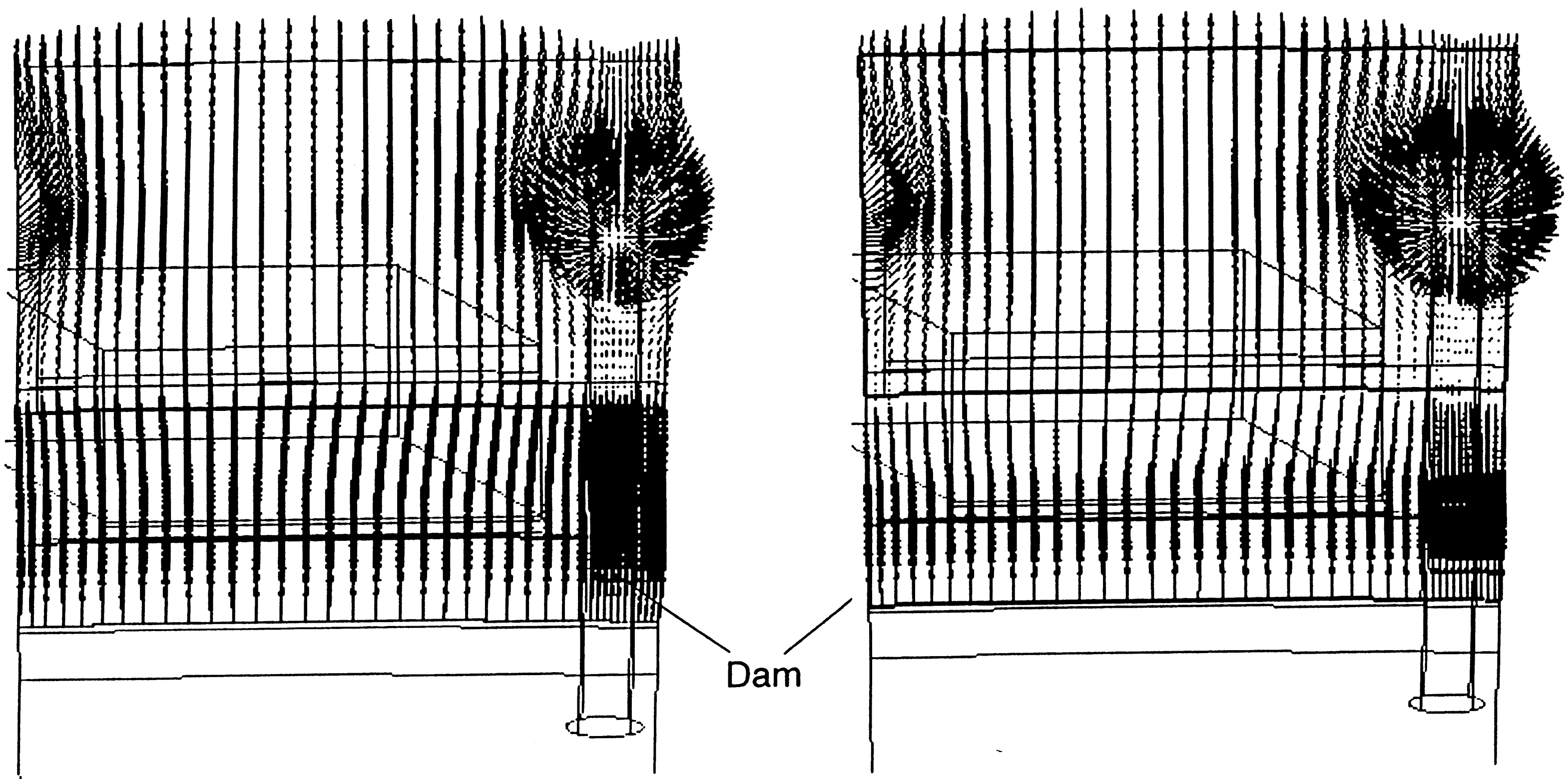


0.003" air gap

- Flow pattern at holes consistent with test observation for 0.016" gap
- Radial flow from the dam dominates the flow in air bearing region
- Even at clearance of 0.003", orifice flow is highly localized

Velocity Vector Plot

Plane near the rotor wall

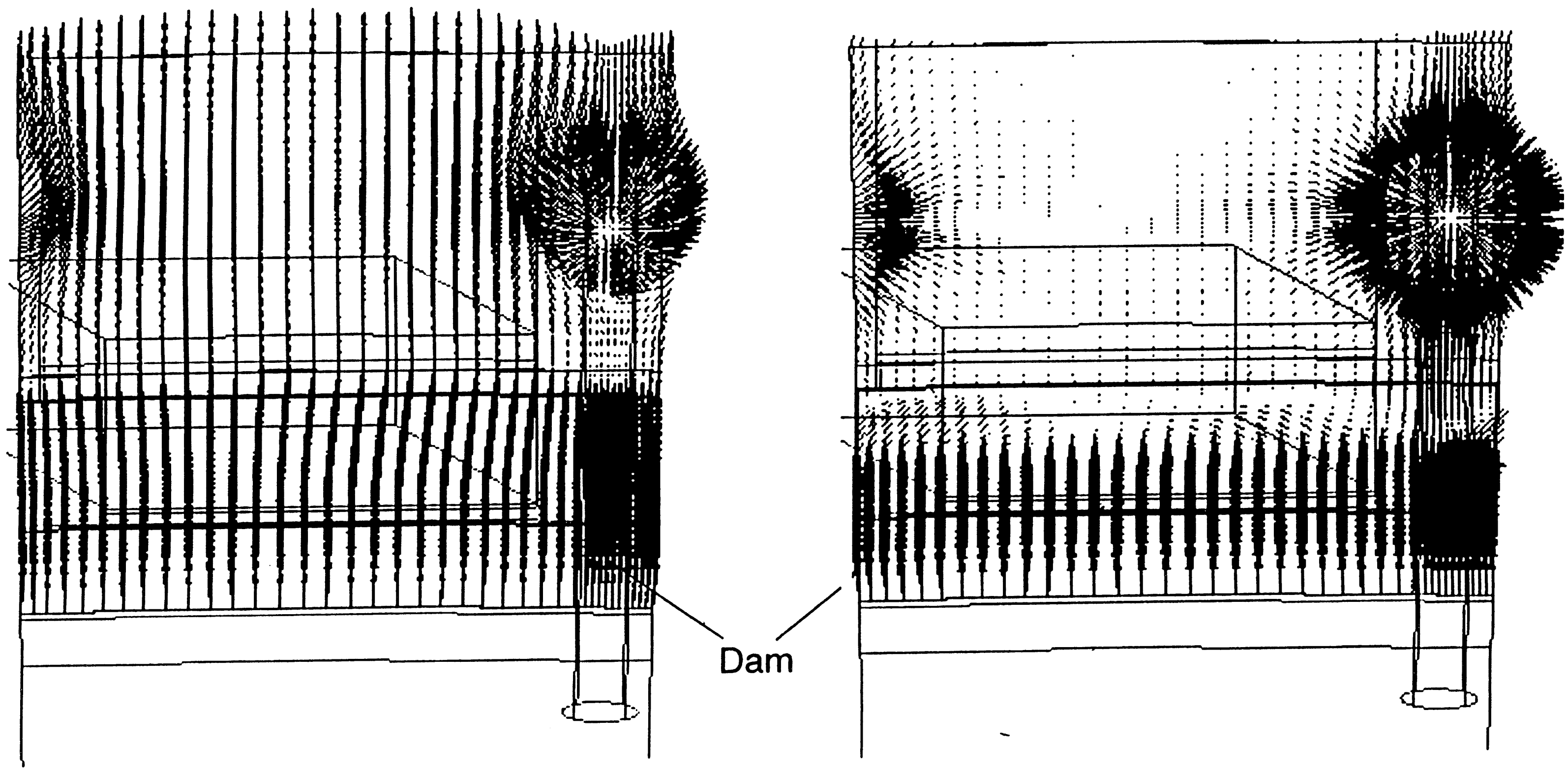


Base Design

Laby clearance 35 mils

Velocity Vector Plot

Plane near the rotor wall

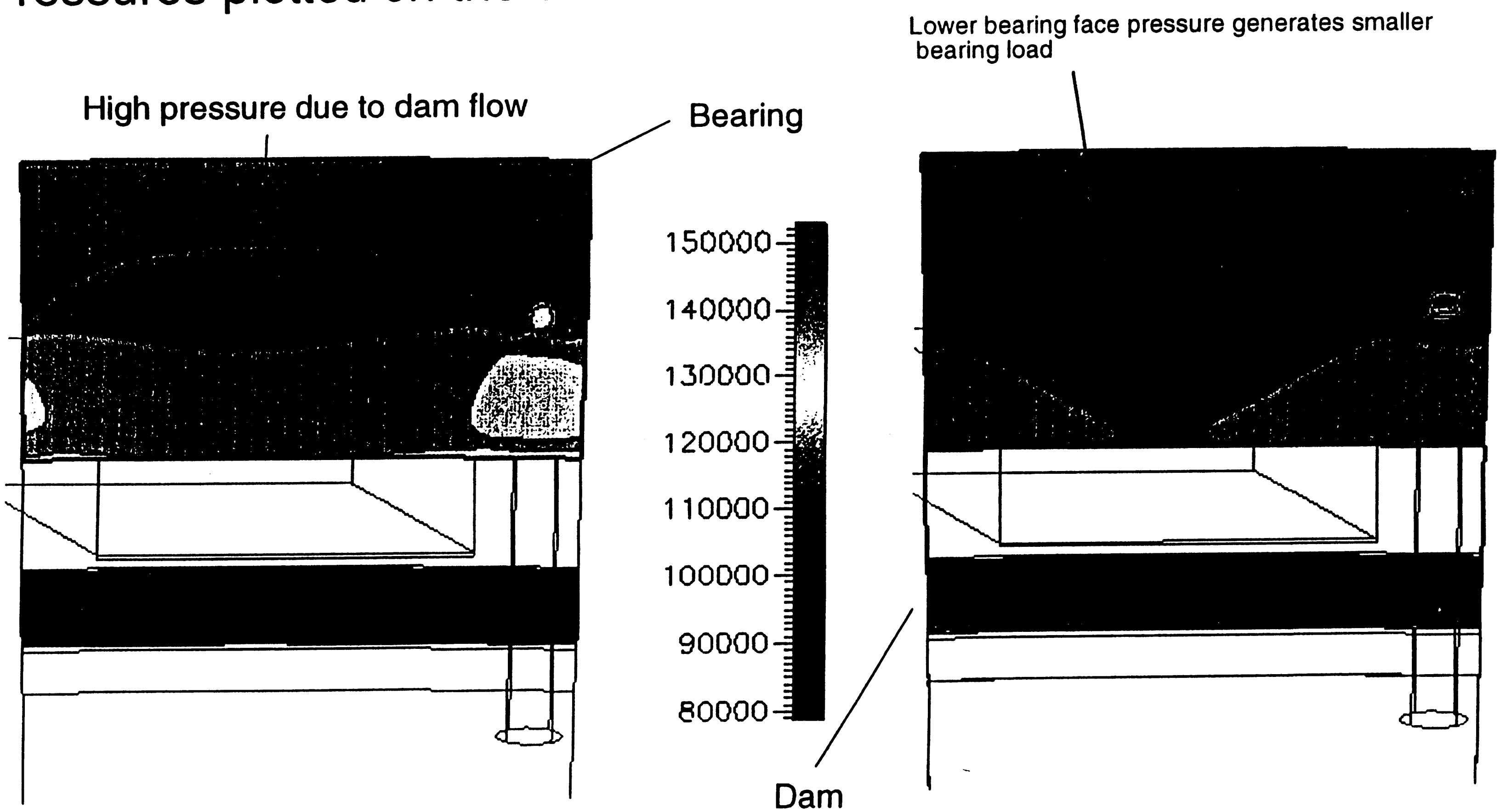


Base Design

With deflector wall

Surface Static Pressure Plot

Pressures plotted on the seal surfaces

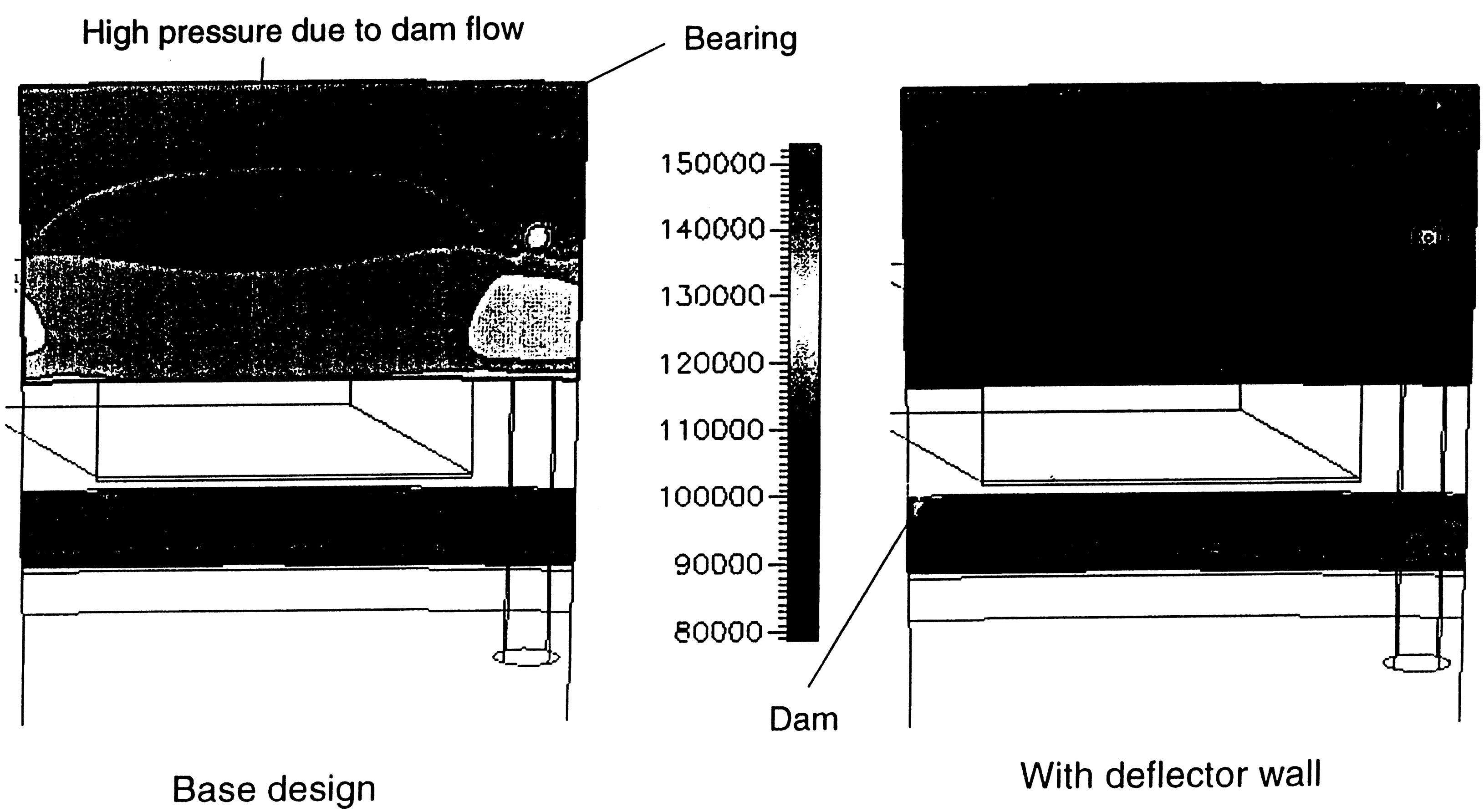


Base design

Labytrinth clearance
35 mils

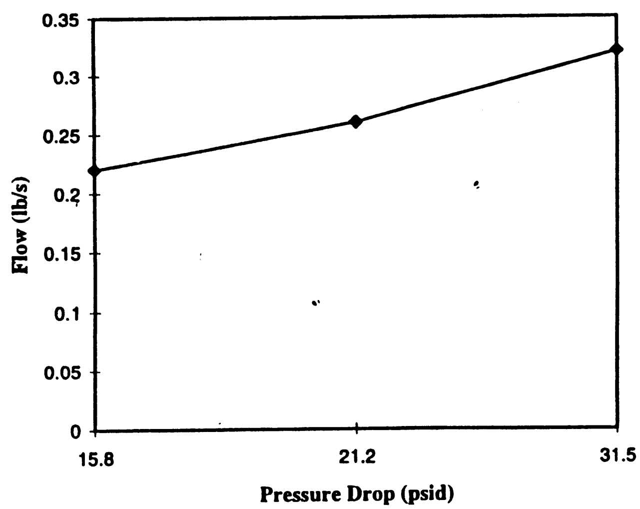
Surface Static Pressure Plot

Pressures plotted on the seal surfaces

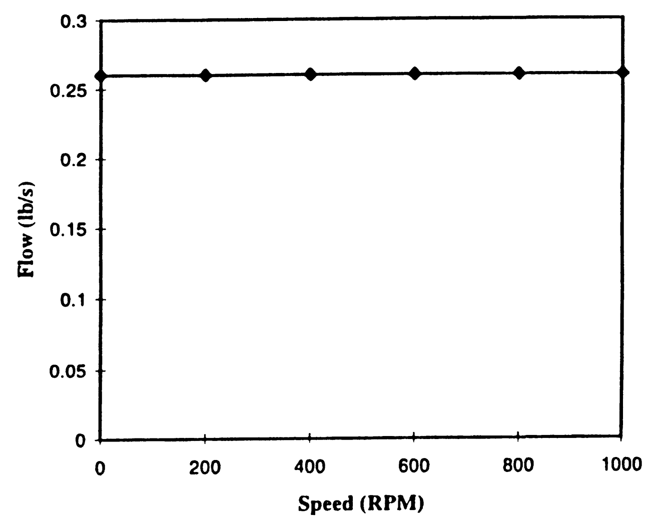


Nominal clearance 16 mils

Aspirating Seal Test Results - Static and Dynamic



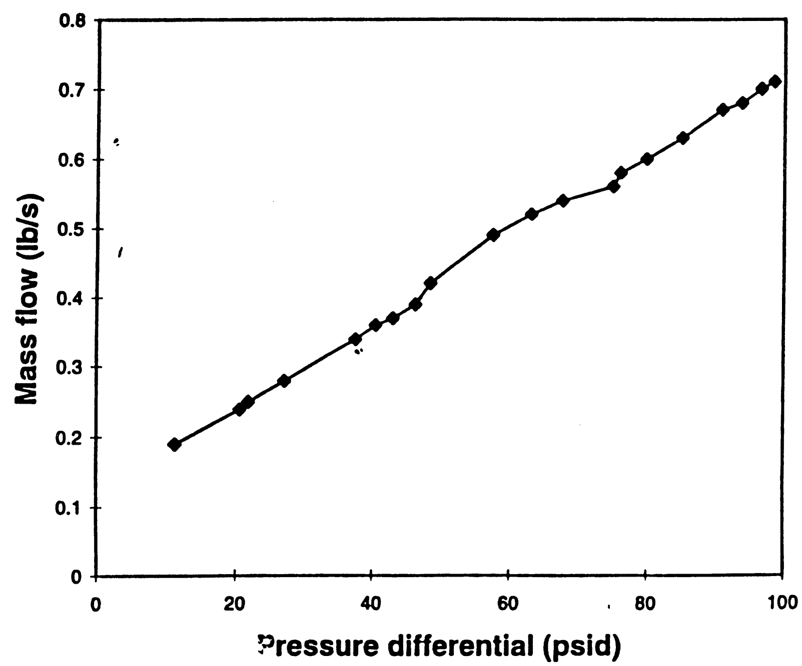
Static Leakage
(0 RPM)



Dynamic Leakage
(20 psid)

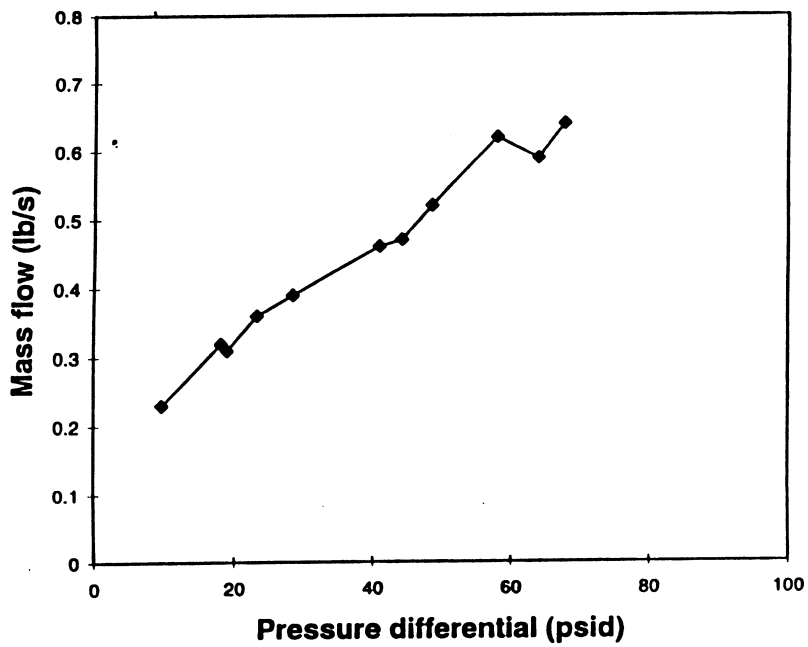
- 0.035” Labyrinth Tooth Clearance
- No Flow Deflector between Air Dam and Air Bearing
- 0.0015” seal/rotor air gap at $\Delta P < 38$ psid, Flow < 0.4 lbm/s for 0 RPM
- 0.0015” seal/rotor air gap at RPM < 1000 for $\Delta P = 20$ psid

Aspirating Seal Test Results - Static Leakage



- 0.035" Labyrinth Tooth Clearance
- Flow Deflector in place between Air Dam and Air Bearing
- 0.0015" seal/rotor air gap for entire range of pressures

Aspirating Seal Test Results - Static Leakage



- 0.085” Labyrinth Tooth Clearance
- Flow Deflector in place between Air Dam and Air Bearing
- Seal behavior is more erratic than with 0.035” labyrinth tooth clearance
- Damage to flow deflector discovered upon seal inspection.

Conclusions

36" Aspirating Face Seal testing and analysis has revealed the following:

1. **Isolation of dam and air bearing flows is vital for seal performance.**
2. **The existing seal design seeks equilibrium 0.016" from the rotor surface.**
3. **Minimizing the labyrinth tooth clearance allows the seal to operate at low pressures/flows with some rotation. Rotation at elevated speeds appears to induce seal opening.**
4. **Positive isolation of dam and air bearing flows allows the seal to operate over full range of pressures; effect of rotation TBD.**

The aspirating face seal shows potential as a replacement for labyrinth and brush seals as a durable low leakage seal after modifications to move its equilibrium position from 0.016" to 0.002"