S1-37

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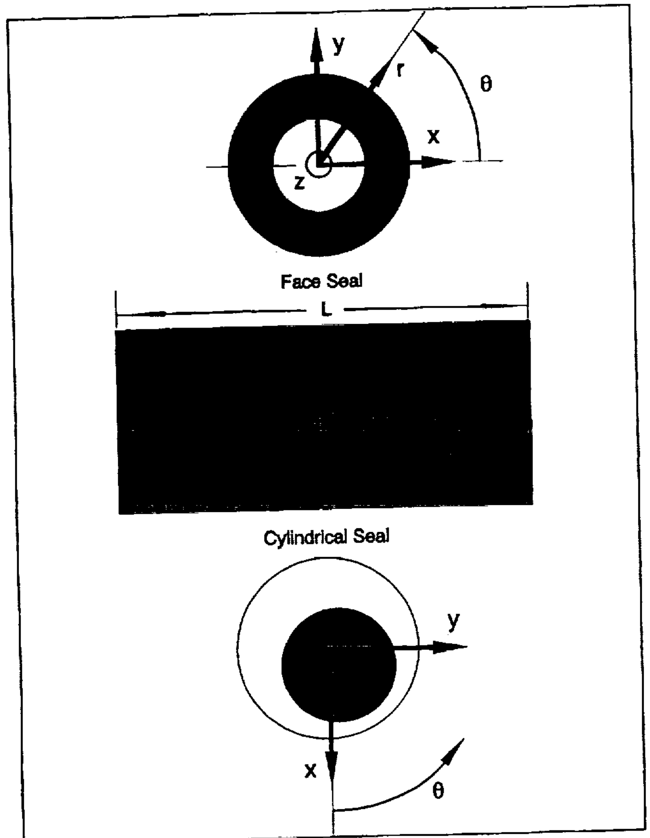
14

PRESENTATION OF COMPUTER CODE SPIRALI FOR INCOMPRESSIBLE, TURBULENT, PLANE AND SPIRAL GROOVED CYLINDRICAL AND FACE SEALS

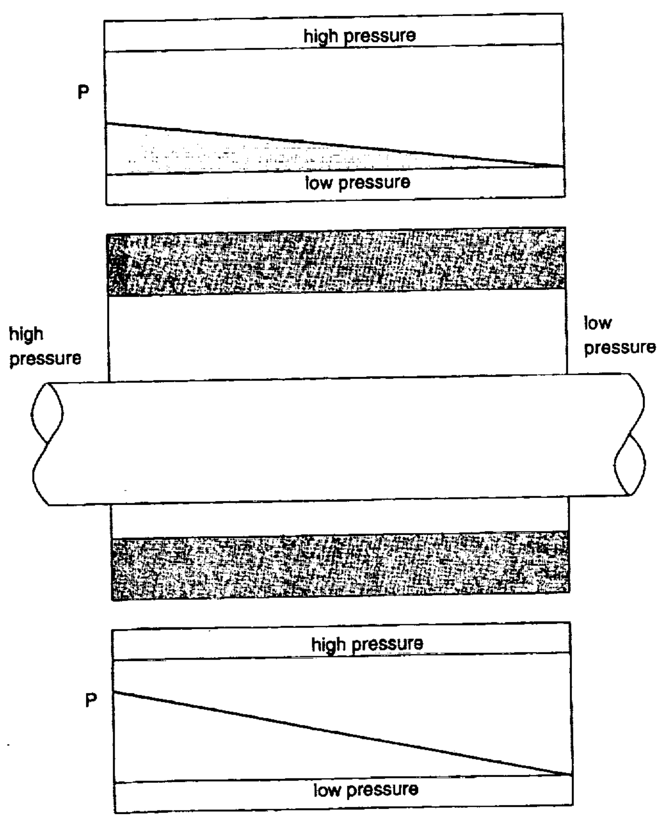
Jed A. Walowit
Jed A. Walowit, Inc.
Clifton Park, New York

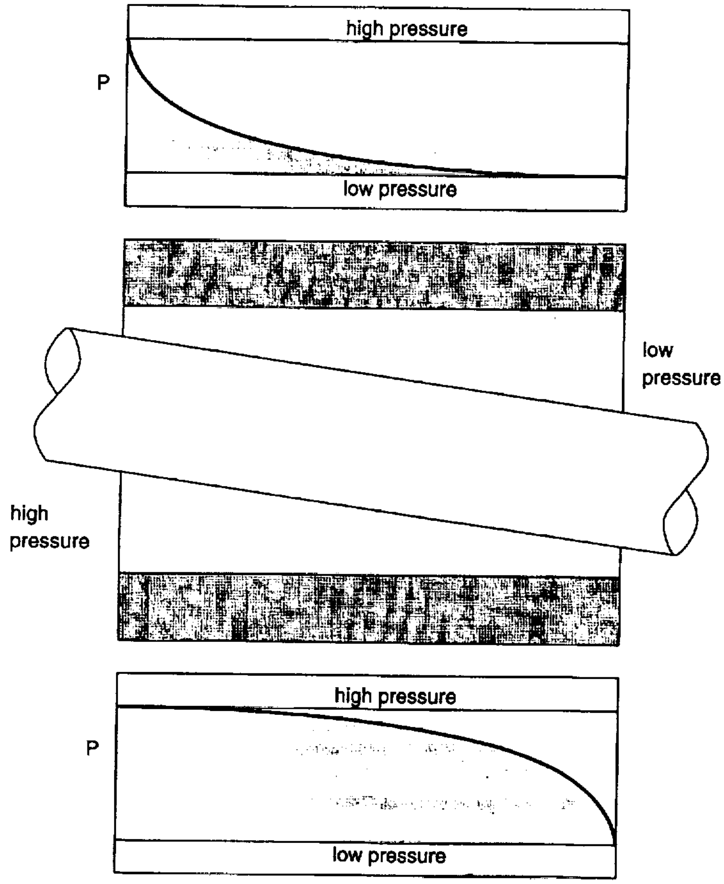
OVERALL CAPABILITIES OF PROGRAM

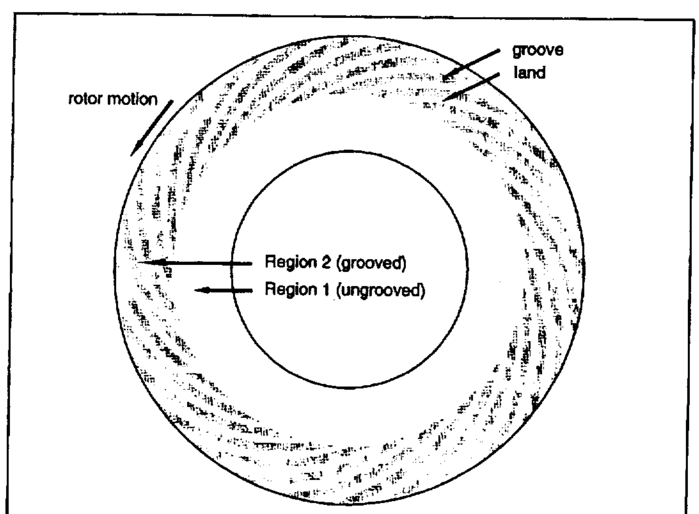
- Computes rotordynamic coefficients, flow and power loss for cylindrical and face seals
- Treats turbulent and laminar, Couette and Poiseuille dominated flows
- Fluid inertia effects included
- Rotordynamic coefficients in 3 (face) or 4 (cylindrical) degrees of freedom
- Includes effects of spiral grooves
- User definable transverse film geometry including circular steps and grooves
- Independent user definable friction factor models for rotor and stator
- User definable loss coefficients for sudden expansions and contractions



Coordinate system for seal analysis.



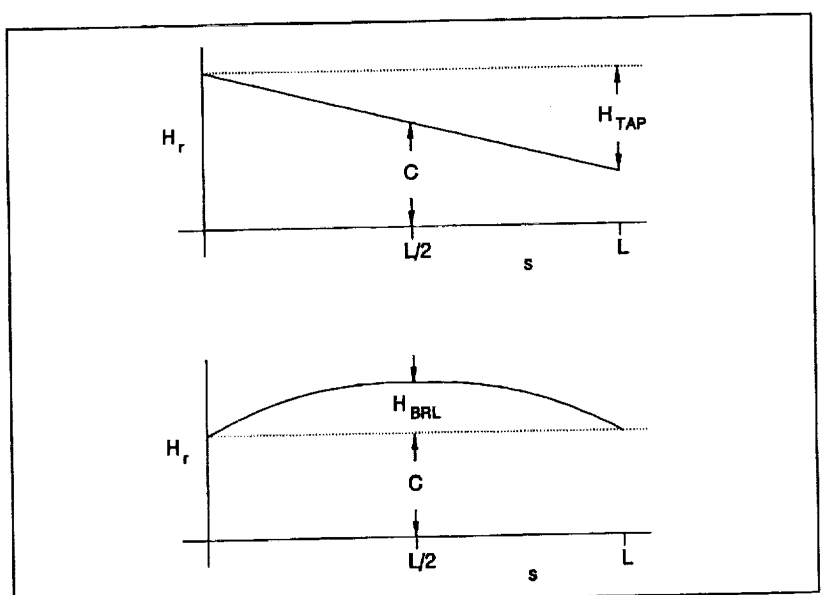




Face seal stator with inward pumping grooves

ASSUMPTIONS

- Incompressible and isothermal flow
- Film thickness small in comparison with other geometric parameters
- Bulk flow turbulence model
- Loss coefficients used to treat inertia effects at film discontinuities
- Axisymmetric primary flow with small perturbations theory used for transient and circumferential effects
- Narrow groove theory used for spiral grooves with inertia treated globally
- No cavitation



Parameters for characterizing quadratic film variation.

BULK FLOW EQUATIONS FOR TURBULENT FLOW

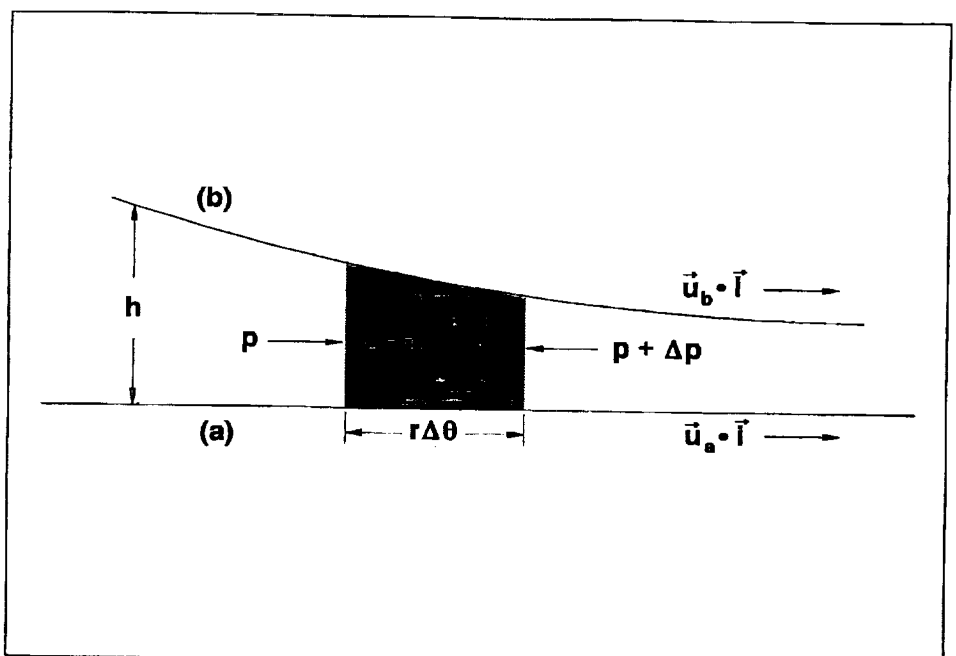
integrated momentum

$$\rho h\left(\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial s}+\frac{u}{r}\frac{\partial u}{\partial \theta}+\frac{uvI_f}{r}\right)=-\frac{h}{r}\frac{\partial p}{\partial \theta}+(\vec{\tau}_b-\vec{\tau}_a)\cdot\vec{i}\quad ,$$

$$\rho h\left(\frac{\partial v}{\partial t}+v\frac{\partial v}{\partial s}+\frac{u}{r}\frac{\partial v}{\partial \theta}-\frac{u^2I_f}{r}\right)=-h\frac{\partial p}{\partial s}+(\vec{\tau}_b-\vec{\tau}_a)\cdot\vec{j}\quad .$$

integrated continuity

$$\frac{1}{r}\frac{\partial}{\partial s}(rvh)+\frac{1}{r}\frac{\partial}{\partial \theta}(uh)+\frac{\partial h}{\partial t}=0\quad .$$



Velocities and forces on a differential element in the θ direction.

SHEAR STRESS AND FRICTION FACTOR RELATIONSHIPS

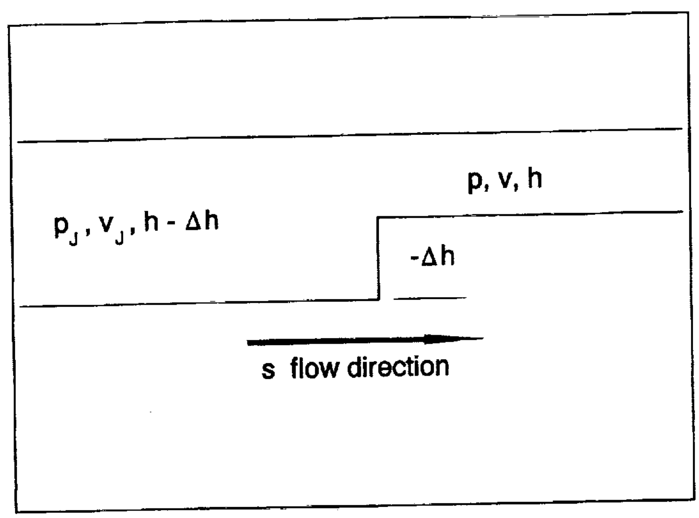
$$\vec{\tau}_a = \frac{1}{2}\rho\,|\vec{u}-\vec{u}_a|\,f_a\!\left(\frac{2h\rho\,|\vec{u}-\vec{u}_a|}{\mu}\right)(\vec{u}-\vec{u}_a) = \frac{1}{4}\frac{\mu}{h}R_a f_a(R_a)\,(\vec{u}-\vec{u}_a) \quad ,$$

$$\vec{\tau}_b = -\frac{1}{2}\rho\,|\vec{u}-\vec{u}_b|\,f_b\!\left(\frac{2h\rho\,|\vec{u}-\vec{u}_b|}{\mu}\right)(\vec{u}-\vec{u}_b) = -\frac{1}{4}\frac{\mu}{h}R_b f_b(R_b)\,(\vec{u}-\vec{u}_b) \quad ,$$

$$R_a = 2h\,|\vec{u}-\vec{u}_a|\,\rho/\mu \quad , \quad R_b = 2h\,|\vec{u}-\vec{u}_b|\,\rho/\mu \quad .$$

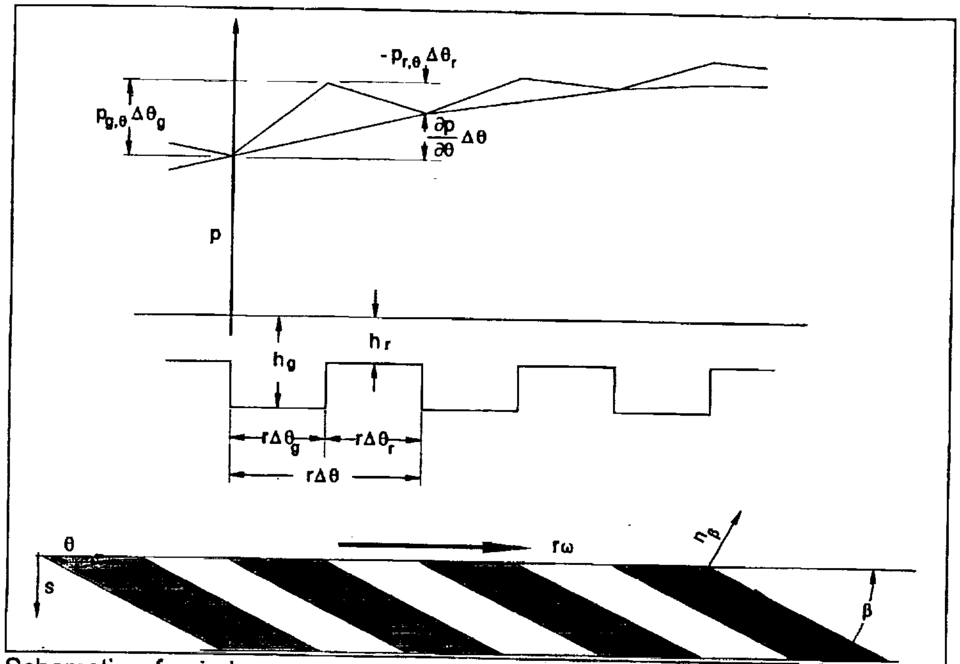
$$f_a(R_a) = n_0 R_a^{m_0} \; , \quad f_b(R_b) = n_0 R_b^{m_0} \; , \quad \text{Hirs - Blasius}$$

$$f_{a,b} = 0.001375\left[1 + \left(10^4\frac{k_{a,b}}{h} + \frac{10^6}{R_{a,b}}\right)^{\frac{1}{3}}\right] \quad , \quad \text{Moody}$$

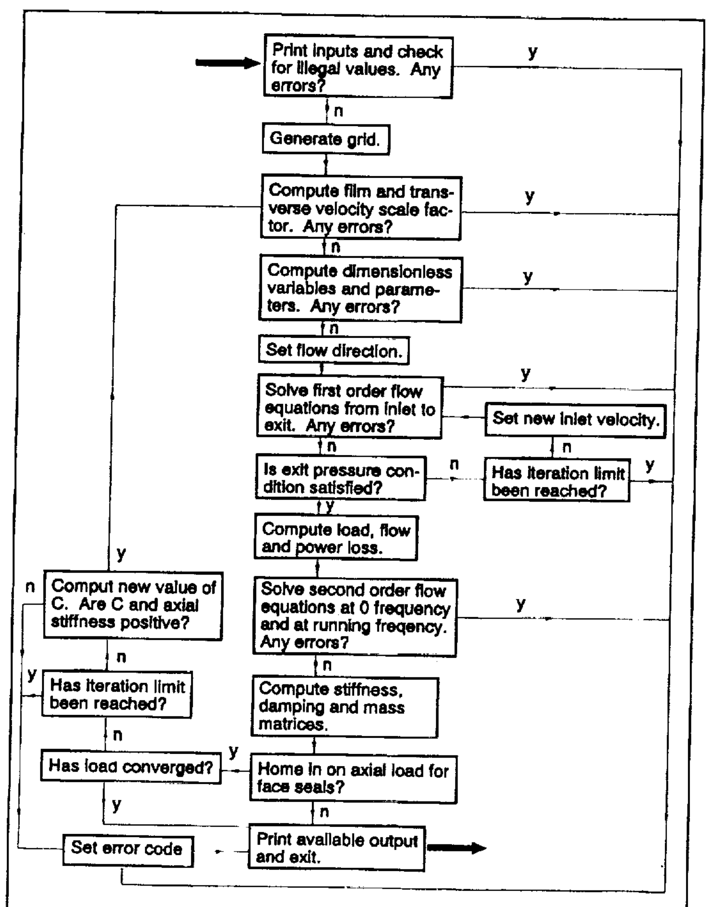


$$p_J + \frac{1}{2}\rho v_J^2 = p + \frac{1}{2}\rho v^2(1+\xi) \quad @\; s = s_J \quad .$$

$$\xi = \begin{cases} \zeta(\bar{R},\bar{h},\bar{v}) & , \quad \Delta\bar{h} < 0 \text{ (contraction)} \\ \left(1 - \dfrac{\bar{h}}{\bar{h}-\Delta\bar{h}}\right)^2 & , \quad \Delta\bar{h} \geq 0 \text{ (expansion)} \end{cases}$$



Schematic of spiral groove parameters, global and local pressures.



Flow diagram for overall logic used in computations

(CASE 1) Cylindrical seal with grooves, laminar, no press. grad.

```
&INPUTS
   TITLE  = 'Cylindrical seal with grooves, laminar, no press. grad.'
   IFACE  = 0                ISIUN  = 0
   IGROT  = 0                NOI    = 2                IFLOW  = 1
   RO     = 1.0000E+00       EL     = 5.0000E-01       C      = 1.0000E-03
   RPM    = 5.0000E+04       RPMO   = 2.5000E+04       RPMD   = 0.0000E+00
   PLEG   = 0.0000E+00       PRIG   = 0.0000E+00       FZD    = 0.0000E+00
   VISC   = 3.0000E-08       DENS   = 0.0000E+00
   EMA    = -2.5000E-01      ENA    = 7.9100E-02
   EMB    = -2.5000E-01      ENB    = 7.9100E-02
   HTAP   = 0.0000E+00       HBRL   = 0.0000E+00
   TOLH   = 1.0000E-04       TOLV   = 1.0000E-05       DUT    = 1.0000E-06
   IHOME  = 0                NITH   = 10               NITV   = 30
   NREG   = 2                NRSUB  = 50   50
   ELFR   = 5.0000E-01  5.0000E-01
   ALPI   = 5.0000E-01  0.0000E+00
   BETI   = 2.5000E+01  0.0000E+00
   DELT   = 2.0000E-03  0.0000E+00
   ZET    = 0.0000E+00  0.0000E+00
```

CYLINDRICAL SEAL, INERTIA NEGLECTED

LENGTH, DIAMETER, CLEARANCE = 5.0000E-01, 2.0000E+00, 1.0000E-03 (IN)

ROTOR, SWIRL AND DIST. SPEEDS = 5.0000E+04, 2.5000E+04, 0.0000E+00 (RPM)

PRESSURE AT START, END AXIAL BOUNDARIES = 0.0000E+00, 0.0000E+00 (PSI)

VISCOSITY = 3.0000E-08 (PSI-SEC), DENSITY = 0.0000E+00 (LB-SEC/IN4)

ERROR CODE = 0, ITERATIONS IN PRIMARY FLOW = 2

FLOW = 1.1506E+00 (IN**3/SEC)

TORQUE = 4.3909E-01 (IN-LB), FILM POWER LOSS = 3.4835E-01 (HP)

AXIAL REYNOLDS NUMBER = 0.0000E+00
CIRC. REYNOLDS NUMBERS FOR ROTOR AT SEAL ENDS = 0.0000E+00, 0.0000E+00

DYNAMIC COEFFICIENTS (FORCE UNIT / DISP. UNIT)

DISP.	x (IN)	y (IN)	phi (RAD)	psi (RAD)	FORCE UNIT
Kx	2.7021E+04	1.3511E+04	-6.3081E+02	-1.2959E+03	LB
Ky	-1.3511E+04	2.7021E+04	1.2959E+03	-6.3081E+02	LB
Kphi	2.3387E+02	-6.5242E+01	1.6699E+02	8.6419E+01	IN-LB
Kpsi	6.5242E+01	2.3387E+02	-8.6419E+01	1.6699E+02	IN-LB
Bx	5.1297E+00	7.8477E-11	-2.0242E-02	1.3973E-01	LB-SEC
By	-7.8477E-11	5.1297E+00	-1.3973E-01	-2.0242E-02	LB-SEC
Bphi	-2.0242E-02	-1.3973E-01	3.0437E-02	3.8319E-13	IN-LB-SEC
Bpsi	1.3973E-01	-2.0242E-02	-3.8319E-13	3.0437E-02	IN-LB-SEC
Ax	4.7708E-19	4.0552E-18	7.4544E-20	-1.7891E-19	LB-SEC2
Ay	-4.0552E-18	4.7708E-19	1.7891E-19	7.4544E-20	LB-SEC2
Aphi	1.1927E-19	5.4045E-20	-1.8636E-20	3.3545E-20	IN-LB-SEC2
Apsi	-5.4045E-20	1.1927E-19	-3.3545E-20	-1.8636E-20	IN-LB-SEC2

Comparison with results published by D. W. Childs (1983)

	$u_{in}=r_0\omega/2$, L/D=.2		$u_{in}=r_0\omega/2$, L/D=1		$u_{in}=0$, L/D=.2		$u_{in}=0$, L/D=1	
	SPIRALI	Childs	SPIRALI	Childs	SPIRALI	Childs	SPIRALI	Childs
Q (cm^3/s)	4006.	4019.	1771.	1779.	3989.	4019.	1767.	1779.
K_{xx} (MN/m)	18.90	18.65	10.79	9.756	18.58	18.52	13.25	12.48
K_{xy} (MN/m)	4.127	4.213	91.78	94.05	-.3027	-.3000	75.18	77.61
B_{xx} (KN-s/m)	21.89	22.35	487.2	500.6	21.89	22.47	489.5	502.2
B_{xy} (KN-s/m)	1.140	1.206	102.9	107.5	.8518	.8932	89.26	93.39
A_{xx} (kg)	3.020	3.200	272.6	285.3	3.003	3.189	272.1	285.3

DEFINITIONS OF COEFFICIENTS

Overall Seal Discharge Coefficient

$$C_d = \frac{\Delta P}{\frac{1}{2}\rho V^2}$$

Radial Force Coefficient

$$-f_r = K + c\omega - M\omega^2 = K_{ef} - M_{ef}\omega^2$$

Tangential Force Coefficient

$$-f_\theta = C\omega - k = C_{ef}\omega$$

```
TITLE  =  'Childs,Nolan & Kilgore Stator 1, 25% swirl, 1000 RPM'
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IGROT  =  0                NOI    =  0                IFLOW  =  0
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RPM    =  1.0000E+03       RPMO   =  2.5000E+02       RPMD   =  0.0000E+00
PLEG   =  0.2500E+06       PRIG   =  0.0000E+00       FZD    =  0.0000E+00
VISC   =  1.5400E-04       DENS   =  1.5700E+03
EMA    = -2.5000E-01       ENA    =  7.9100E-02
EMB    = -2.5000E-01       ENB    =  7.9100E-02
HTAP   =  0.0000E+00       HBRL   =  0.0000E+00
TOLH   =  1.0000E-04       TOLV   =  1.0000E-05       DUT    =  1.0000E-06
IHOME  =  0                NITH   =  10               NITV   =  30
NREG   =  19
NRSUB  =  5 5 5 5 5 5 5 5 5 5
          5 5 5 5 5 5 5 5 5
ELFR   =  .1005 .047 .047 .047 .047 .047 .047 .047 .047 .047
          .047 .047 .047 .047 .047 .047 .047 .047 .1005
ALPI   =  1. 1. 1. 1. 1. 1. 1. 1. 1. 1.
          1. 1. 1. 1. 1. 1. 1. 1. 1.
BETI   =  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
          0. 0. 0. 0. 0. 0. 0. 0. 0.
DELT   =  0. 3.8E-4 0. 3.8E-4 0. 3.8E-4 0. 3.8E-4 0. 3.8E-4 0. 3.8E-4
          0. 3.8E-4 0. 3.8E-4 0. 3.8E-4 0.
ZET    =  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
          0. 0. 0. 0. 0. 0. 0. 0. 0.
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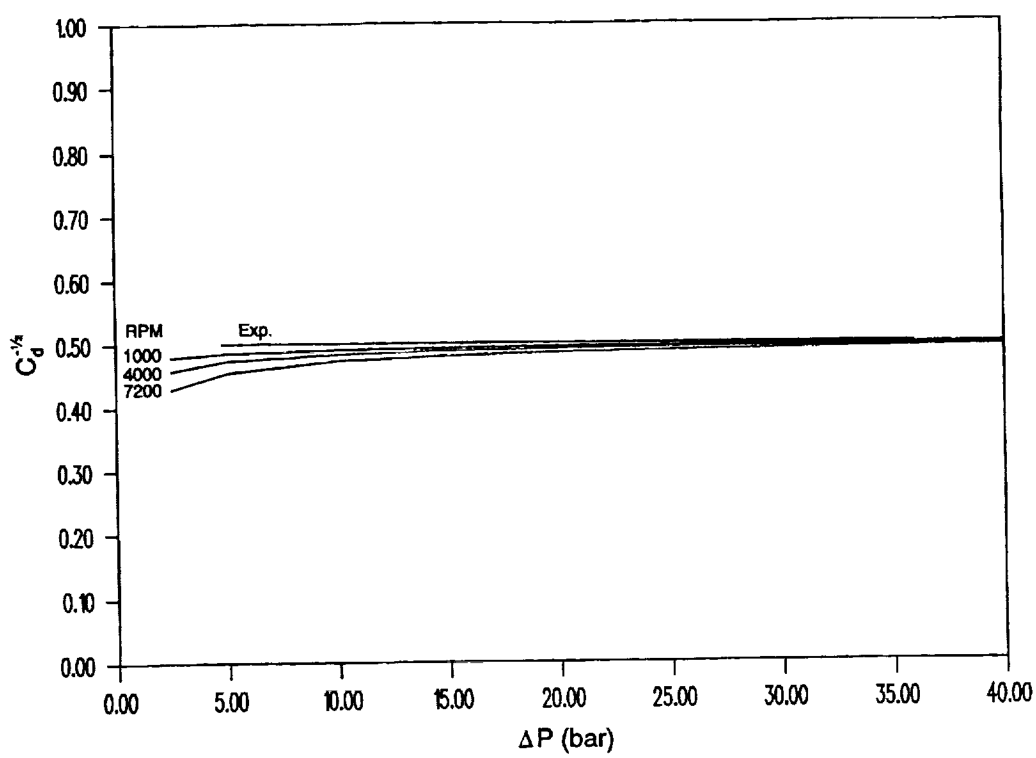
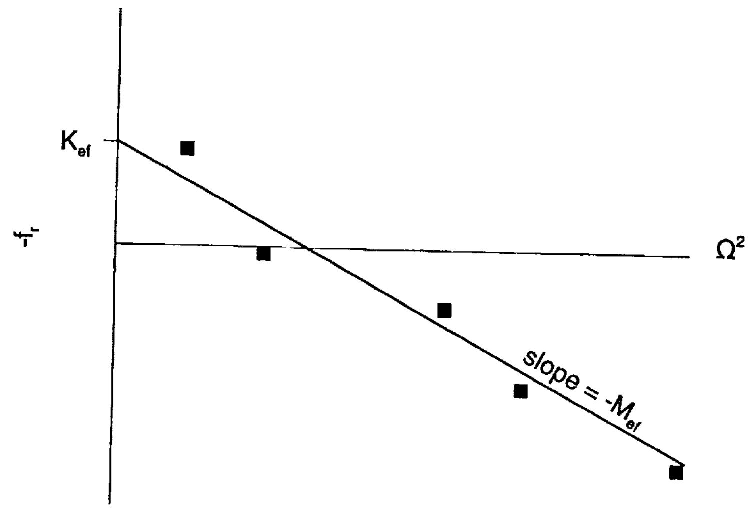
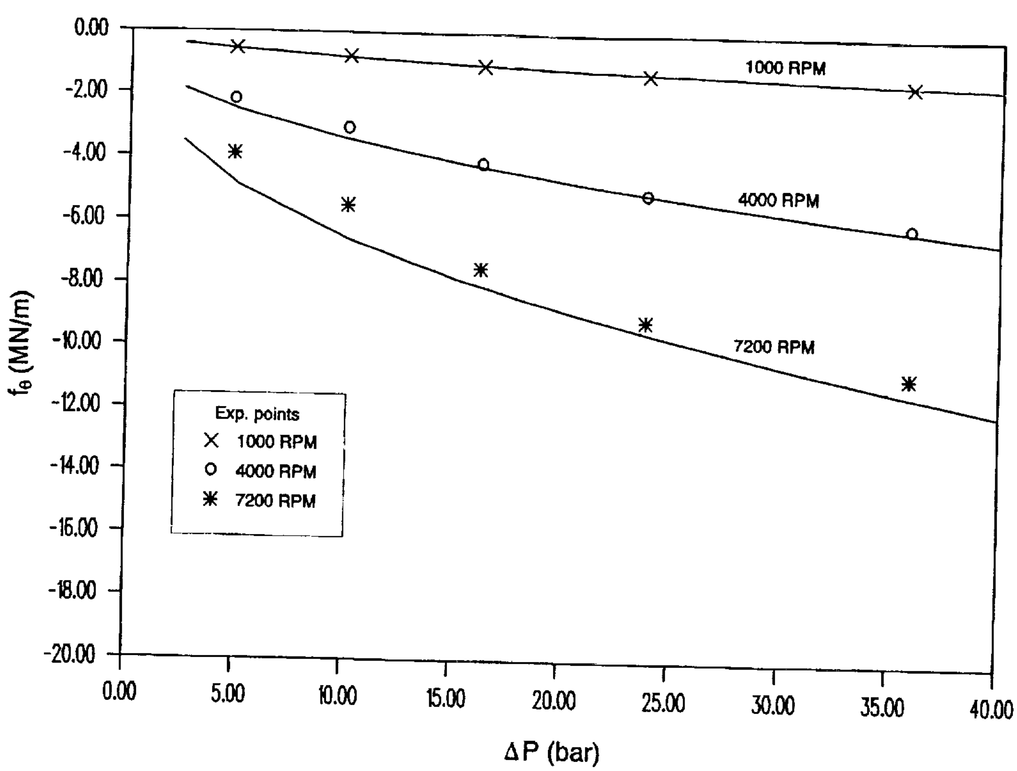


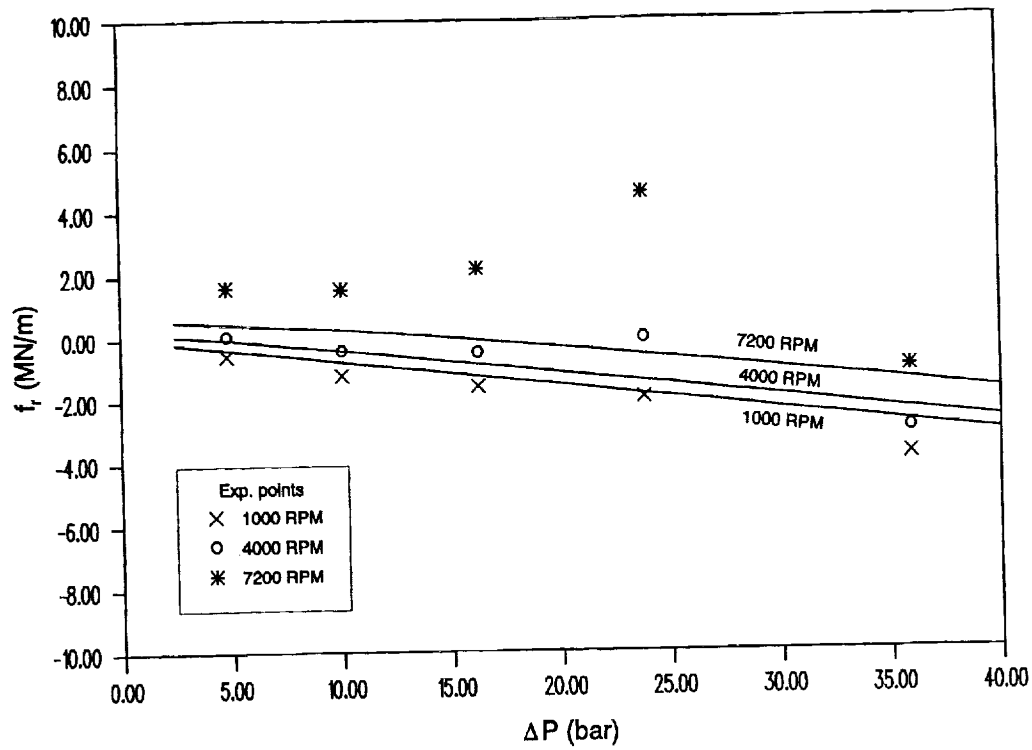
Dimensionless axial flow rates



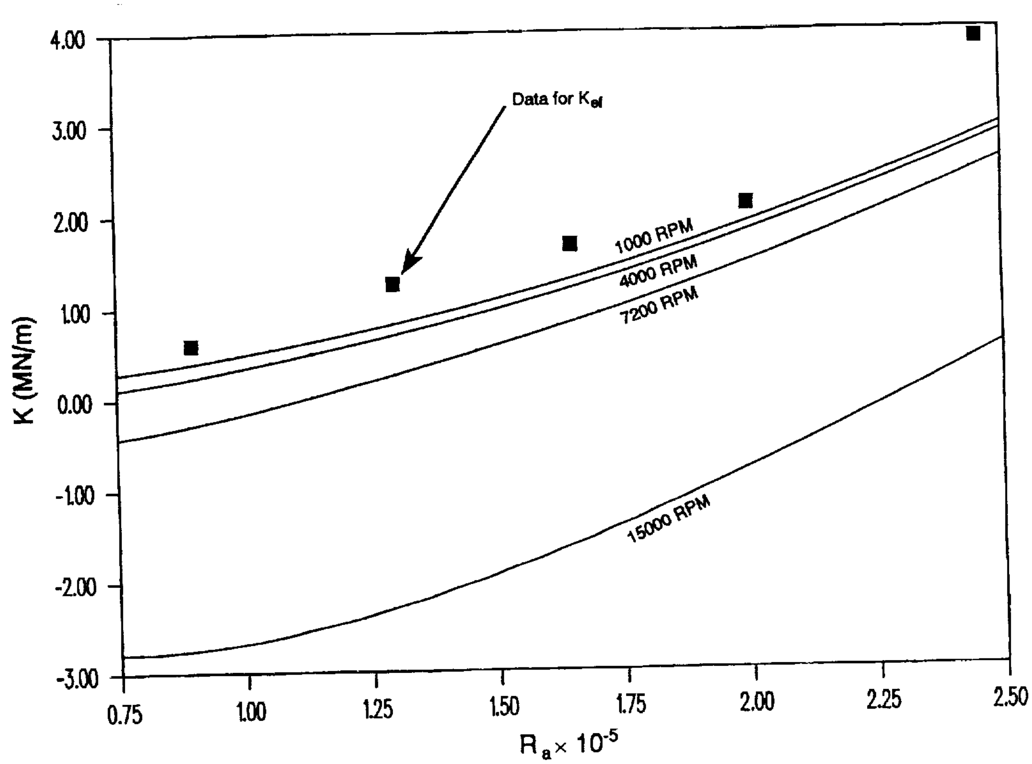
Extraction of effective stiffness and added mass



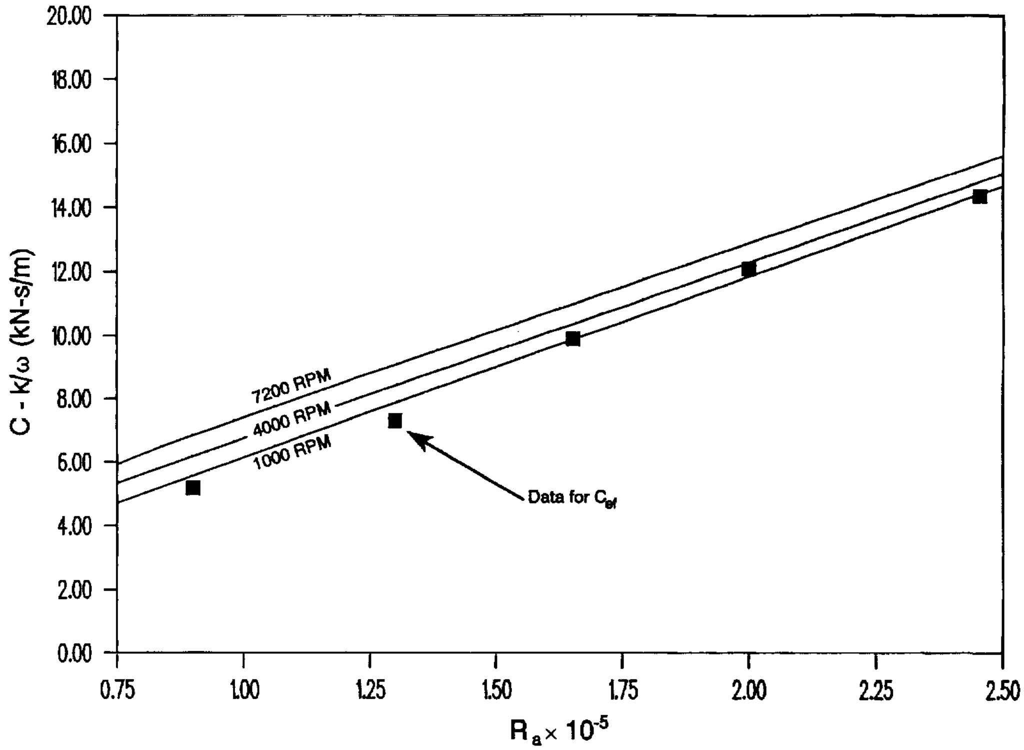
Tangential force coefficients



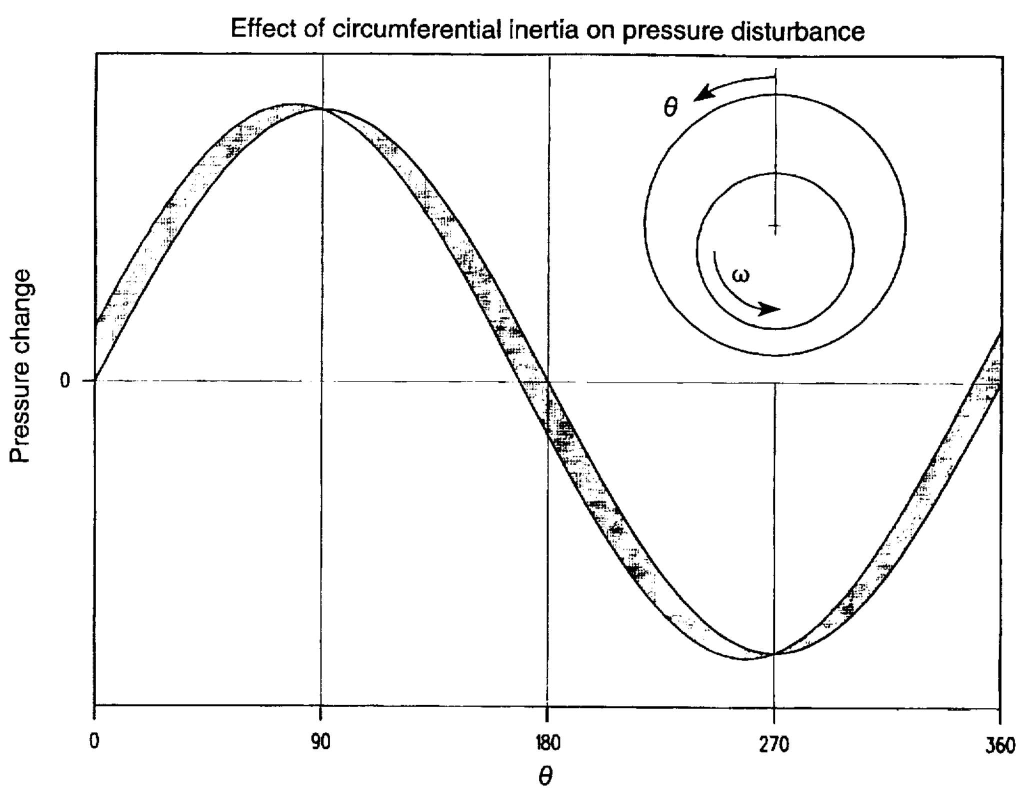
Radial force coefficients

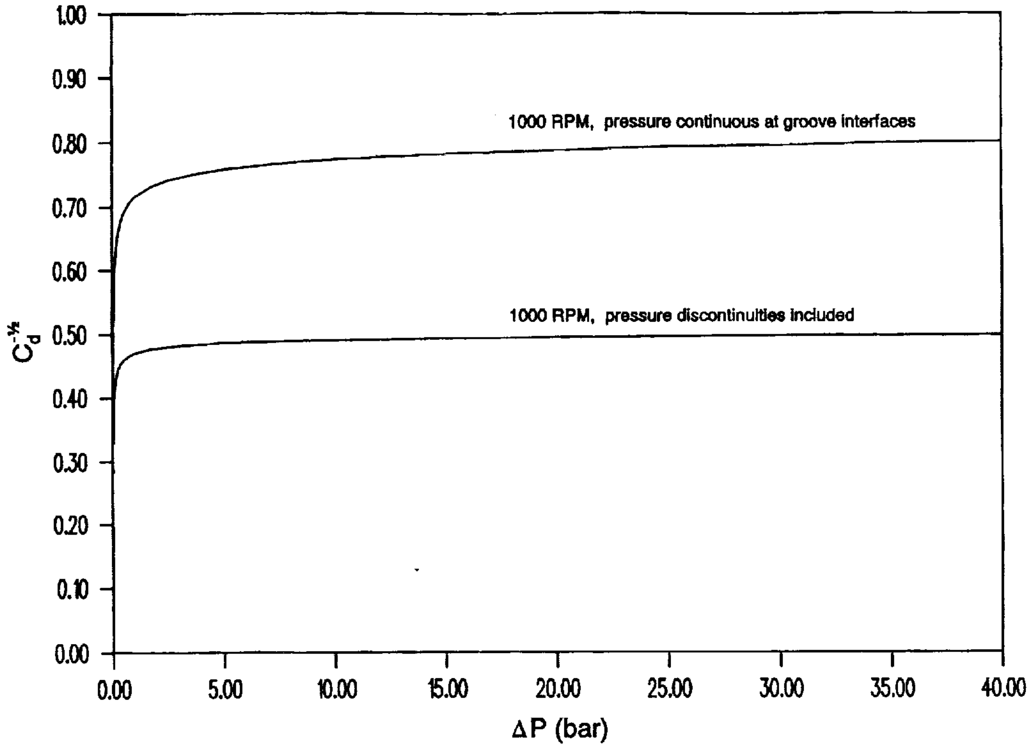


Comparison between K and K_{ef} at various rotating speeds



Comparison between C - k/ω and C_{ef} at various rotating speeds





Effect of local pressure discontinuities on predicted axial flow rates