FULL SCALE TESTING OF AN ASPIRATING FACE SEAL WITH ANGULAR MISALIGNMENT

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Objectives

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

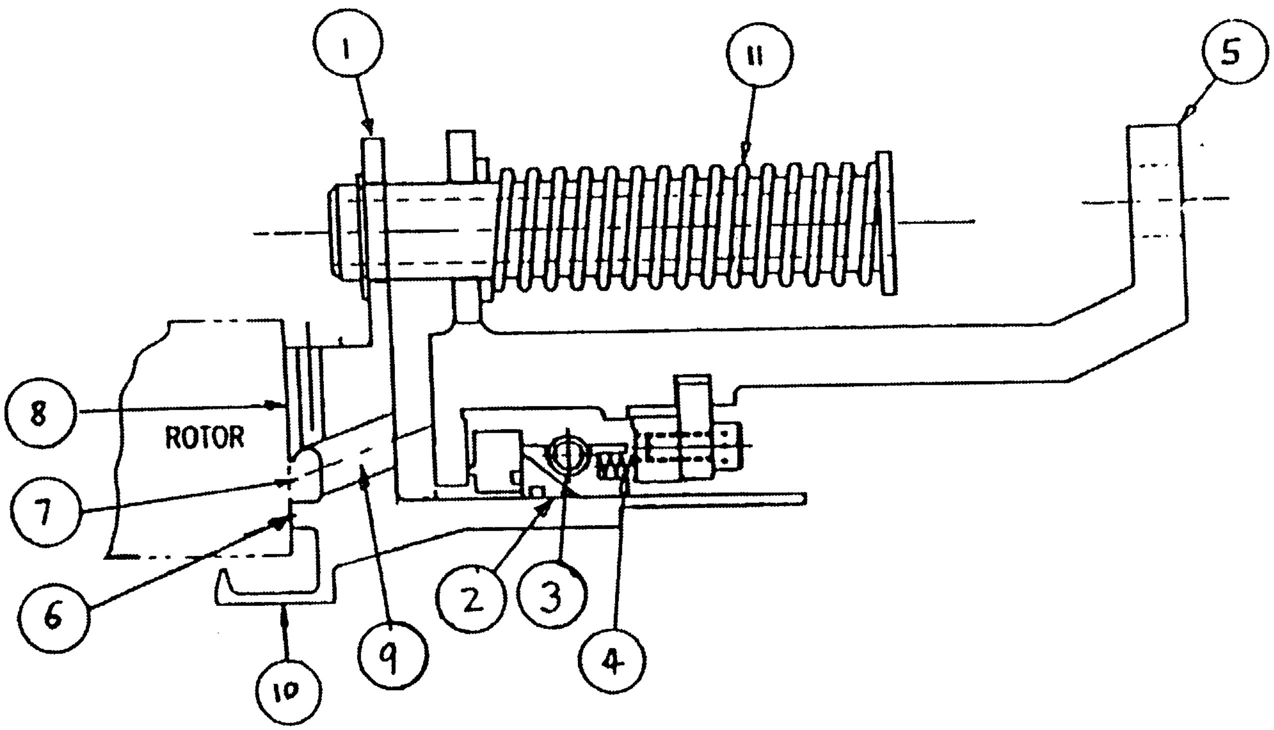
Motivation

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

Outline

Enhanced Aspirating Seal Design
Test Plan & Facilities
Analytical Verification of Seal Design
Rig Modifications for Seal Tilt
Test 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 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

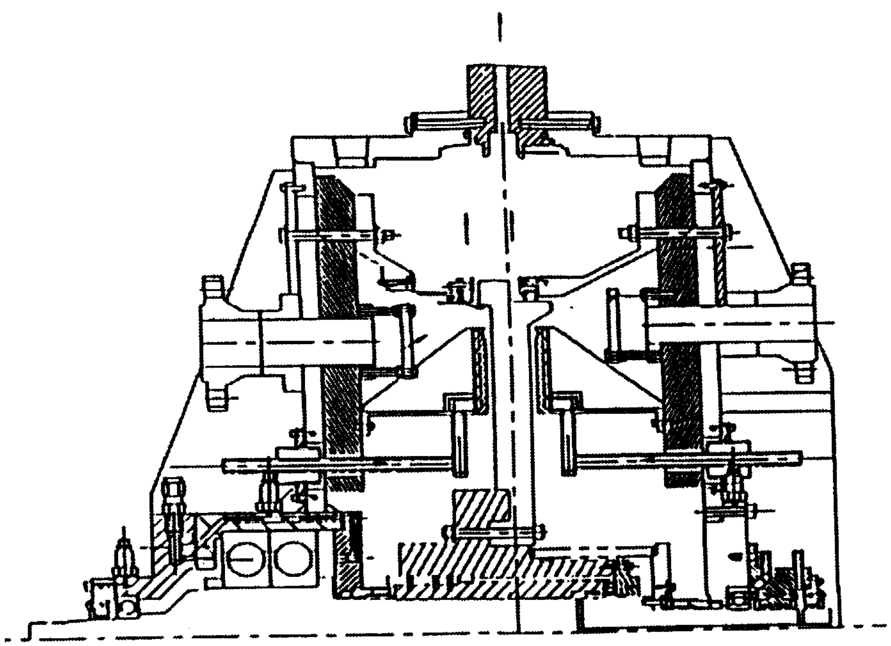
3. Tracking
- 0.75" relative axial motion

4. Dynamic Leakage
- leakage performance up to 100 psid, 2400 rpm, 750° F

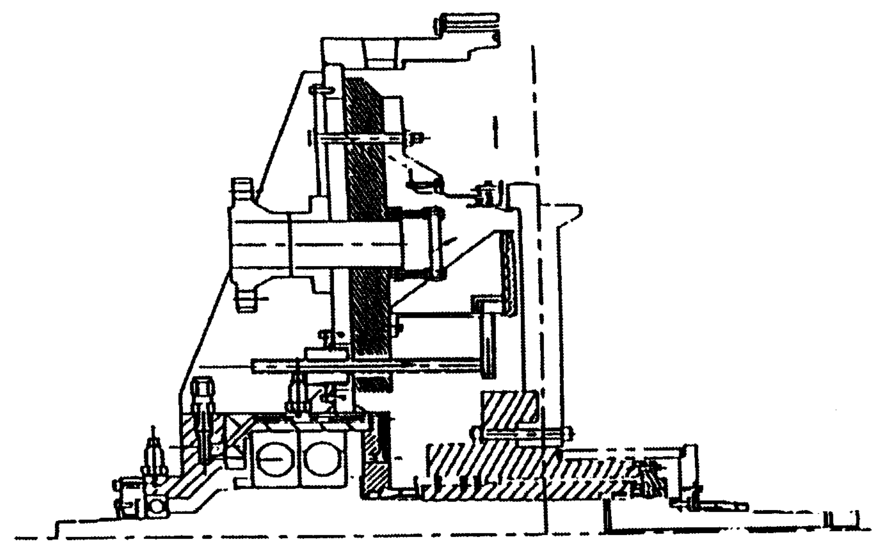
5. Rotor Runout
- leakage performance up to 100 psid, 2400 rpm with 0.005 and 0.010" TIR

6. Seal Tilt
- leakage performance up to 100 psid, 2400 rpm with 0.27° tilt

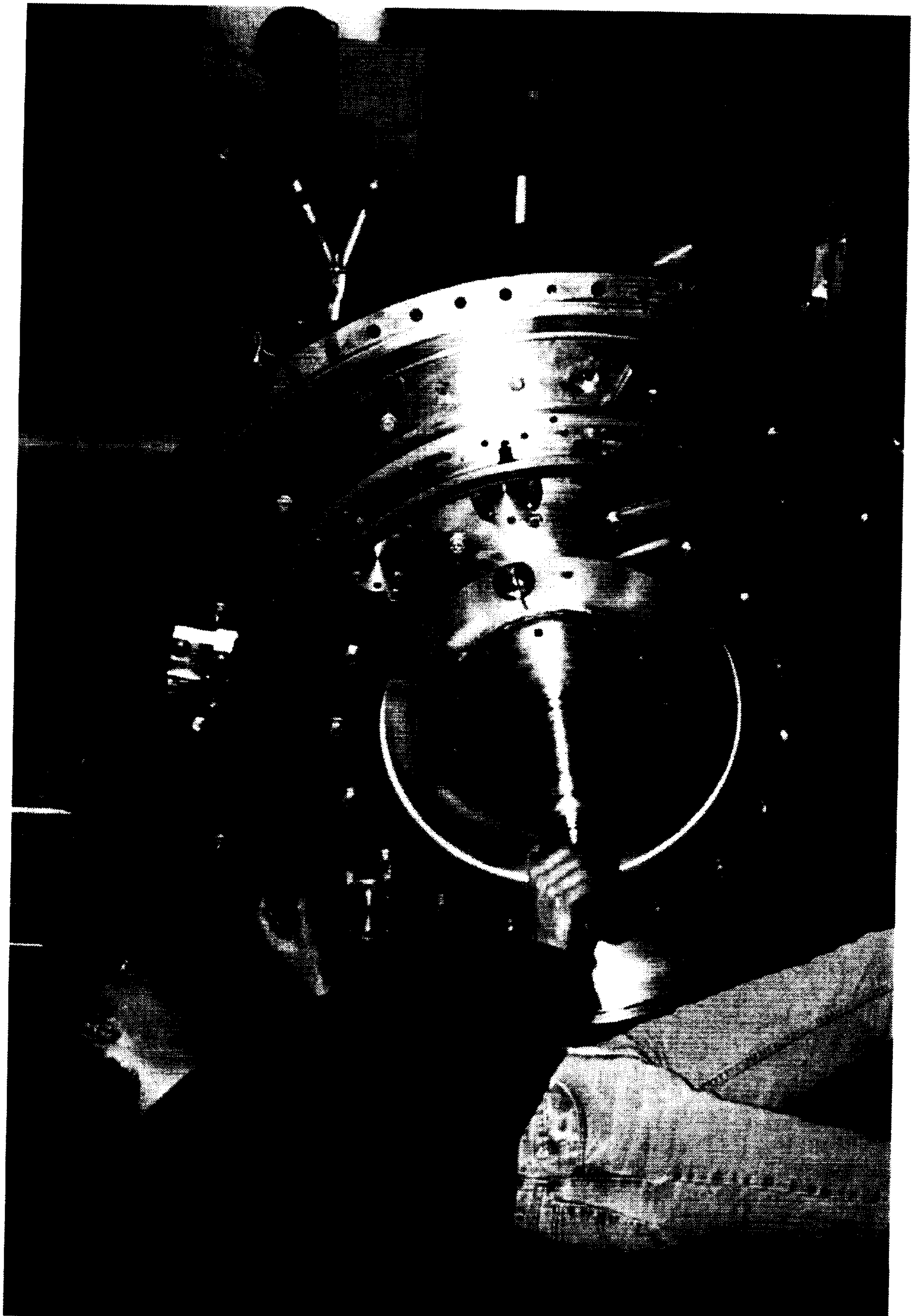
The Full Scale Test Rig



Fully Assembled
Rig Configuration

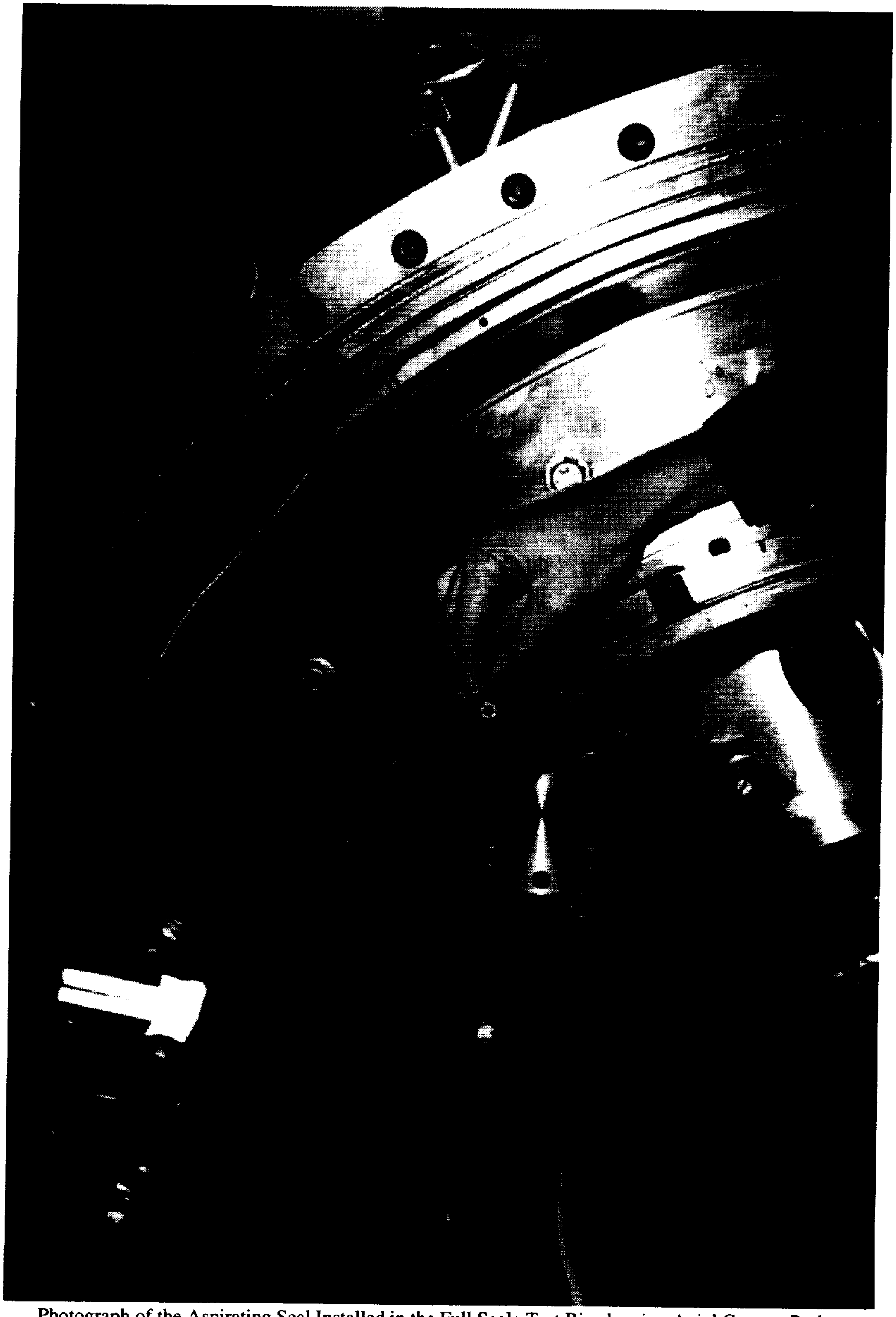


Open Vessel Test
Configuration

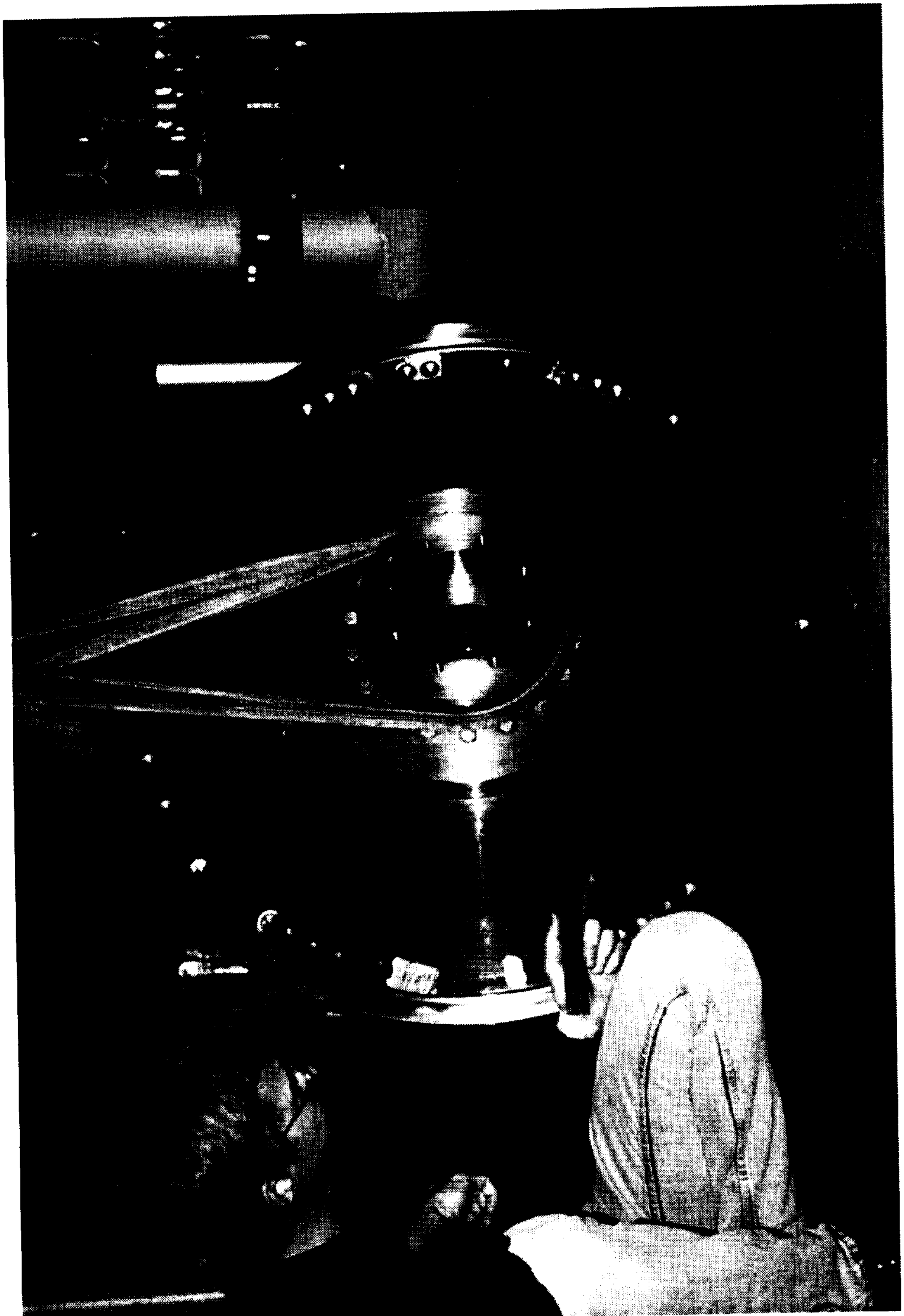


Photograph of the Open Full Scale Test Rig with the Aspirating Seal Installed

Detailed Photograph of the Aspirating Seal showing the Air Bearing Face and Orifice Holes

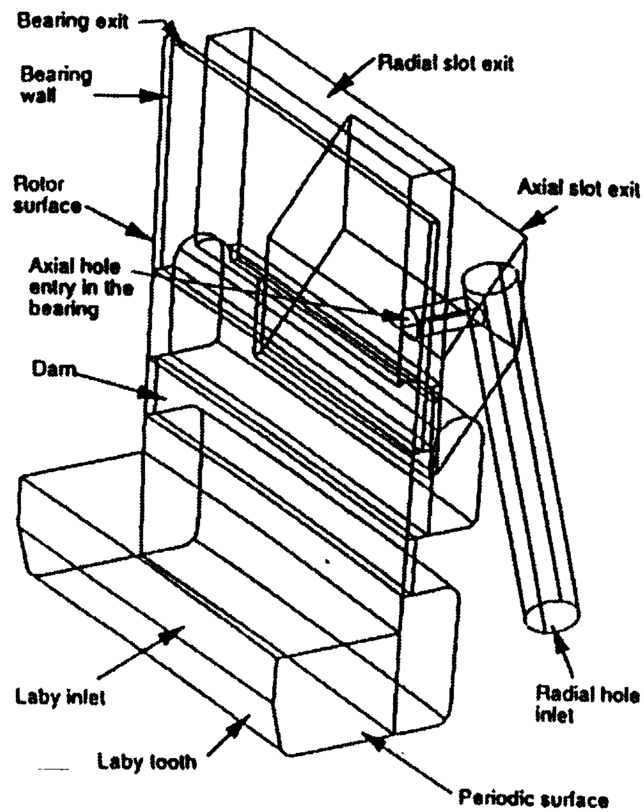


Photograph of the Aspirating Seal Installed in the Full Scale Test Rig showing Axial Contact Probe



Photograph of the Full Scale Test Rig Rotor

The CFD Model

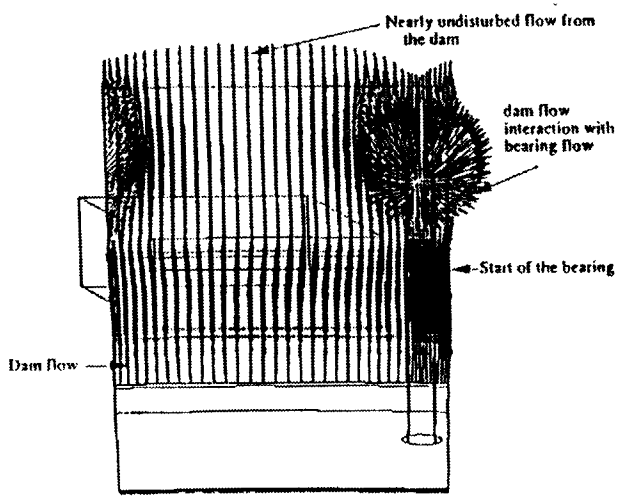


- 3-D Pie Sector of seal
- Includes labyrinth tooth, air dam, and hydrostatic air bearing
- Captures effect of discrete orifice holes in air bearing face

CFD Results - Flow Fields

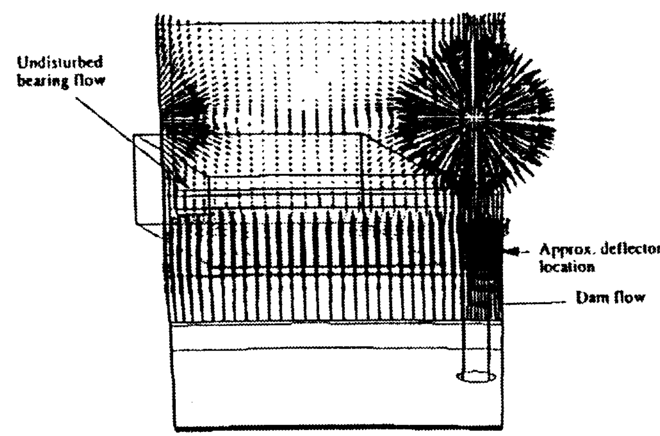
Original Configuration

Velocity field near rotor surface, baseline seal, 16 mils



With Flow Deflector

Velocity field near rotor surface, Seal with deflector, 16 mils

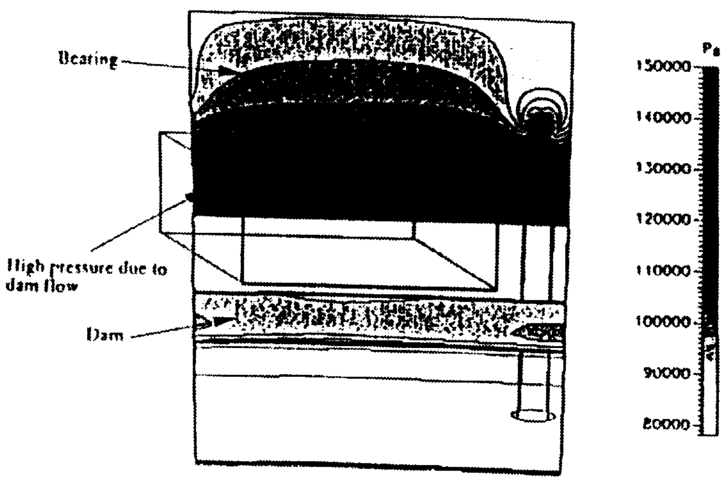


- Without deflector, air dam/air bearing flow mixing occurs.
- Deflector effectively isolates air dam/air bearing flows.

CFD Results - Pressure Distributions

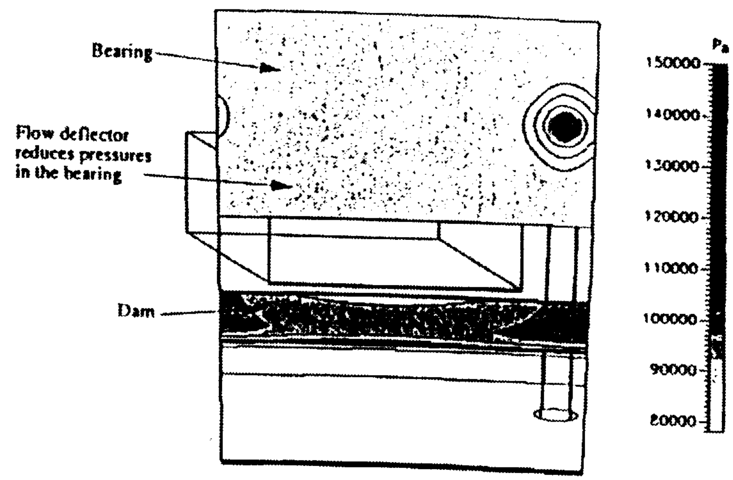
Original Configuration

Bearing and dam surface pressure, baseline seal, 16 mils



With Flow Deflector

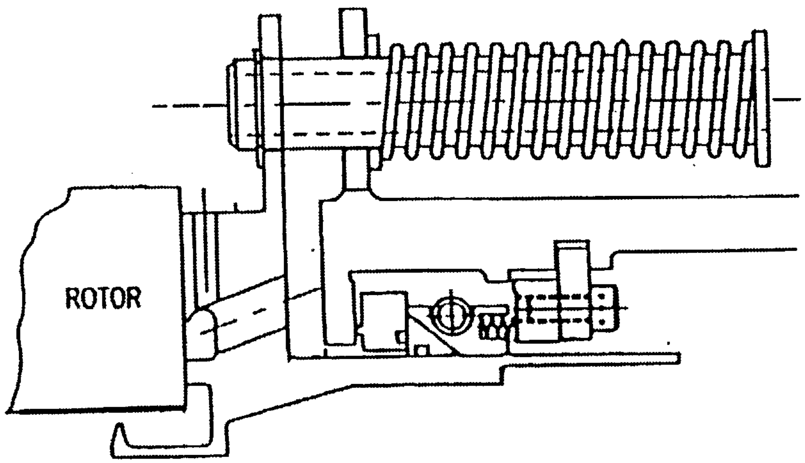
Bearing and dam surface pressure, seal with deflector, 16 mils.



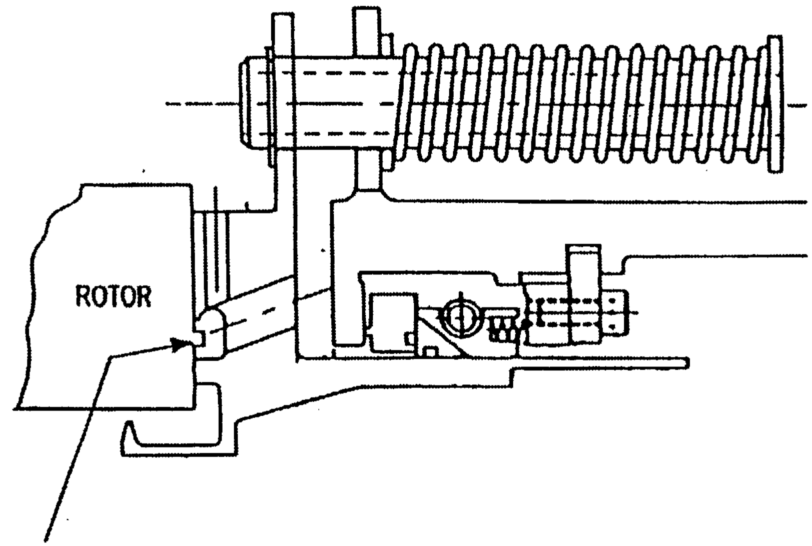
- Without deflector, increased pressure prevents seal closure.
- Deflector reduces pressure in seal/rotor air gap.

Seal/Rotor Configurations

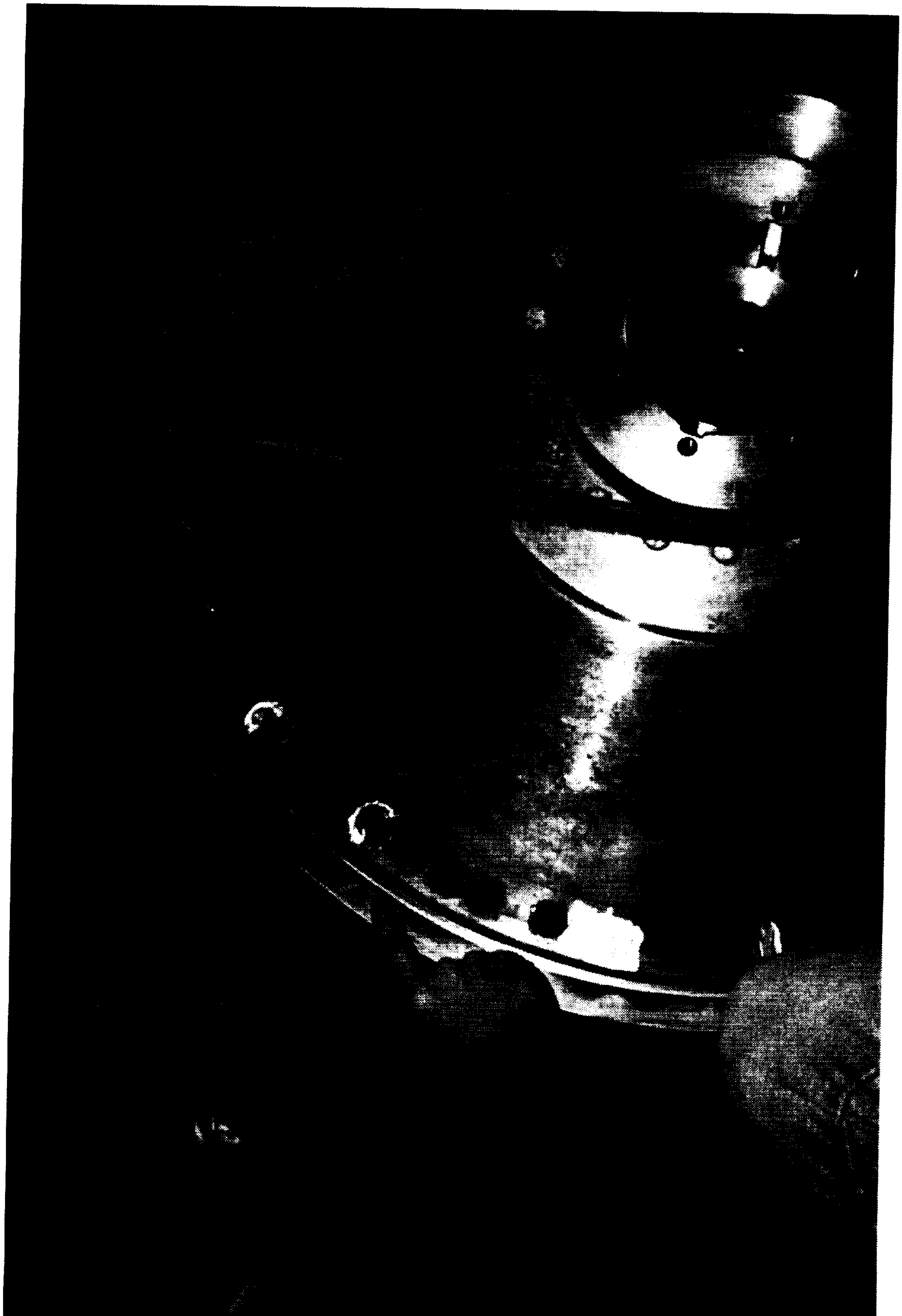
Original



With Flow Deflector



- Flow Deflector machined directly onto rotor surface, radially centered between air dam and air bearing.

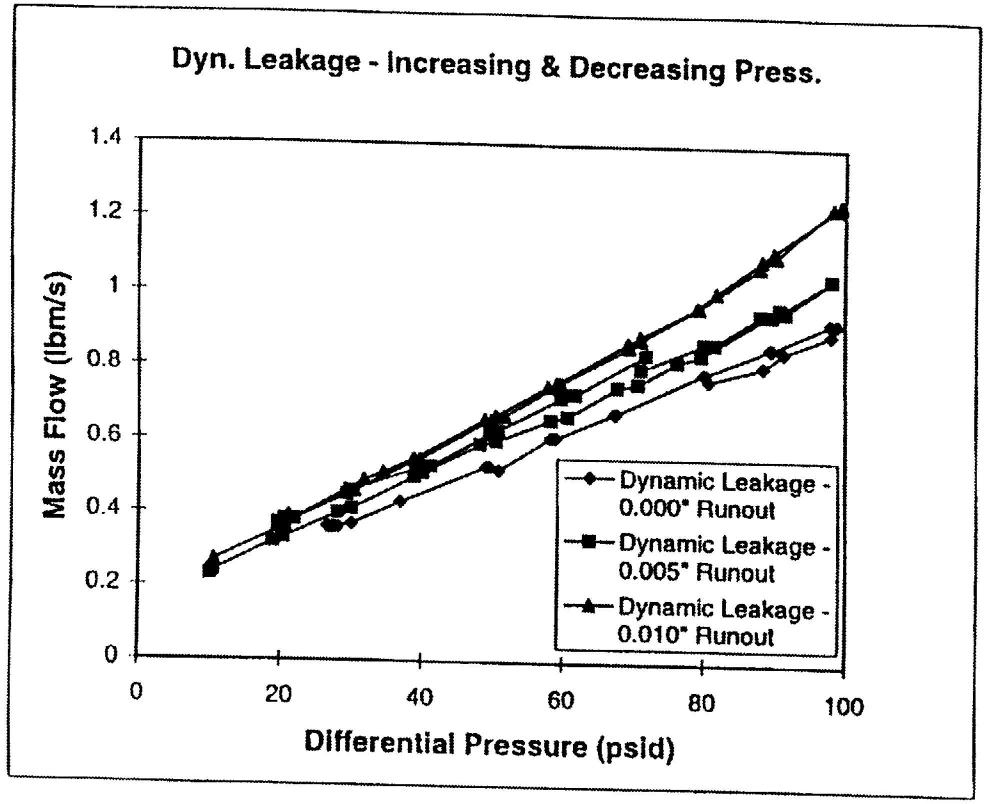


Photograph of Full Scale Test Rig Rotor showing Flow Deflector Modification

Detailed Photograph of Full Scale Test Rig Rotor showing Flow Deflector Modification

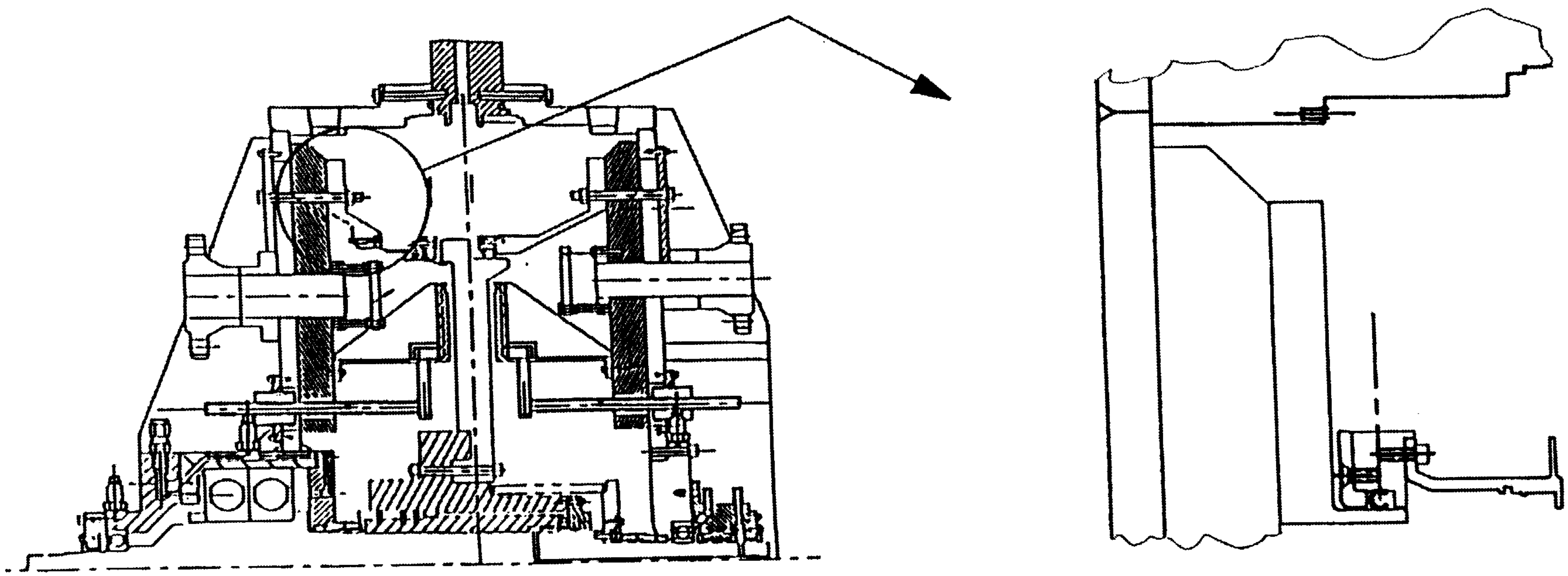
Test Results with Flow Deflector

Dynamic leakage for 0.000", 0.005", and 0.010" Rotor TIR.



- Seal closure occurs at 2-3 psid for all cases.

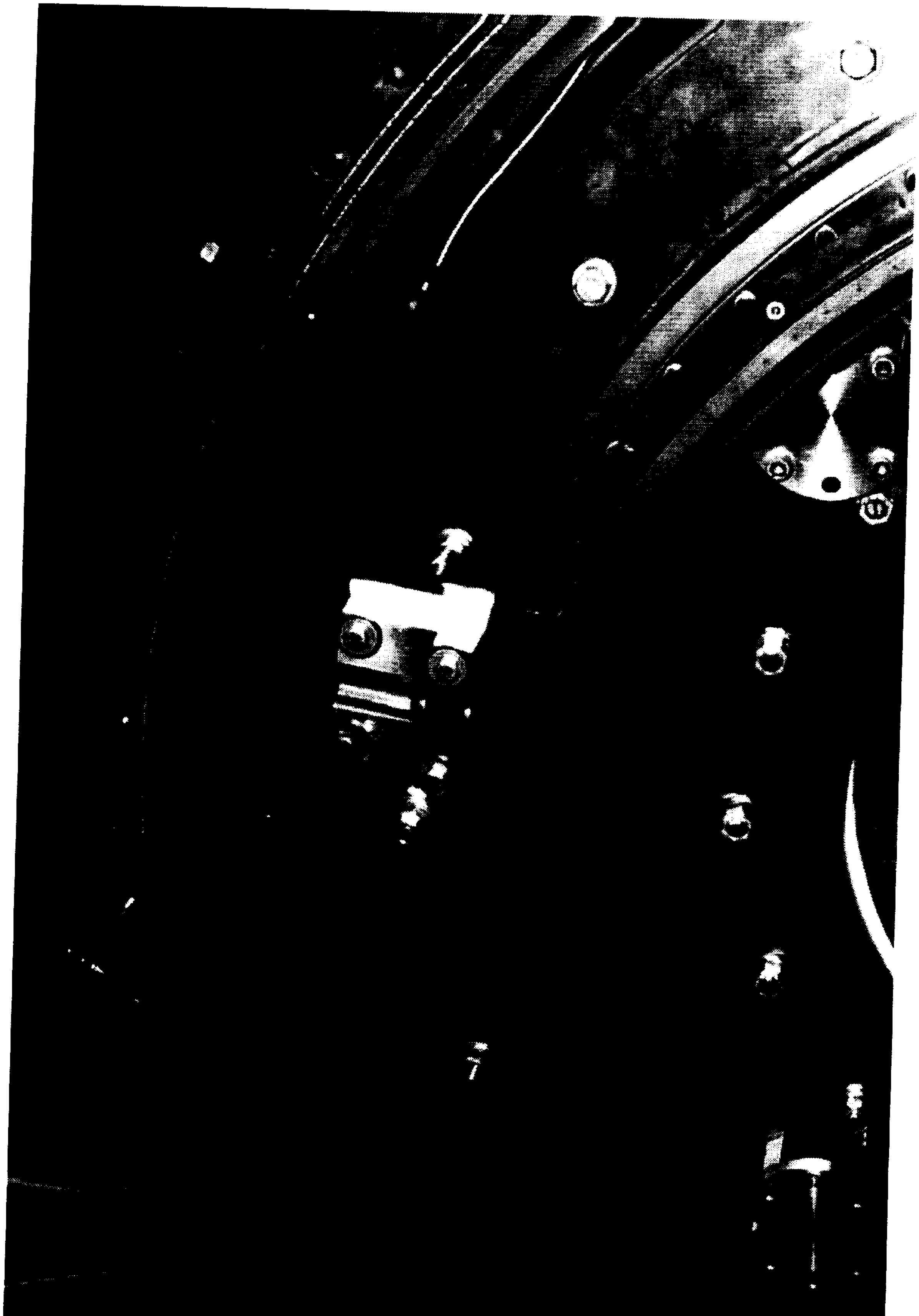
Test Rig Modification - Seal Tilt Mechanism



Standard Configuration

Tilt Mechanism Details

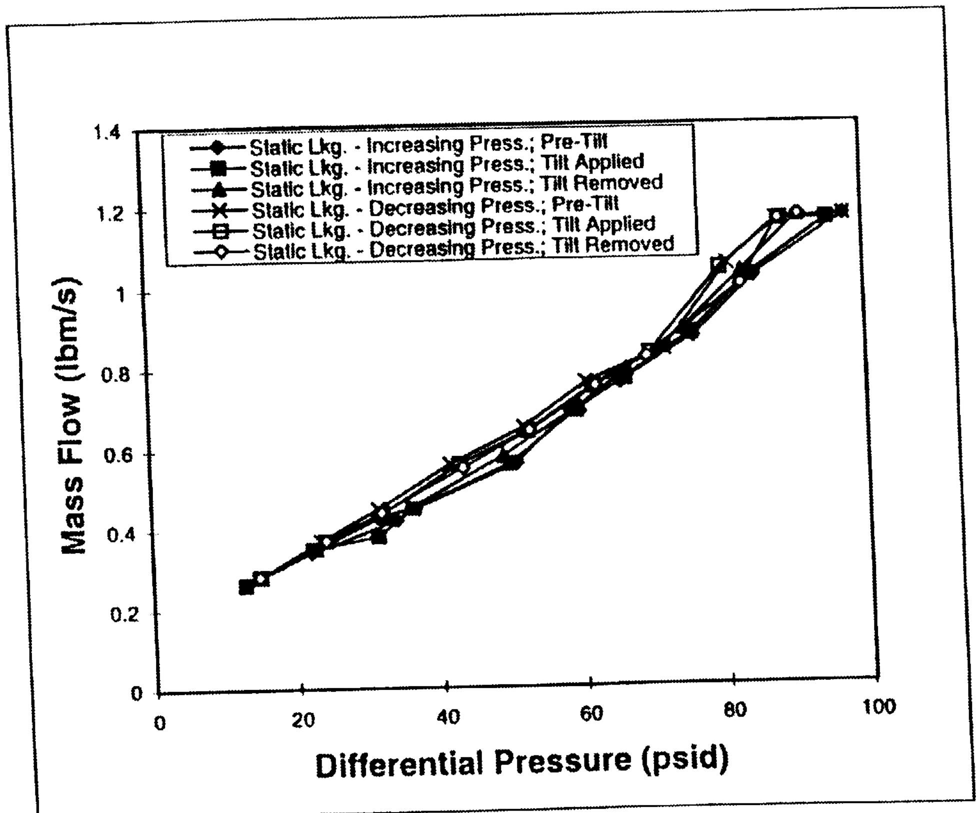
- *Seal mounting ring pivots at two locations*
- *Linear actuators act out-of-phase to tilt ring*
  - *Tilt = 0°- 0.27°- 0° in 0.8 seconds*



Photograph of Tilt Mechanism Pivot and Seal Holder with Aspirating Seal Installed

Test Results - Static Leakage with Tilt

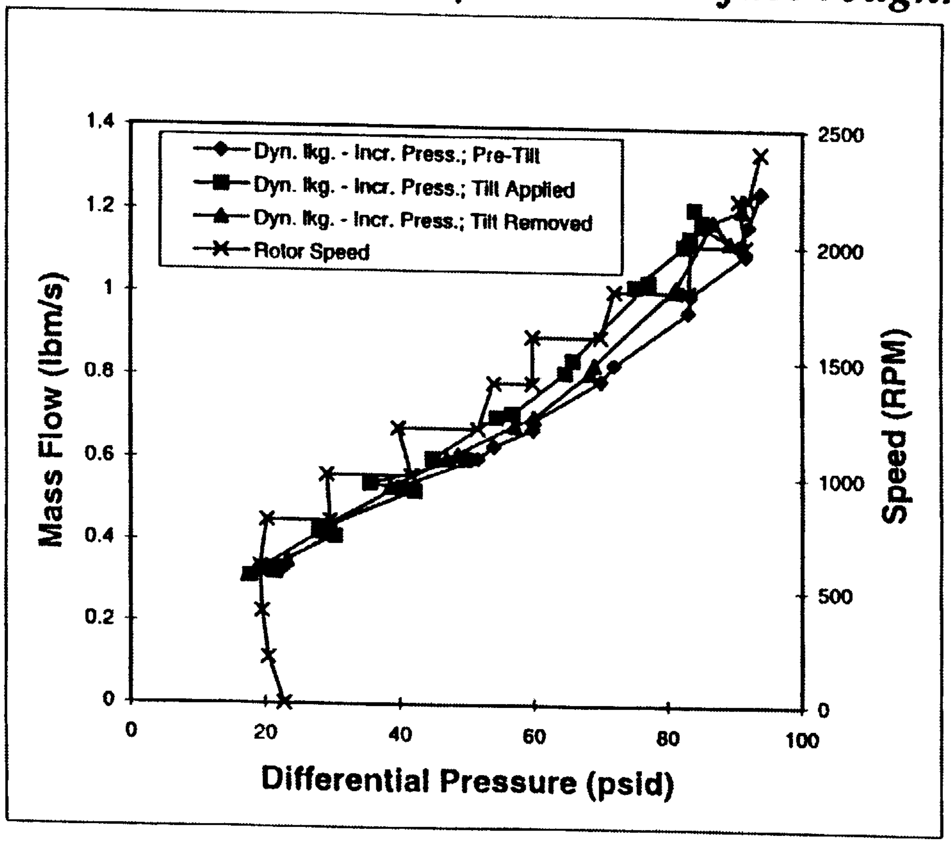
Tilt 0.27° in 0.4 seconds, hold to collect data, remove in 0.4 seconds.
<u>Note</u>: 0.007" rotor axial TIR, 140 μin. rotor surface roughness.



- **At maximum conditions, pressure falls by 6% with tilt while leakage remains essentially constant.**

Test Results - Dynamic Leakage with Tilt

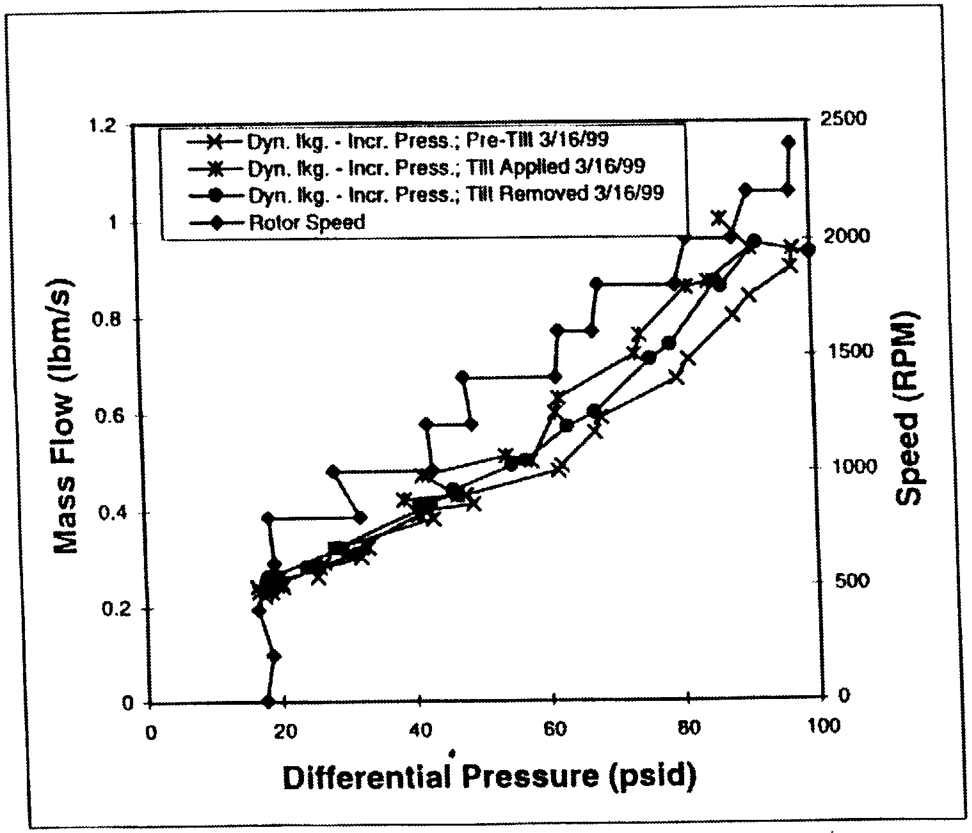
Tilt 0.27° in 0.4 seconds, hold to collect data, remove in 0.4 seconds.
Note: ***0.007" rotor axial TIR, 141 μin. rotor surface roughness.***



- **At maximum conditions, pressure falls by 10% with tilt while leakage remains essentially constant; recovery is > 95%.**

Test Results - Dynamic Leakage with Tilt

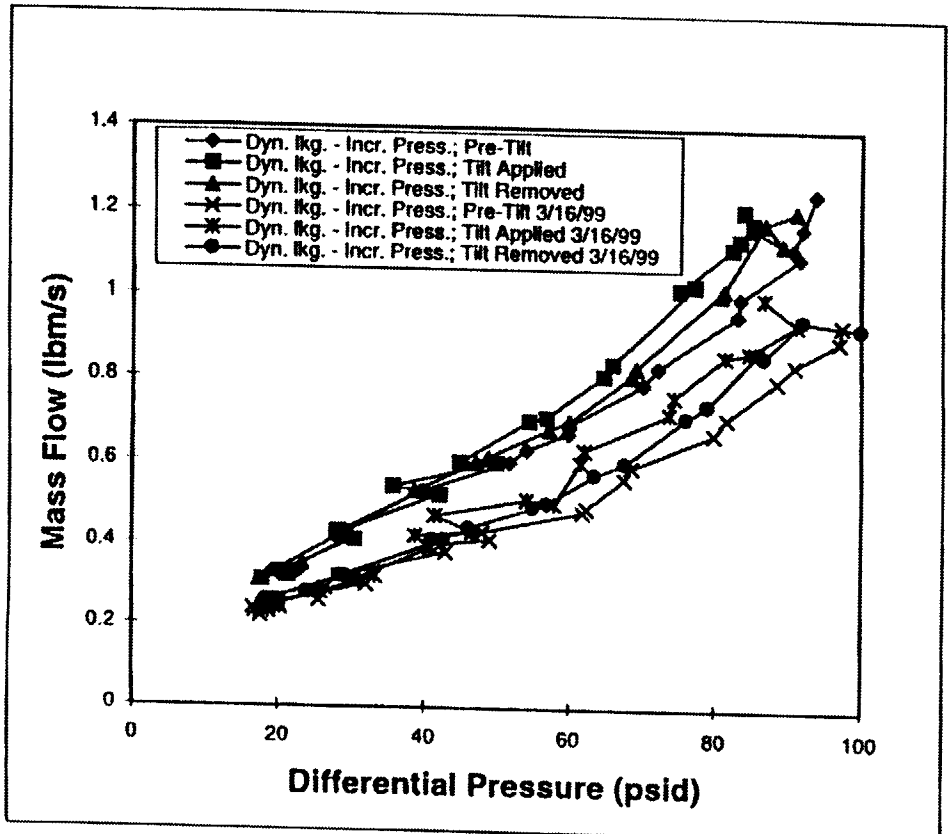
Tilt 0.27° in 0.4 seconds, hold to collect data, remove in 0.4 seconds.
<u>Note</u>: 0.007" rotor axial TIR, 13-19 μin. rotor surface roughness.



- **At maximum conditions, pressure falls by 10% with tilt while leakage remains essentially constant; recovery is > 95%.**

Test Results - Dynamic Leakage with Tilt

Comparison of seal performance with 141 μin. rotor surface roughness and 13-19 μin. rotor surface roughness (03/16/99 data).



- **Seal performance improves by 24% at maximum conditions when rotor surface roughness is improved to 13-19 μin.**

Conclusions

Testing and analysis of the Original and Improved 36" Aspirating Face Seal has revealed the following:

1. Isolation of air flows from the air dam and air bearing regions of the seal is crucial to seal performance.

2. A flow deflector between the air dam and air bearing is effective in isolating flows, allowing a 0.0015" air film to form; for 0.000" TIR, leakage is less than 1 lbm/s at 100 psid.

3. Leakage increases by 17% and 33% for rotor TIR's of 0.005" and 0.010", respectively, at 100 psid and 2400 RPM.

4. The aspirating seal can accommodate 0.27° of angular tilt with a performance reduction of approx. 10%. Recovery is 95-100%.

5. A rotor surface roughness of up to 140 μin. can be accommodated, but performance improves by 24% for a roughness of 20 μin.

The aspirating face seal shows promise as a potential replacement for labyrinth seals in aircraft engine applications.

Description of Slides

1. Title slide
2. Objectives and Motivation for Aspirating Face Seal Testing and Analysis
3. Cross-section of the Original 36" Diameter Aspirating Face Seal, showing seal components
4. The Aspirating Seal Test Plan
5. Cross-section of the Full Scale Test Rig, in the Fully Assembled and Open Vessel Configurations
6. Photograph of the Open Full Scale Test Rig with the Aspirating Seal Installed
7. Detailed Photograph of the Aspirating Seal showing the Air Bearing Face and Orifice Holes
8. Photograph of the Aspirating Seal Installed in the Full Scale Test Rig showing Axial Contact Probe
9. Photograph of the Full Scale Test Rig Rotor
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12. CFD Results - Pressure Distributions for Original Configuration and Improved Configuration with Flow Deflector; both for measured 0.016" seal/rotor air gap at 7.1 psid
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18. Photograph of Tilt Mechanism Pivot and Seal Holder with Aspirating Seal Installed
19. Test Results – Improved Design Static Lkg. vs. Pressure Differential with Tilt (0.007" TIR, 140μin. Rotor Roughness)
20. Test Results – Improved Design Dynamic Lkg. and Rotor Speed vs. Pressure Differential with Tilt (0.007" TIR, 140 μin. Rotor Roughness)
21. Test Results – Improved Design Dynamic Lkg. and Rotor Speed vs. Pressure Differential with Tilt (0.007" TIR, 13-19 μin. Rotor Roughness)
22. Test Results – Improved Design Dynamic Lkg. vs. Pressure Differential with Tilt (0.007" TIR, 140 μin. and 13-19 μin. Rotor Roughness Cases)
23. Conclusions