N92-15090

SEALS RESEARCH AT TEXAS A&M UNIVERSITY

Gerald L. Morrison
Turbomachinery Laboratory
Texas A&M University

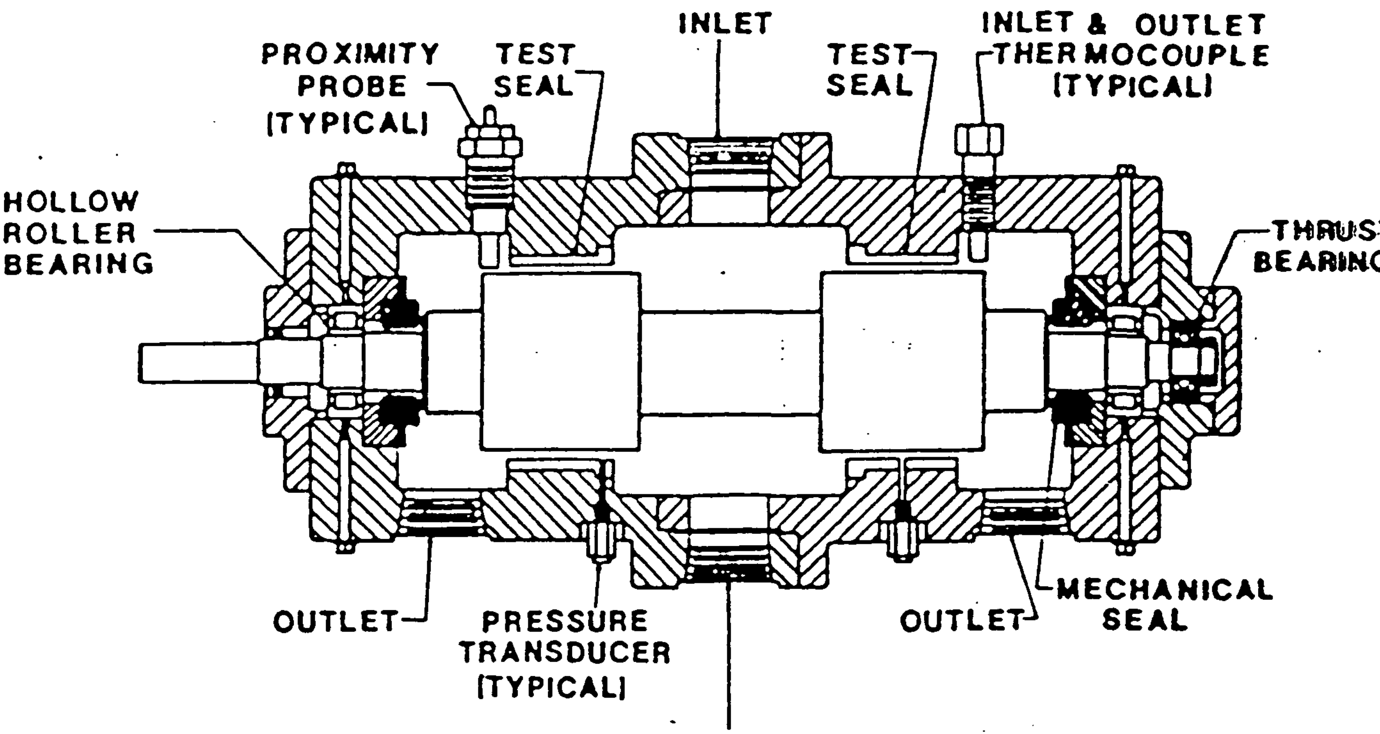
The Turbomachinery Laboratory at Texas A&M University has been providing experimental data and computational codes for the design seals for many years. Dr. Dara Childs began the program with the development of a Halon based seal test rig. This facility provided information about the effective stiffness and damping in whirling seals. The Halon effectively simulated cryogenic fluids. Dr. Childs then developed another test facility (using air as the working fluid) where the stiffness and damping matrices can be determined. This data has been used to develop bulk flow models of the seal's effect upon rotating machinery. In conjunction with Dr. Child's research. Dr. Luis San Andres has developed a bulk flow model for calculation of performance and rotordynamic coefficients of annular pressure seals of arbitrary non-uniform clearance for barotropic fluids such as LH2, LOX, LN2, and CH4. This program is very efficient (fast) and converges for very large eccentricities. Dr. Childs is now working on a bulk flow analysis of the effects of the impeller-shroud interaction upon the stability of pumps.

Dr. Gerald Morrison designed and used this data along with data from other researchers to develop an empirical leakage prediction code for NASA Marshall. He is presently studying, in detail, the flow field inside labyrinth and annular seals. Dr. Morrison is using an advanced 3-D laser Doppler anemometer system to measure the mean velocity and entire Reynolds stress tensor distribution throughout the seals. Concentric and statically eccentric seals have been studied. He is presently studying whirling seals. The data obtained are providing valuable information about the flow phenomena occurring inside the seals, as well as a data base for comparison with numerical predictions and for turbulence model development.

Dr. David Rhode has developed a finite difference computer code for solving the Reynolds averaged Navier Stokes equations inside labyrinth seals. He is currently evaluating a multi-scale k-e turbulence model. Using his computer code, Dr. Rhode designed and patented a new seal geometry. Dr. Rhode is also developing a large scale, 2-D seal flow visualization facility.

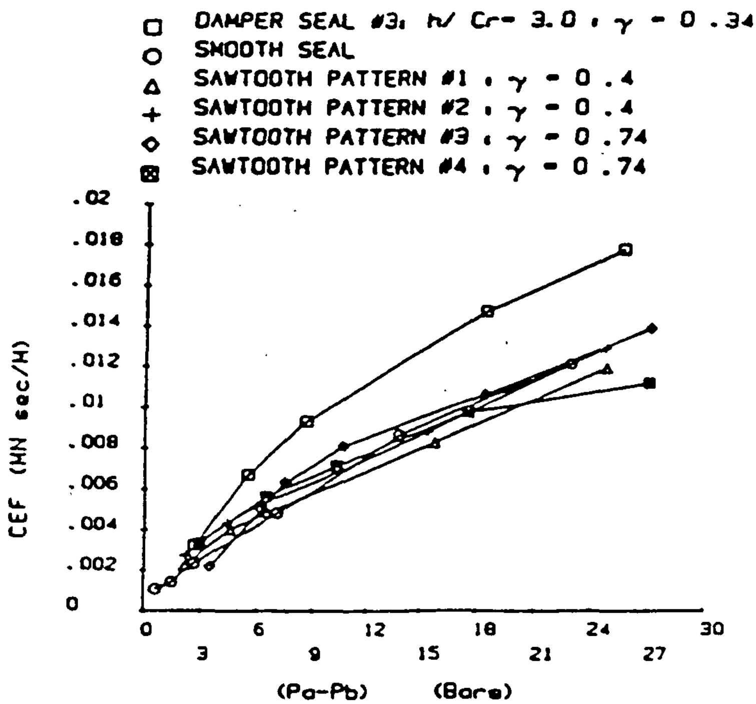
HIGH REYNOLDS NUMBER

SEAL TEST SECTION

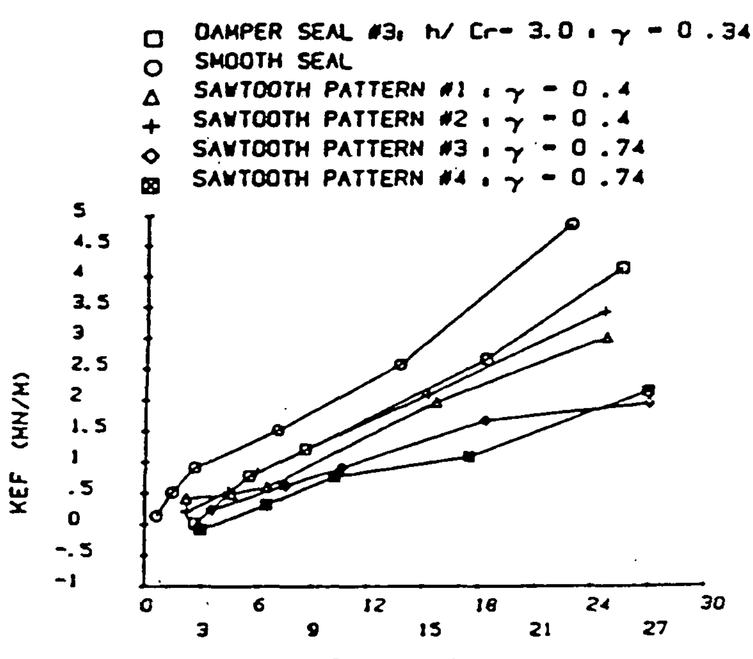


High-Reynolds-number seal test section

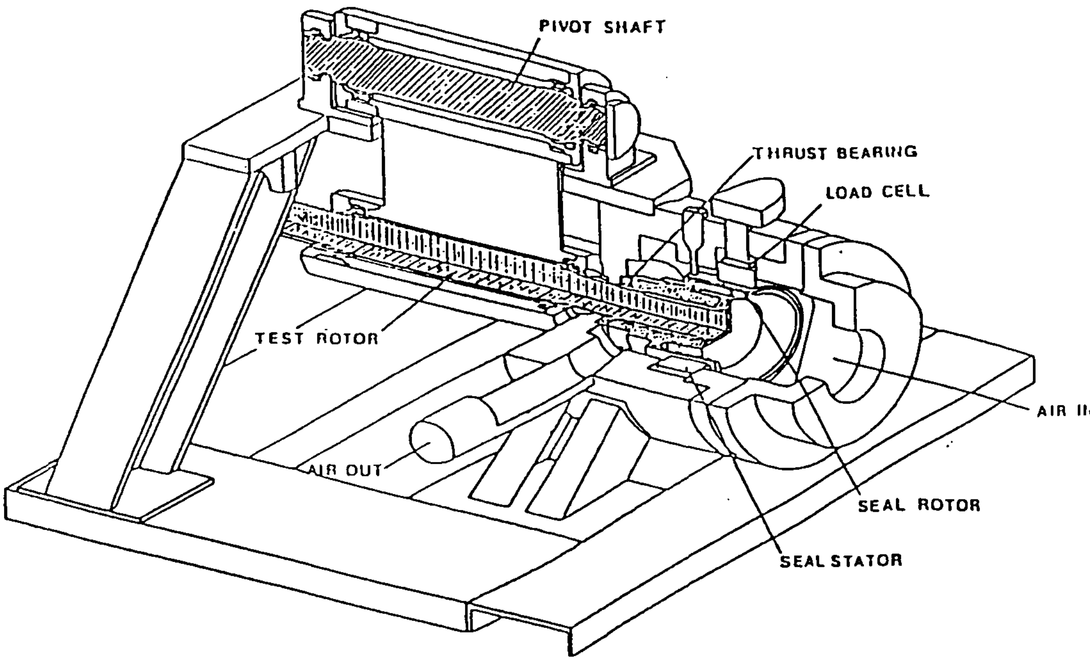
$$-\begin{Bmatrix} F_X \\ F_Y \end{Bmatrix} = \begin{bmatrix} K & k \\ -k & K \end{bmatrix} \begin{Bmatrix} X \\ Y \end{Bmatrix} + \begin{bmatrix} C & c \\ -c & C \end{bmatrix} \begin{Bmatrix} \dot{X} \\ \dot{Y} \end{Bmatrix} + M \begin{Bmatrix} \ddot{X} \\ \ddot{Y} \end{Bmatrix}$$



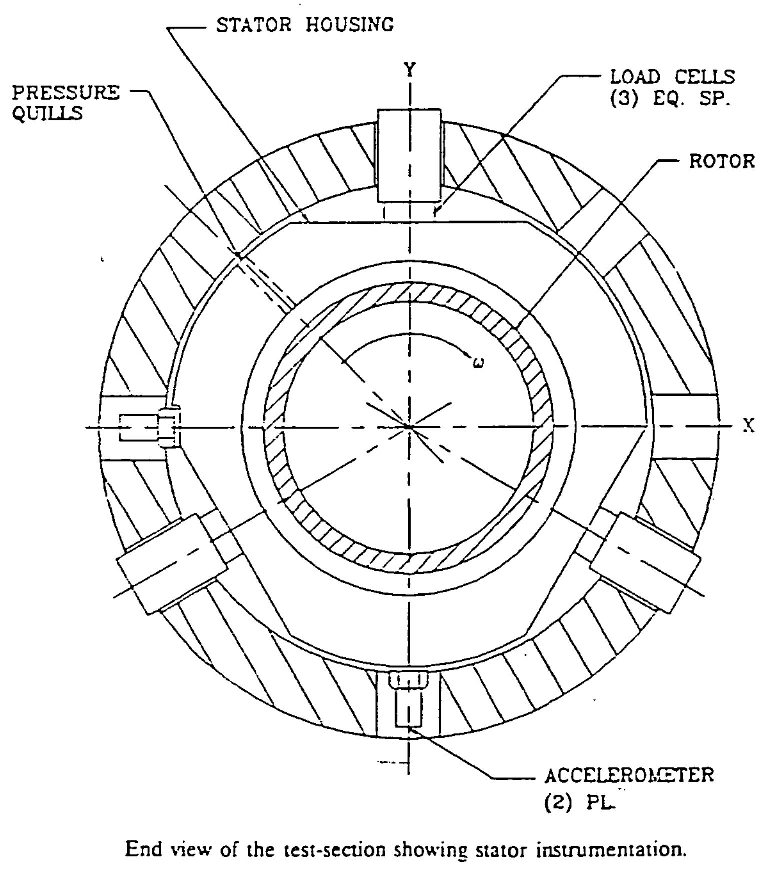
C_{ef} versus ΔP for sawtooth stators 1 through 4 ($h/C_r = 4.8$), a smooth stator, and the optimum-damping round-hole pattern stator



K_{ef} versus ΔP for sawtooth stators 1 through 4 ($h/C_r = 4.8$), a smooth stator, and the optimum-damping round-hole pattern stator



Test apparatus.



End view of the test-section showing stator instrumentation.

Research Objective

To obtain a better understanding of the flow field inside annular and labyrinth seals.

This information is important for:

1. Gaining insight into the turbulent flow fields, how they change with operating conditions, and how they effect leakage and stability.

2. Providing detailed flow field measurements for the purpose of comparing to and helping refine computational predictions of the flow field.

3-D LASER DOPPLER VELOCIMETER

Three Colors: Green, Blue, Violet
Three Bragg Cells: 40 MHz
8.5X and 3.75X Beam Expanders
450 mm Lenses
    1 X 1 X 4 Mil Measurement Volume

Simultaneously Measures:
    Mean Velocity Vector
        U, V, W, with Flow Reversals
    Entire Reynolds Stress Tensor
        u'u', v'v', w'w', u'v', u'w', v'w'
3-D Traverse System
Rotary Encoding System for Periodic Flow Mapping
Integrated Data Acquisition, Analysis, and Traverse Control

The 3-D LDA system is uniquely qualified for this study due to:

1. The small size of the probe volume (0.001" X 0.001" X 0.004").

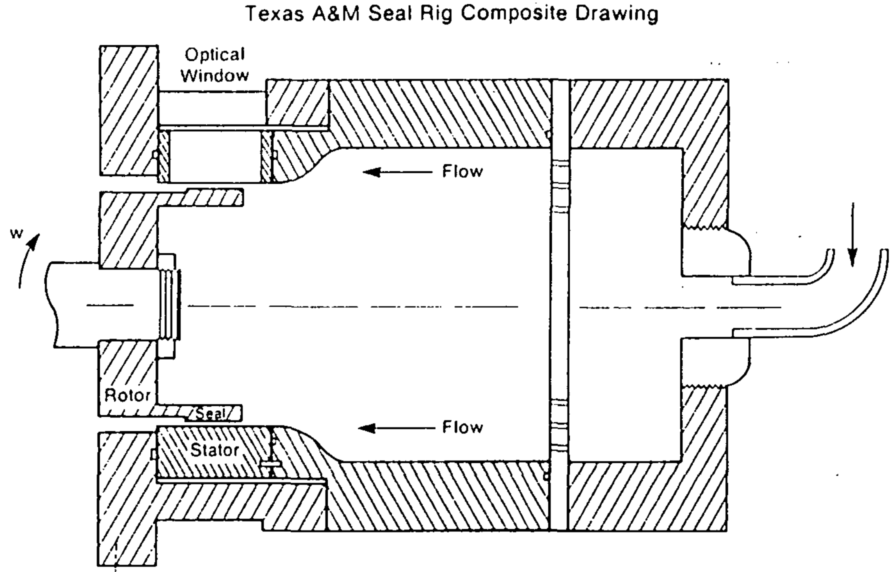
2. The non-invasive nature of the measurement device.

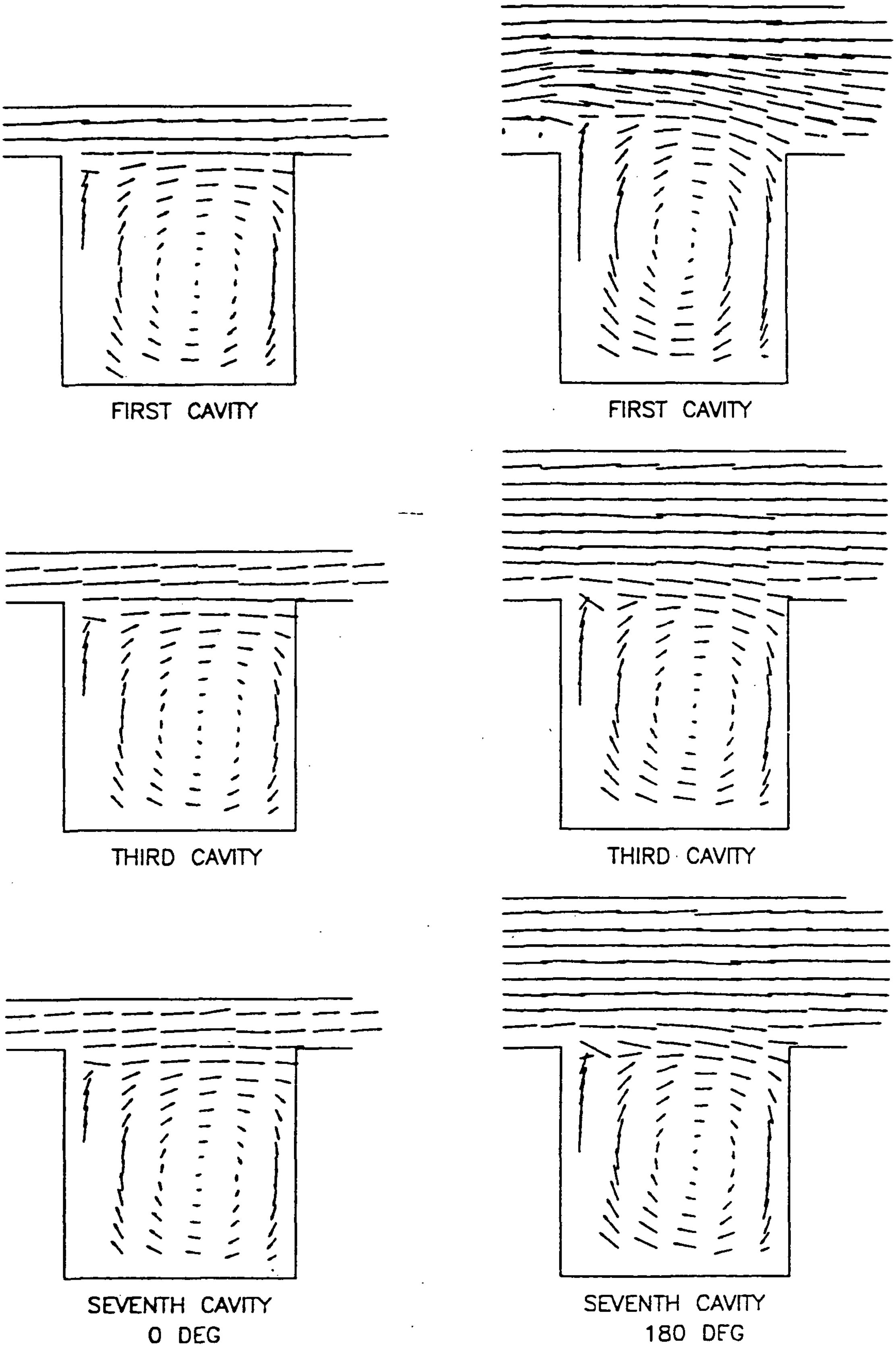
3. The ability to measure the mean velocity and the entire Reynolds stress tensor.

4. Ensemble averaging capability for use on whirling rotors.

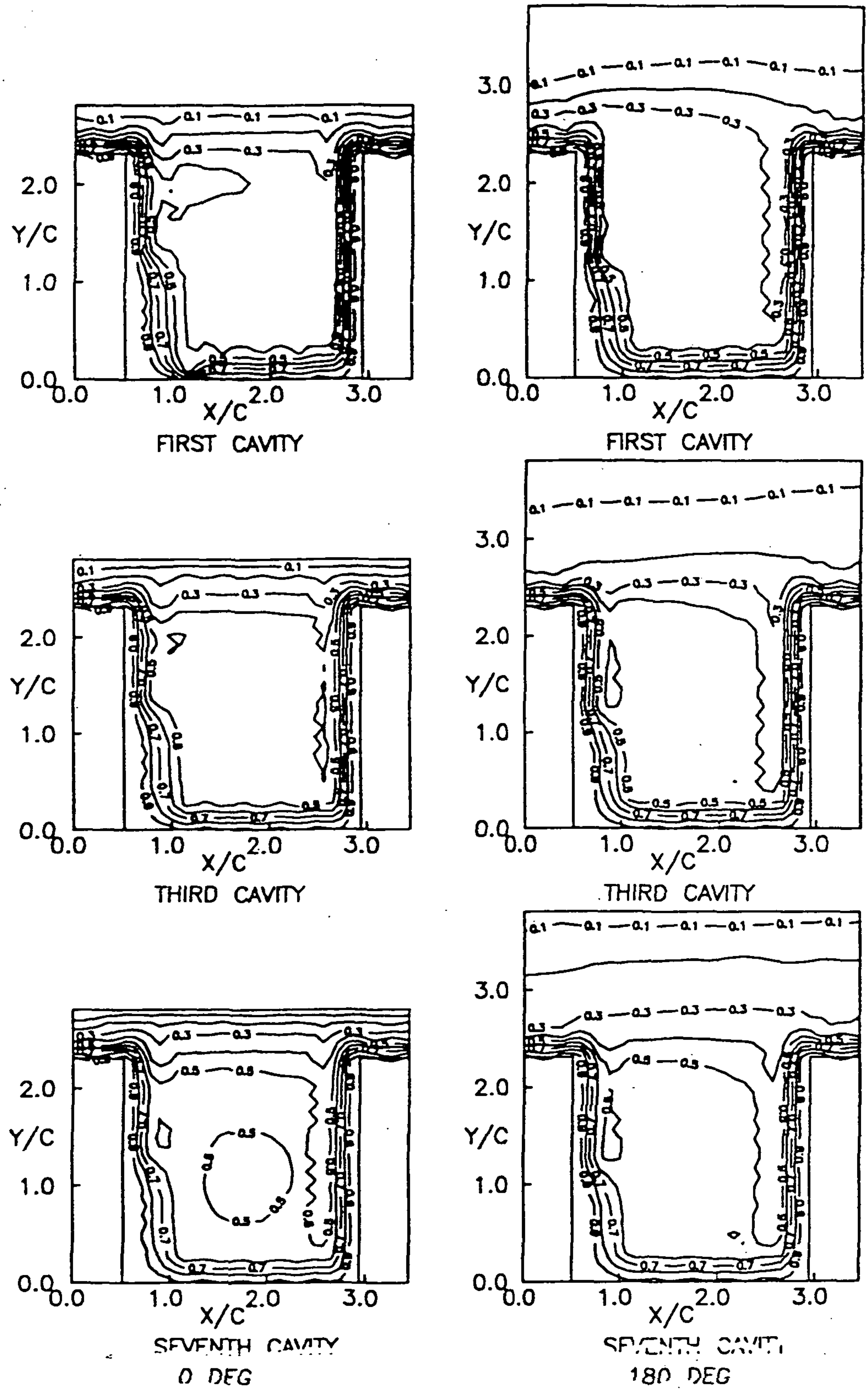
5. The ability to measure flow reversals.

Texas A&M Seal Rig Composite Drawing

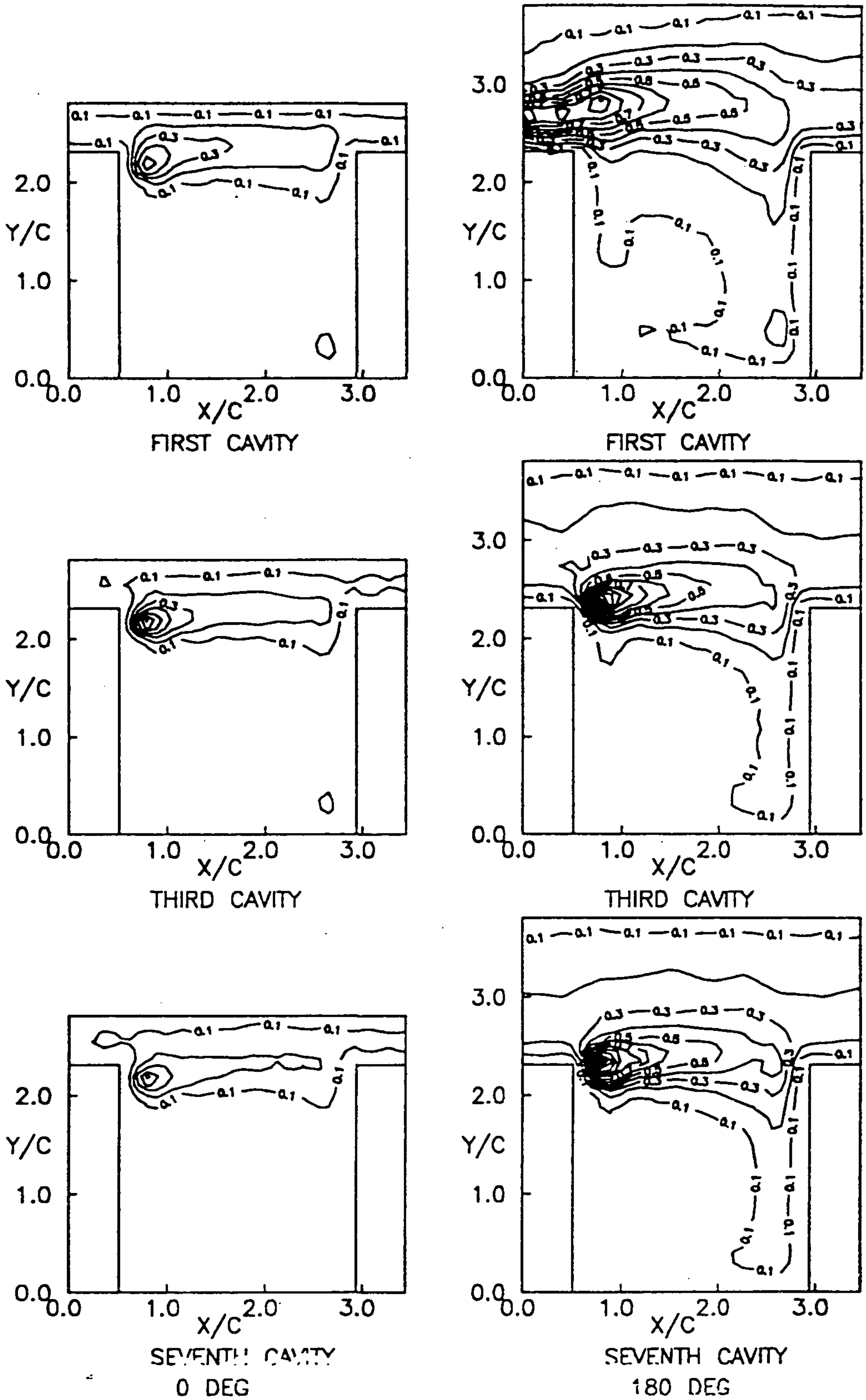




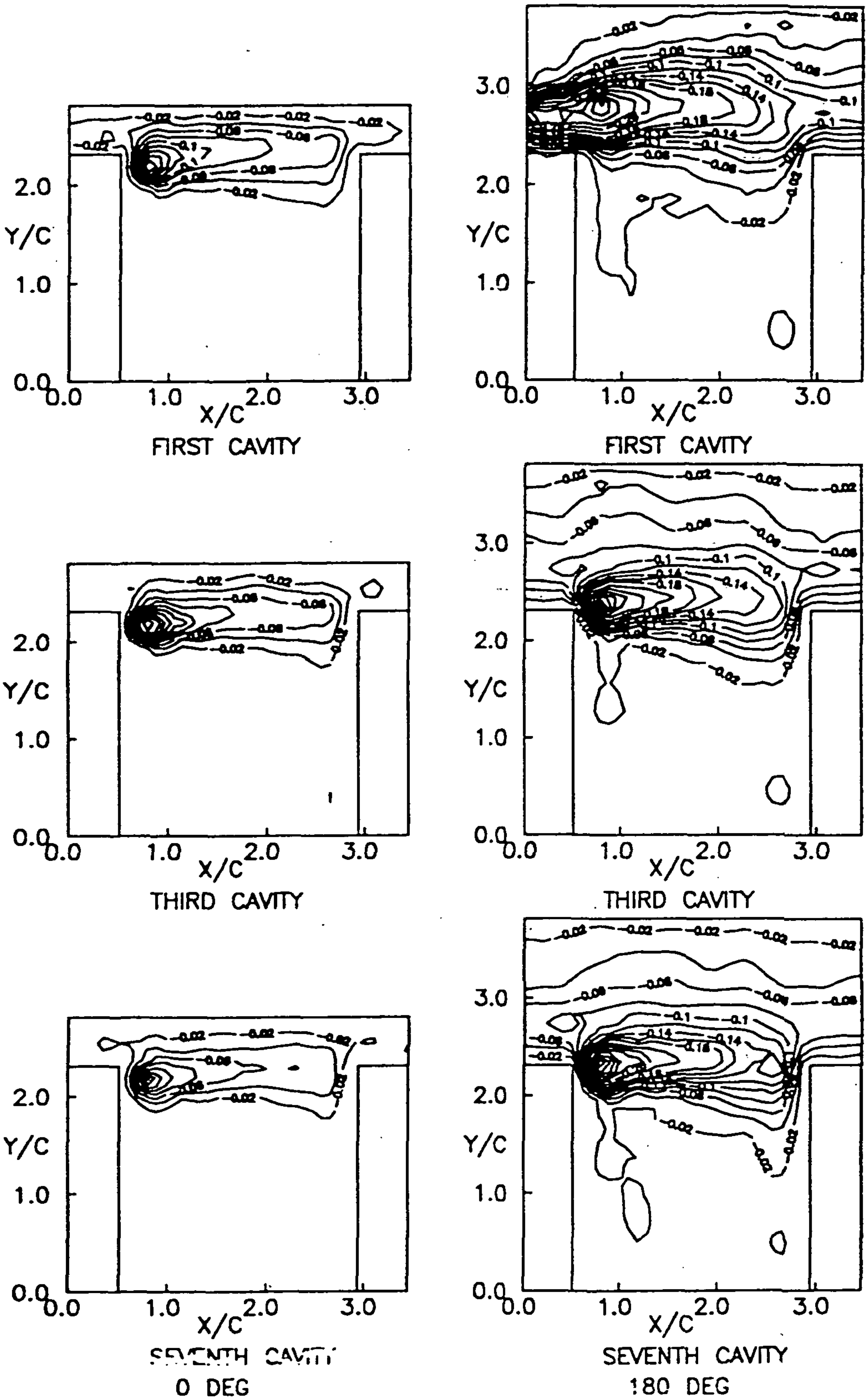
Mean Velocity Vector Fields, $\theta = 0^\circ$ and 180°.



Mean Azimuthal Velocity Contours, U_θ/W_{sh}, $\theta = 0°$ and $180°$.



Turbulent Kinetic Energy Contours, κ/U^2, $\theta = 0°$ and $180°$.



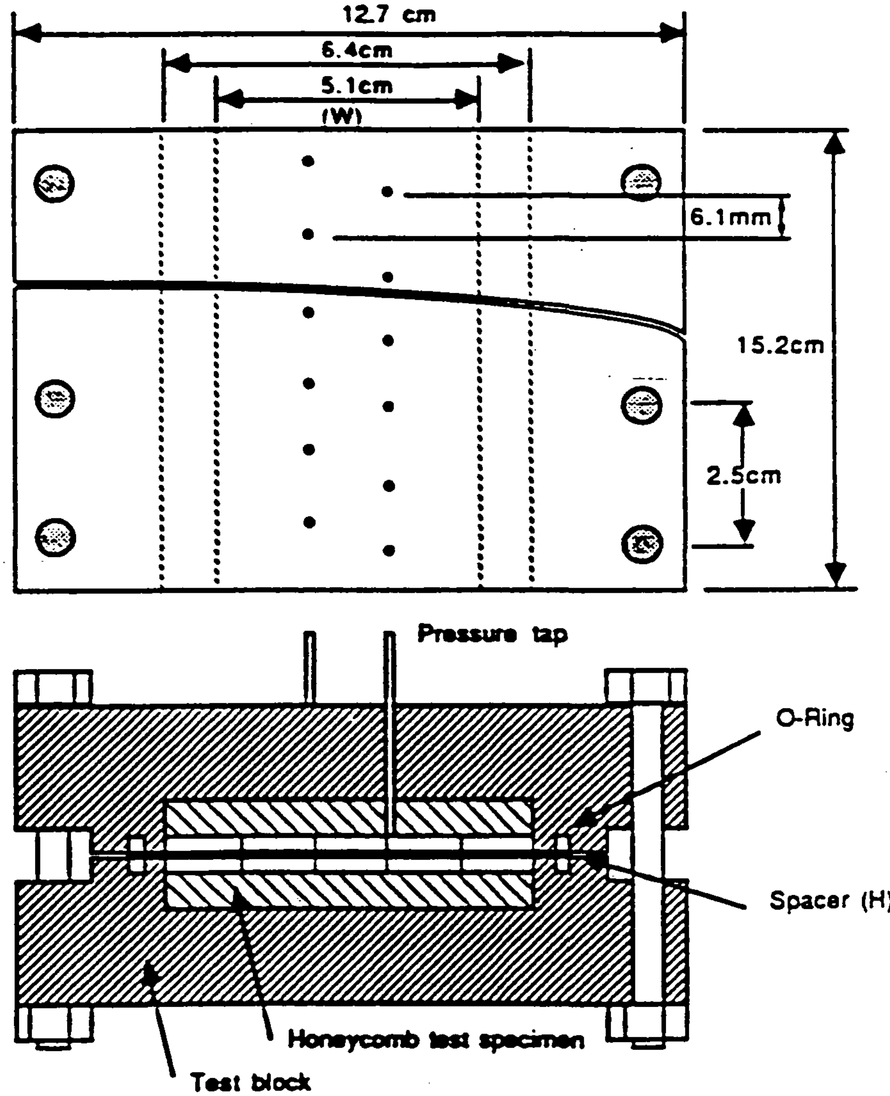
Reynolds Stress Contours, $u_x'u_r'/U^2$, $\theta = 0°$ and $180°$.

Measurements To Date:

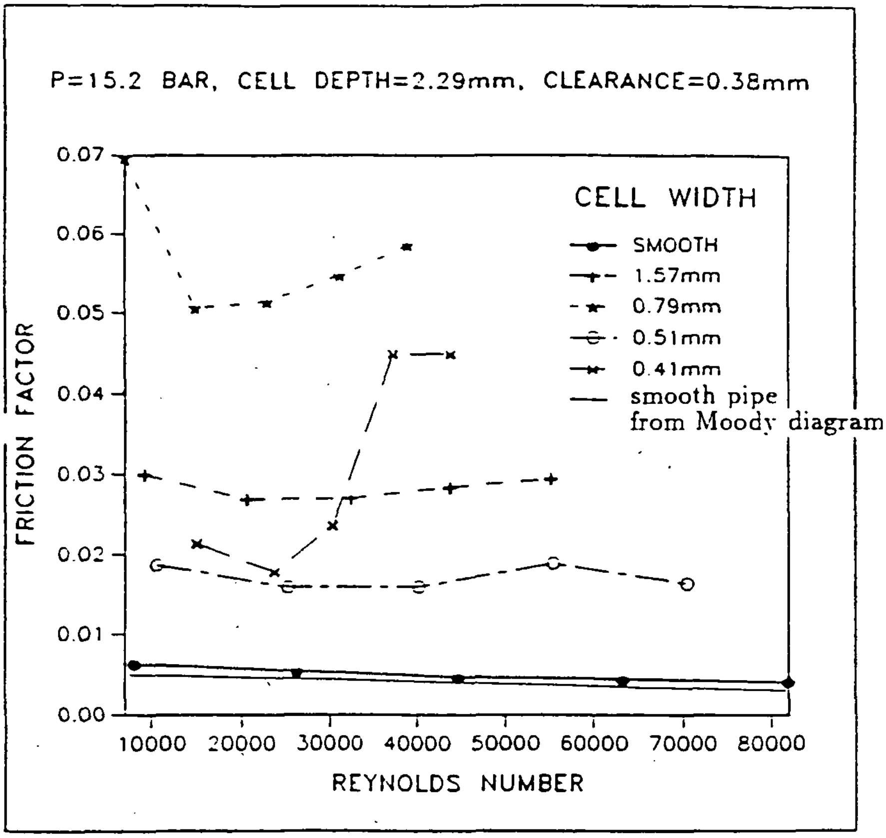
Type of Seal	Whirl	Eccen tricity	RPM	Re	Ta	Swirl	Plug
Annular	None	0	3,600	28,000	7,000	None	Yes
Annular	None	0	0	28,000	0	None	Yes
Annular	None	0.5	3,600	28,000	7,000	None	Yes
Annular	None	0.5	3,600	28,000	7,000	+45°	Yes
Annular	None	0.5	3,600	28,000	7,000	-45°	Yes
Annular	None	0.5	500	0	970	NA	NA
Annular	None	0.5	1,500	0	2,900	NA	NA
Annular	None	0.5	3,000	0	5,800	NA	NA
Labyrinth	None	0.5	3,600	28,000	7,000	None	None
Labyrinth	None	0	3,600	28,000	7,000	None	None
Labyrinth	None	0	3,600	28,000	7,000	+45°	Yes
Labyrinth	None	0	3,600	28,000	7,000	-45°	Yes
Labyrinth	None	0	5,300	15,000	10,300	None	None

Measurements To Be Made This Year

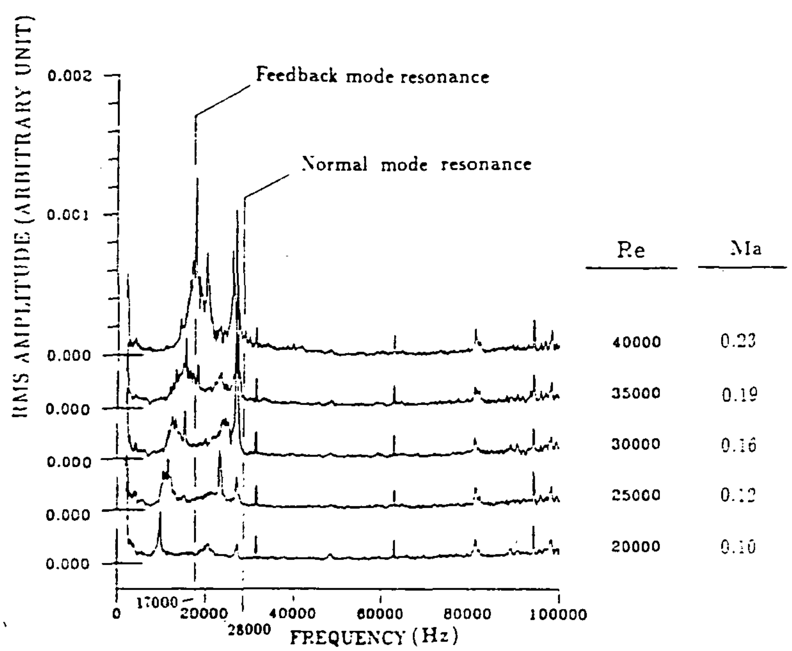
Type of Seal	Whirl Ratio	Eccen-tricity	RPM	Re	Ta	Swirl	Plug
Annular	1.0	0.5	3,600	28,000	7,000	None	Yes
Annular	1.0	0.5	5,300	15,000	10,300	None	Yes
Labyrinth	1.0	0.5	3,600	28,000	7,000	None	Yes
Labyrinth	1.0	0.5	5,300	15,000	10,300	None	Yes



Flat plate tester assembly.

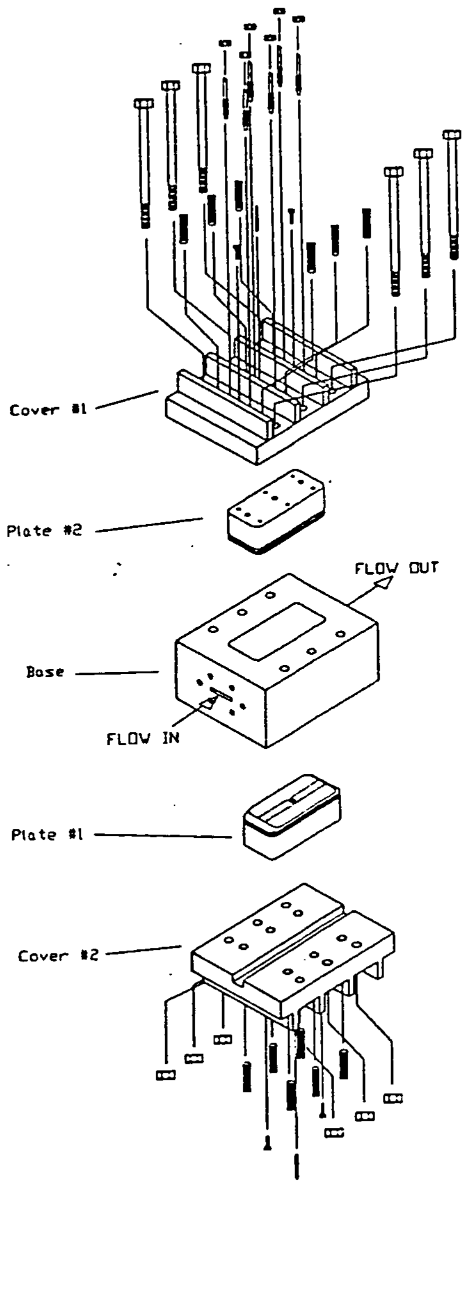


A typical friction-factor pattern.

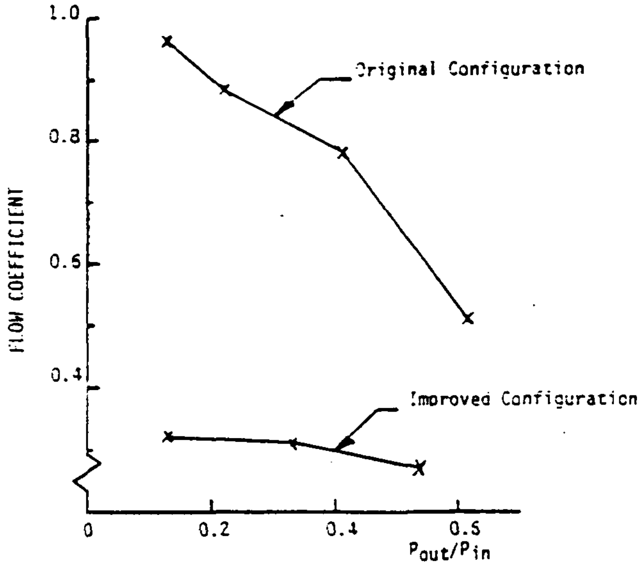


Frequency spectra for test number 7.

(b=1.57, d=3.05 and H=0.25mm)

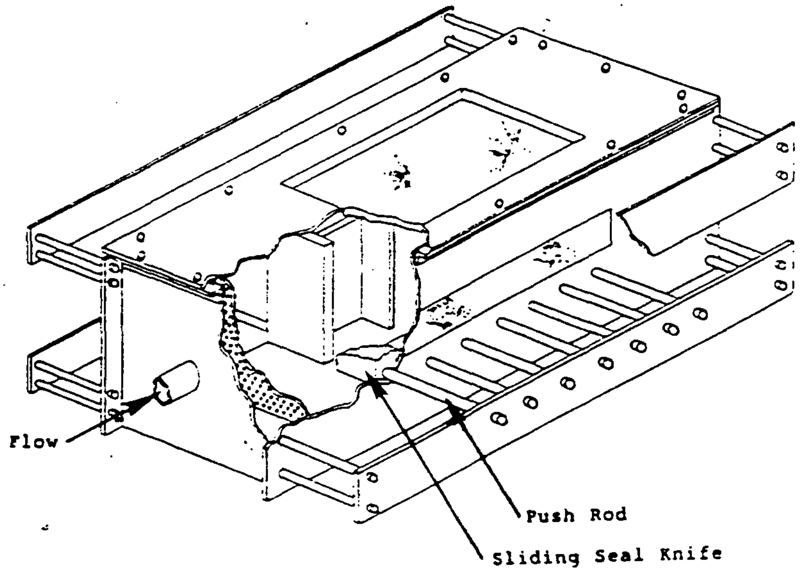

Cover #1
Plate #2
FLOW OUT
Base
FLOW IN
Plate #1
Cover #2

MEASURED LABYRINTH LEAKAGE REDUCTION FROM CFD DESIGN (Rhode, et al.)



Measured leakage rate characteristic for the impeller inlet seal of the space shuttle fuel pump comparing the new CFD design with the current design.

NEW, ADJUSTABLE-GEOMETRY LABYRINTH RIG : LEAKAGE & FLOW VISUALIZATION



Sketch of the quick-change geometry labyrinth seal water test rig

Correlate Large-Scale With Full-Scale Design Results

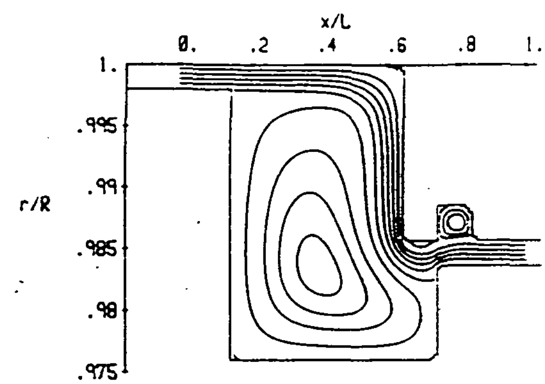
A. Design and Construct Rig (Variable c and Rotor Position)
B. Fabricate Several Advanced Land and Knifed Surfaces
C. Obtain Scale Relationships for Limiting Cases:
   1. With and Without Rub Grooves
   2. Standard and Sharp Corners
   3. Standard and Advanced Knife Tip Shapes

Advanced Geometry Effects on $\dot{m}$ and $\dot{m}$-Variation

A. Standard Corners (R=0.003 in)
   Obtain design data, including $\dot{m}$ Variation with a change of: (a) clearance and (b) relative rotor position for:

Record:
$\dot{m}$
VCR Movies
Photographs
F.D. Solution
Five-Hole Pitot

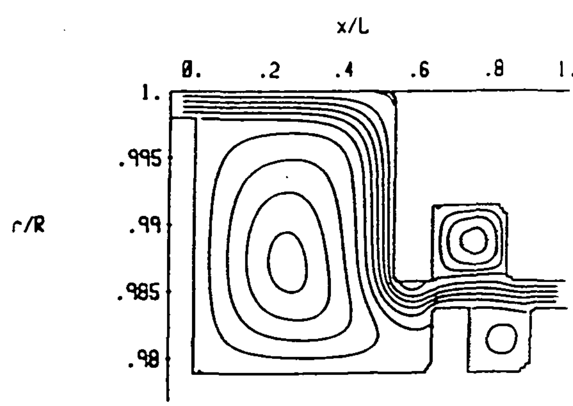
1. Baseline geometry
2. Various annular grooves
   (stator and stator + rotor)
3. Various step heights s
4. Various knife thickness t_2
5. Various knife angles



B. Sharper Corners (R=0.0015 in)
   (Same as A)

Record:
$\dot{m}$
VCR Movies
Photographs
F.D. Solution
Five-Hole Pitot

1. Baseline geometry
2. Various annular grooves
   (stator and stator + rotor)
3. Various step heights s
4. Various knife thickness t_2
5. Various knife angles



Research Objectives on Annular Seals for 1991-92 at Texas A&M University.

P.I. Dr. L. San Andres

- Analysis of thermal effects on the performance and dynamic force response of high pressure annular seals handling cryogenic liquids.
  Adiabatic and Constant Surface Temps.

  Important for LOX due to higher viscosity and lower specific heat than LH2.

- Development of a unified theory for liquid, gas, and two-phase flow annular seals.

- Calculation of dynamic force and moment coeffs. for displacements and angular motions.

- Analysis of high pressure OIL SEAL RINGS for compressors: single and multi-land seals.
  Calculation of lock-up forces and face fricton factors.

- Study of Damper Seals and Hydrostatic Bearings as support elements in cryogenic turbopumps.

- Improved Seal Entrance Factors by CFM simulations hseal.f

Analysis of Turbulent Flow Annular Pressure Seals

Dr. L. SanAndres, Texas A&M University

- 2-D Bulk Flow Model for barotropic liquids
  Surface roughness: Moody's friction factor
- Arbitrary Axial Clearance Distribution:
  uniform, taper, step, wavy via spline, and stator wear profile
- Arbitrary Static Eccentricity Ratio, $0 \leq e/c \leq 1$
- Realistic liquid properties for LH2, LN2, LOX, CH4

Program calculates:
Leakage, Fluid Film Forces, Torque, and
Rotordynamic Coefficients: Kij, Cij, Mij

- *Solution scheme based on efficient CFM methods and improved approximate guesses for fast convergence.*
- Program can be used for flooded or grooved journal bearings.
- Laminar and/or Turbulent Seals and Bearings