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Users' Manual for Computer Code IFACE

Face and Cylindrical Seals Lubricated by Incompressible Fluids

Antonio F. Artiles
Mechanical Technology, Inc., Latham, New York

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NOMENCLATURE

A, B	misalignment of rotor about the x and y axes, respectively. [radians][1]
$b_{ij} = B_{ij}\ (C^3/12\mu R^4)$	dimensionless damping coefficient matrix, where i,j= x, y, z, α, β.
C	nominal clearance. [L]
e_b, e_j	roughness of the housing and journal surfaces. [L]
e_x, e_y, e_z	components of rotor eccentricity. [L]
$\hat{e}_\zeta$, $\hat{e}_\theta$	unit vectors in the meridional and circumferential directions
F_x, F_y, F_z	components of fluid film force. [F]
$f = F/(P_o R^2)$	dimensionless fluid film force.
H	local film thickness. [L]
H_o	local film thickness for the concentric aligned rotor (i.e., $e_x = e_y = e_z = A = B = 0$). [L]
$h = H/C$	dimensionless local film thickness.
K_e	dimensionless coefficient of pressure drop at inlet to film.
K_{ij}, B_{ij}	Stiffness and damping coefficient matrices, where i,j= x, y, z, α, β.
$k_{ij} = K_{ij}\ (C/P_o R^2)$	dimensionless stiffness coefficient matrix.

1 the units of the variables are given in brackets, in any consistent set of units, using L, F and T to mean length, force and time. For example, [F-S/L^2] means [Lb_f-sec/in^2] in English units and [N-sec/m^2] in SI units.

L	meridional extent of seal surface (seal length for a cylindrical seal and radial extent for a face seal). [L]
M_x, M_y	components of fluid film force about x and y axes. [F-L]
$m = M/(P_o R^3)$	dimensionless fluid film moment.
$\hat{\mathbf{n}}$	unit vector normal to fluid film boundary.
P	local pressure. $[F/L^2]$
$p = P/P_o$	dimensionless local pressure.
P_l, P_r	Left and right boundary pressures for a cylindrical seal (boundary pressures at inner and outer radii for a face seal). $[F/L^2]$
P_p, P_s	Pocket and supply pressures. $[F/L^2]$
P_o	Reference pressure, used for scaling the pressure field (set internally by program to maximum of P_s, P_l or P_r). $[F/L^2]$
Q_r	volumetric flow from pocket. $[L^3/T]$
$q_r = Q_r\ (12\mu/P_o C^3)$	dimensionless flow from pocket.
R	seal radius for a cylindrical seal, outer radius for a face seal. [L]
$Re^* = \rho h^3 \nabla p/\mu^2$	local Reynolds number based on pressure-driven flow.
$Re_o^* = \rho C^3 P_o/(R\mu^2)$	reference Reynolds number based on pressure-driven flow.
t	time. [T]
$u = U\ (12\mu R/C^2 P_o)$	dimensionless circumferential component of fluid velocity.

$v = V\ (12\mu R/C^2P_o)$	dimensionless meridional[2] component of fluid velocity.
U, V	circumferential and meridional components of fluid velocity, averaged across the film. [L/T]
U_b, U_j	linear velocity of housing and journal surfaces (equal to $R\omega_b$, $R\omega_j$, respectively). [L/T]
X,Y,Z	cartesian coordinates. [L]
ζ	dimensionless meridional coordinate (Z/R for a cylindrical seal, r/R for a face seal).
α	misalignment ratio about the x-axis (AL/2C for a cylindrical seal, AR/C for a face seal).
β	misalignment ratio about the y-axis (BL/2C for a cylindrical seal, BR/C for a face seal).
ϵ_x, ϵ_y, ϵ_z	components of rotor eccentricity ratio ($\epsilon = e/C$).
θ	circumferential coordinate. [radians]
$\Lambda_b = 6\mu U_bR/(C^2P_o)$	dimensionless housing surface velocity.
$\Lambda_j = 6\mu U_jR/(C^2P_o)$	dimensionless rotor surface velocity.
$\Lambda_r = \rho C^6P_o/(288\ A_o^2C_d^2\mu^2)$	dimensionless orifice restriction coefficient.
$\Lambda_e = K_e\ (Re_o^*C/288\ R)$	dimensionless coefficient of pressure drop at inlet to film.
μ	fluid dynamic viscosity. [F-S/L^2]
ρ	fluid density. [F-T^2L^{-4}]
ω_b, ω_j	angular velocity of housing and journal surfaces. [rad/T]
$\tau = t\ (C^2P_o/12\mu R^2)$	dimensionless time.

2 the meridional direction is the axial direction for a cylindrical seal and the radial direction for a face seal.

1.0 INTRODUCTION

The computer code ICYL was developed[1] to evaluate the performance of cylindrical seals operating with incompressible fluids. The computer code IFACE was subsequently developed to also handle face seals. The pressures generated in plain cylindrical seals with incompressible fluids typically result in forces which are normal to the displacement and therefore tend to destabilize the rotating shaft. Surface roughness, geometry alterations, and external pressurization are ways in which the direct stiffness and damping coefficients can be improved and the cross-coupled stiffness decreased in order to improve stability.

The pressure and velocity distributions within the seal clearance are first evaluated from the governing equations. From these, design quantities such as seal leakage flows, power loss and resulting forces and moments are calculated. Minimum film thicknesses and maximum pressures as well as critical rotor-dynamics coefficients such as stiffness, damping and critical mass are evaluated.

Program capabilities:

1. 2-D incompressible isoviscous flow in cylindrical and face geometry.
2. Rotation of both rotor and housing.
3. Roughness of both rotor and housing.
4. Arbitrary film thickness distribution, including features such as steps, pockets, tapers and preloaded arcs
5. Rotor position described by four degrees of freedom (translational and rotational)

6. Up to 32 dynamic coefficients as well as the critical mass may be calculated for use in rotor-dynamic design, including system response and stability calculations.
7. Steady external forces and/or moments may be prescribed to find the position of the rotor relative to the housing.
8. Pocket pressures or orifice size are prescribed.
9. Laminar or turbulent flow.
10. Cavitation.
11. Inertia pressure drop at inlets to fluid film (from ends of seal and from pressurized pockets).

Assumptions:

1. The film thickness is assumed to be small compared with seal lengths and diameters but large compared with surface roughness.
2. Pockets supplied from an external pressure source through an orifice restriction are assumed to be sufficiently deep that the pressure is constant within them.
3. Wall roughness is assumed to be isotropic and represented by an "equivalent sand roughness" height.
4. Fluid inertia effects in the film are negligible.

2.0 THEORETICAL DESCRIPTION AND NUMERICAL METHODS

Figures 1 and 2 illustrate the geometry of a cylindrical seals as well as the coordinate system used to describe it. Figure 1 shows the seal housing of length L separated from the rotor by the film thickness C. The coordinate system is placed at the mid-length of the seal with the circumferential coordinate θ measured from the x-axis. Figure 2 shows an axial cross-section of the film thickness with an eccentric rotor. Figure 3 similarly illustrates the geometry and coordinate system used to describe a face seal, from side and end views. The top part illustrates the seal ring rotating with a stationary mating ring, while the bottom illustrates the reversed situation. Figure 4 illustrates the lateral and angular displacements of the rotor as well as the direction of the fluid film forces and moments.

For the cylindrical geometry, the film thickness and time rate-of-change thereof are written:

$$H = H_o - (e_x + ZB)\cos\theta - (e_y - ZA)\sin\theta$$

$$\frac{\partial H}{\partial t} = -\left(\frac{\partial e_x}{\partial t} + Z\frac{\partial B}{\partial t}\right)\cos\theta - \left(\frac{\partial e_y}{\partial t} - Z\frac{\partial A}{\partial t}\right)\sin\theta \qquad (1)$$

where H_o, an arbitrary function of film coordinates, represents the film thickness distribution for a rotor that is aligned and centered with the housing. A and B represent the angles of rotor rotation about the x and y axes, respectively, while e_x and e_y represent the components of rotor eccentricity at the seal mid-length. The former are referred to as the angular displacements and the latter as the lateral displacements.

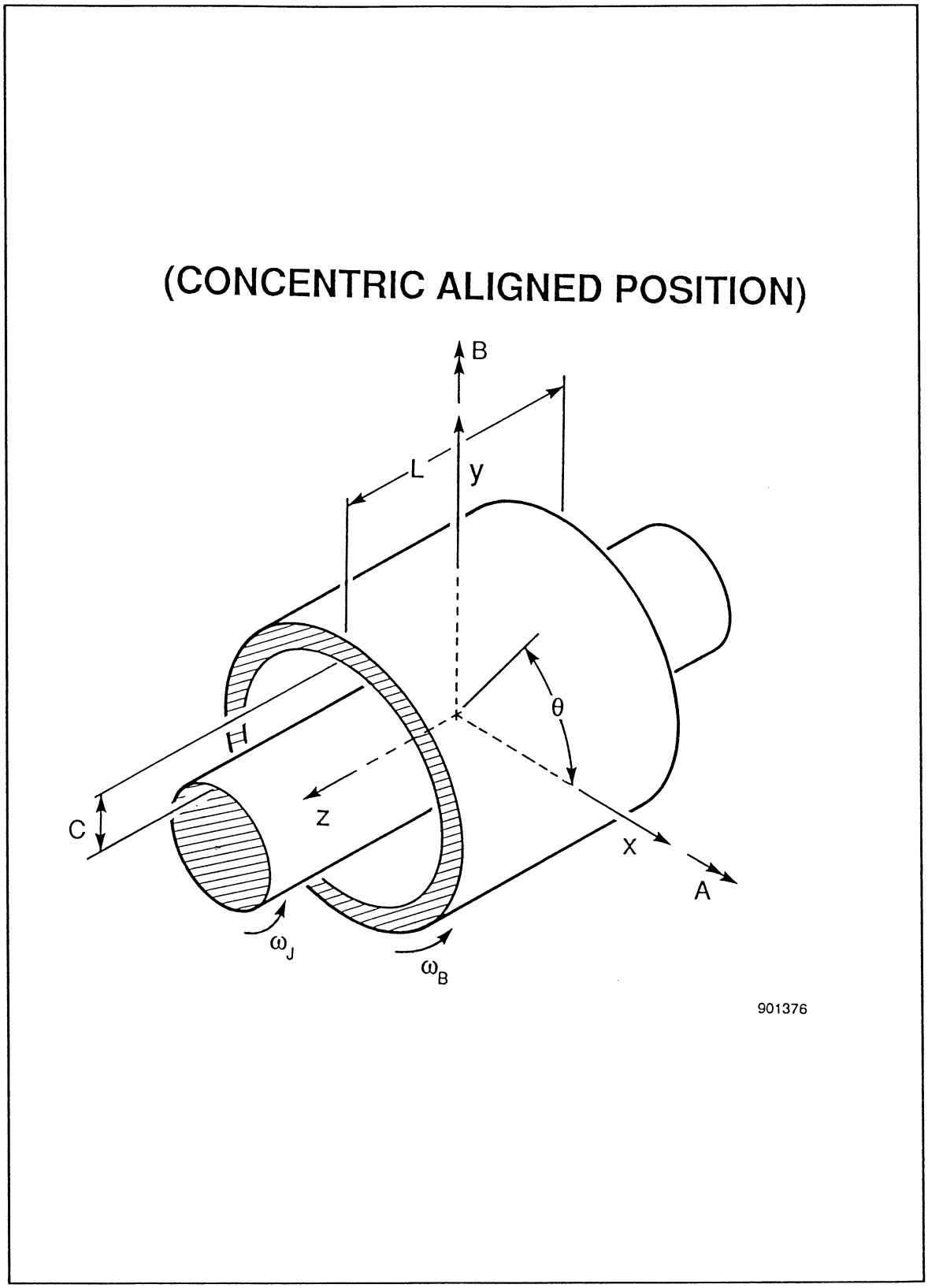

Figure 1 Cylindrical seal geometry

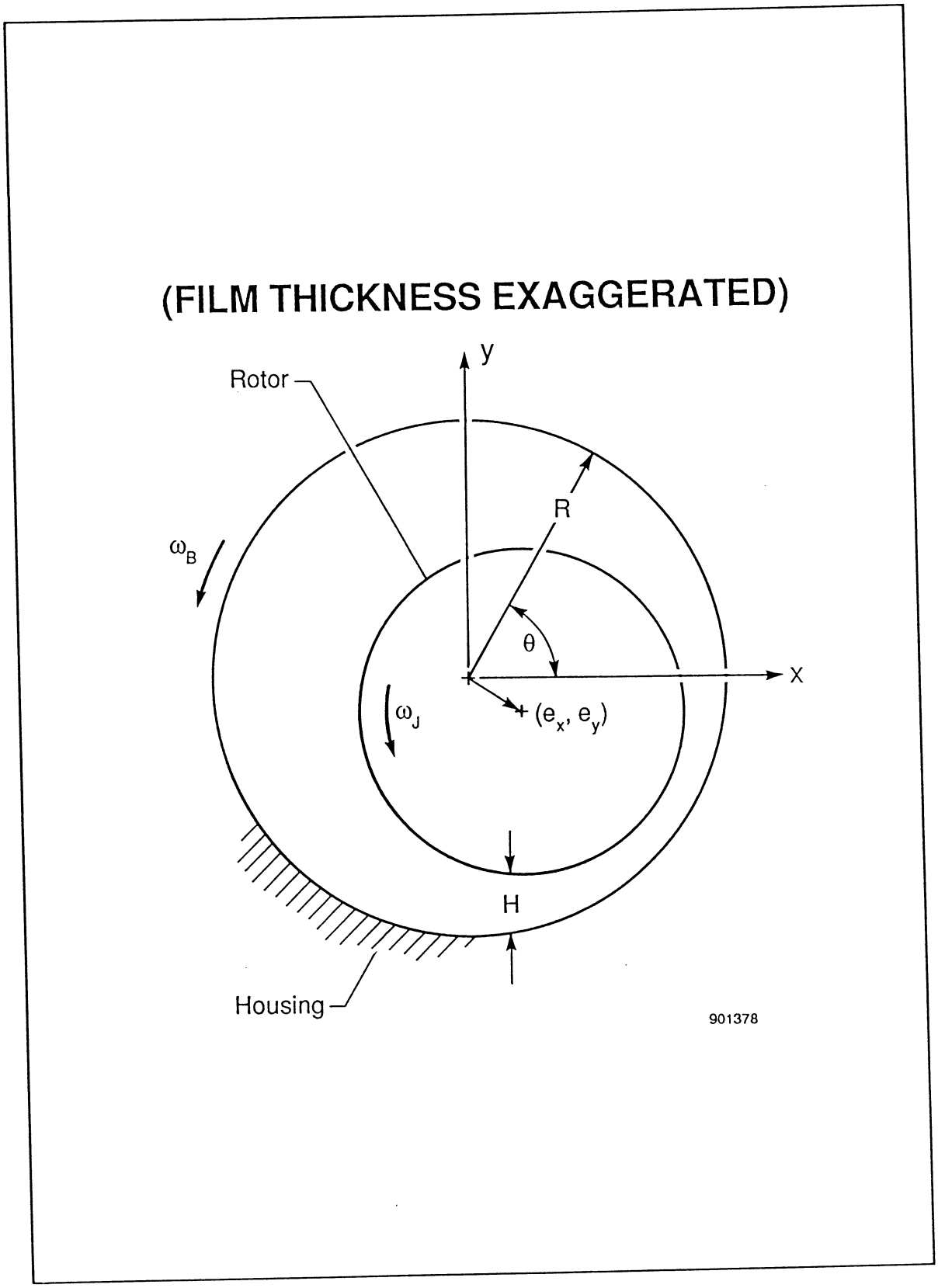

Figure 2 Axial cross-section of seal with eccentric rotor.

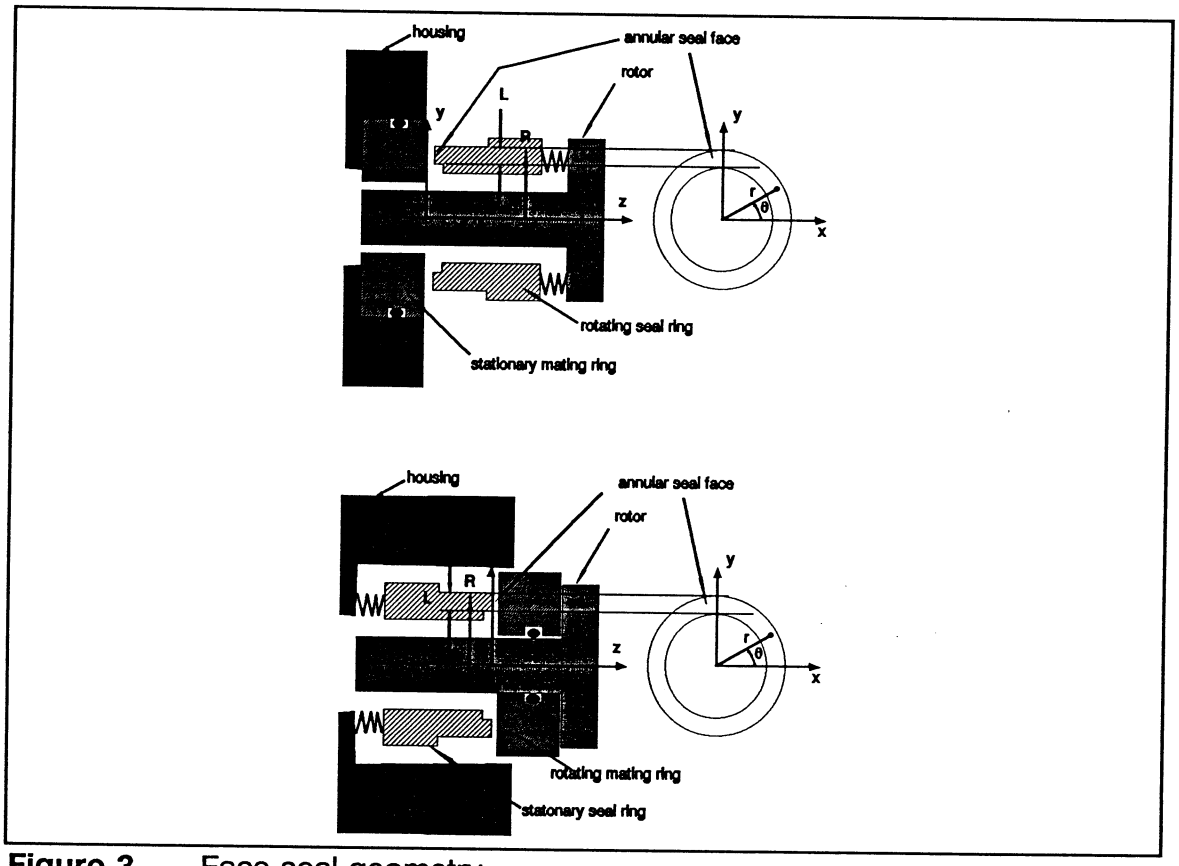

Figure 3 Face seal geometry

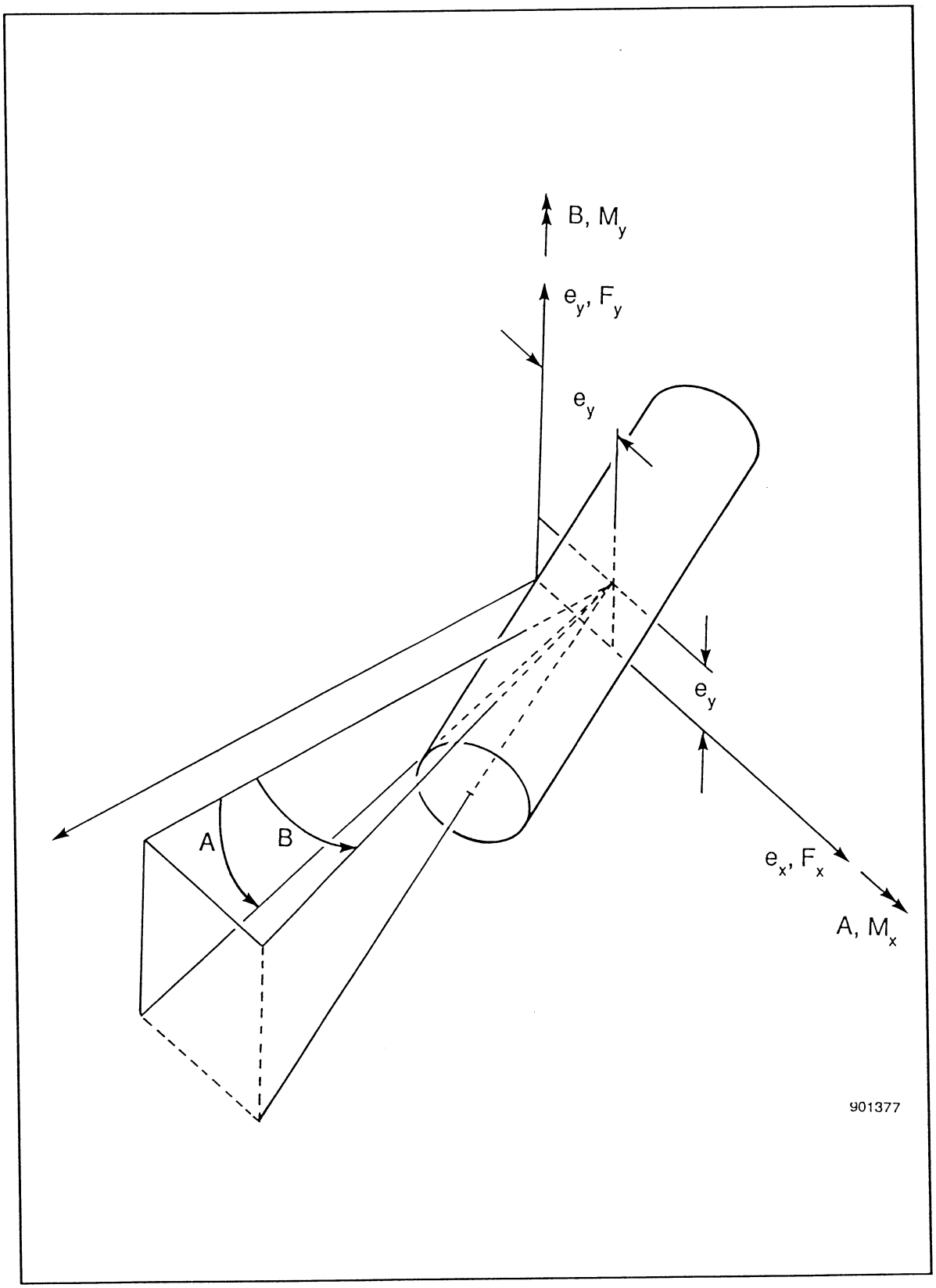

Figure 4 Rotor with lateral and angular displacements.

For the face geometry,

$$H = H_o + e_z - Br\cos\theta + Ar\sin\theta$$
$$\frac{\partial H}{\partial t} = \frac{\partial e_z}{\partial t} - \frac{\partial B}{\partial t} r\cos\theta + \frac{\partial A}{\partial t} r\sin\theta \qquad (2)$$

where r is the local radius and e_z represents an axial eccentricity of the rotor away from the housing.

2.1 Governing equations

The equations governing the flow of incompressible fluids in thin films are obtained [11,12,16] by integrating the Navier-Stokes momentum and continuity equations across the film[3]:

$$\frac{(f_j Re_j + f_b Re_b)}{2} U = -\frac{H^2}{\mu r}\frac{\partial P}{\partial \theta} + \frac{(Re_j f_j U_j + Re_b f_b U_b)}{2}$$
$$\frac{(f_j Re_j + f_b Re_b)}{2} V = -\frac{H^2}{\mu R}\frac{\partial P}{\partial \zeta} \qquad (3)$$

$$\frac{1}{r}\frac{\partial}{\partial \theta}(UH) + \frac{1}{R}\frac{\partial}{\partial \zeta}(VH) + \frac{\partial H}{\partial t} = 0 \qquad (4)$$

where f_j and f_b are the friction factors relative to the housing and journal surfaces, respectively, and are functions of the Reynolds numbers relative to these surfaces as well as their roughness. They are given by:

3 the word film or the term film thickness will be used to mean the gap of lubricant separating the rotor and housing.

$$Re_i = \frac{\rho H}{\mu}\sqrt{(U-U_i)^2 + V^2} \tag{5}$$

where i=j,b, and:

$$f_i = \begin{cases} \dfrac{12}{Re_i}, \; Re_i \le 1000 & (laminar) \\ \dfrac{12}{Re_i}(1 - 3\xi^2 + 2\xi^3) + f_i^*(3\xi^2 - 2\xi^3), \; 1000 < Re_i < 3000 & \\ f_i^*, \; Re_i \ge 3000 & (turbulent) \end{cases} \tag{6}$$

$$\xi \equiv \frac{Re_i - 1000}{2000}$$

$$f_i^* = 0.001375\left[1 + \left(\frac{10^4 e_i}{H} + \frac{10^6}{2Re_i}\right)^{\frac{1}{3}}\right] \tag{7}$$

The friction factor for turbulent flow through pipes, f^*, in equation (7) uses the curve-fit obtained by Nelson [13] to Moody's data. The transition from laminar to turbulent flow is obtained using a cubic polynomial which matches values and slopes at both ends, as reflected by equation (6). Figure 5 is a plot of the friction factor versus Reynolds number and surface roughness, while Figure 6 is an enlargement showing the detail of the transition region.

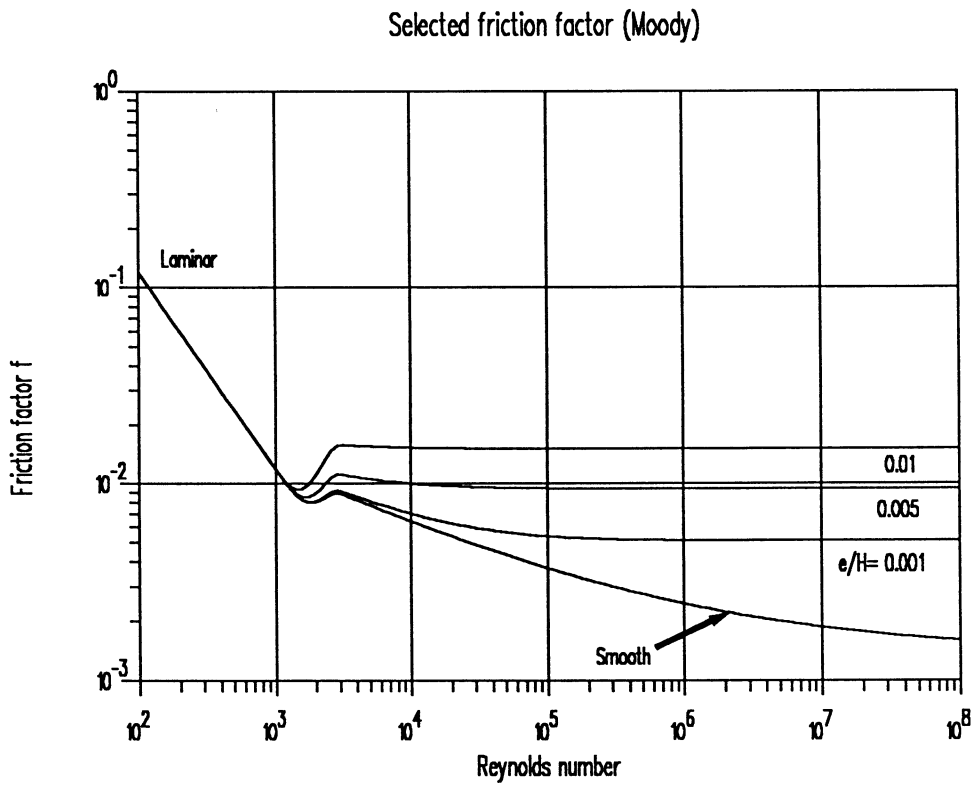

Figure 5 Friction factor versus Reynolds number

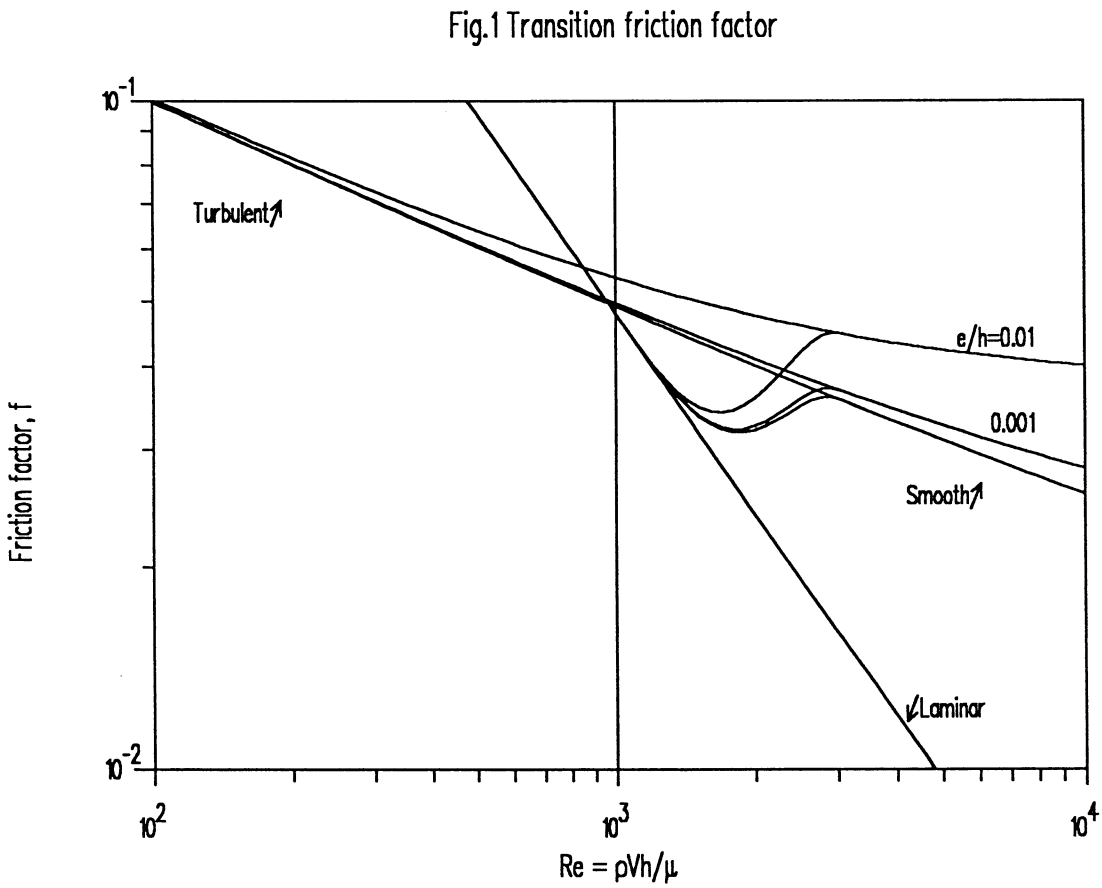

Figure 6 Detail of friction factor in transition region

Under laminar flow the friction factors are equal to 12/Re and the momentum equations can be solved explicitly for the velocities in terms of the pressure gradients:

$$U = -\frac{12H^2}{\mu R}\frac{\partial P}{\partial \theta} + R\frac{\omega_j + \omega_b}{2}$$
$$V = -\frac{12H^2}{\mu R}\frac{\partial P}{\partial \zeta} \tag{8}$$

There is no effect of roughness if the flow is laminar.

Lubrication Background:

In the classical theory of lubrication, when the housing is stationary and the rotor wall velocity is $U_j = \omega r$, the fluid velocity components are expressed explicitly in terms of the pressure gradients:

$$U = -\frac{H^2 G_x}{12\mu r}\frac{\partial p}{\partial \theta} + \frac{\omega r}{2}, \quad V = -\frac{H^2 G_z}{12\mu R}\frac{\partial p}{\partial \zeta} \tag{9}$$

where G_x and G_z are turbulence coefficients[2] which become unity in the laminar regime. Substituting these velocity components into the continuity equation, results in the classical Reynold's equation:

$$\frac{1}{r^2}\frac{\partial}{\partial \theta}\left(H^3 G_x \frac{\partial P}{\partial \theta}\right) + \frac{1}{R^2}\frac{\partial}{\partial \zeta}\left(H^3 G_z \frac{\partial P}{\partial \zeta}\right) = 6\mu\omega\frac{\partial H}{\partial \theta} + 12\mu\frac{\partial H}{\partial t} \tag{10}$$

Boundary conditions:

Boundary conditions on the film pressure distribution consist of prescribing either the pressure at the boundaries of the film, the flow normal to these boundaries, or a relation between these two quantities.

At the circumferential ends of the seal surface model, either the pressures are prescribed:

$$P = 0 \text{ at } \theta = \theta_s \text{ and } P = 0 \text{ at } \theta = \theta_e,$$

or periodic boundary conditions exists:

$$P(\theta = \theta_s) = P(\theta = \theta_e) \text{ and } U(\theta = \theta_s) = U(\theta = \theta_e)$$

Periodic boundary conditions are used, for example, for a 360° seal, where $\theta_e = \theta_s + 2\pi$.

For a cylindrical seal the pressure/flow relationship is prescribed by:

$$P = P_l - K_e \tfrac{1}{2}\rho V_n^2 \text{ and } P = P_r - K_e \tfrac{1}{2}\rho V_n^2$$

at the left and right ends of the seal surface model, respectively. When a symmetry boundary is present at the seal mid-length, only the left half ($-\frac{1}{2}L \leq z \leq 0$) of the seal is modeled and the right end relationship is replaced by a zero axial velocity, $V(0,\theta)=0$. For a face seal, the same relationships are used at the inner and outer radii, although no symmetry boundary is possible.

$$P = P_l - K_e \tfrac{1}{2}\rho V_n^2 \text{ and } P = P_r - K_e \tfrac{1}{2}\rho V_n^2$$

At pocket boundaries, the relationship of film pressure to flow is written:

$$P = P_p - K_e \tfrac{1}{2}\rho V_n^2.$$

In all of the above relationships, V_n is the flow velocity at the entrance to the film, normal to the pressurized boundary and given by:

$$V_n = \begin{cases} \vec{V}\cdot\hat{n}, & \vec{V}\cdot\hat{n} > 0 \\ 0, & \vec{V}\cdot\hat{n} \le 0 \end{cases} \tag{11}$$

$$\vec{V} \equiv U\hat{e}_z + V\hat{e}_\theta$$

No pressure drop exists in the case of reverse flow (i.e., flow into the pressurized boundary).

External pressurization:

The pressure drop across the orifice supplying the pocket is given by:

$$P_s - P_p = sgn(Q_r)\,\frac{\rho}{2}\left(\frac{Q_r}{A_o C_d}\right)^2 \tag{12}$$

where A_o is the orifice area, C_d is the discharge coefficient and the flow Q_r is obtained by satisfying continuity over the pocket volume:

$$Q_r = \oint_{S_p} H\,\vec{V}\cdot\hat{n}\,dS + \int_{A_p} \frac{\partial H}{\partial t}\,dA \tag{13}$$

where A_p is the pocket area, S_p is its perimeter. The contribution of $\mathbf{V}\bullet\hat{\mathbf{n}}$ to this last equation may be positive or negative.

Dimensionless variables:

Using the following transformation to dimensionless variables,

$b = B\,(C^3/12\,\mu R^4)$

$f = F/(P_o R^2)$

$h = H/C$

$k = K\,(C/P_o R^2)$

$m = M/(P_o R^3)$

$p = P/P_o$

$q_r = Q_r\,(12\,\mu/P_o C^3)$

$u = U\,(12\,\mu R/C^2 P_o)$

$v = V\,(12\,\mu R/C^2 P_o)$

$\zeta = Z/R$ for cylindrical geometry

$= r/R$ for face geometry

$\tau = t\,(C^2 P_o/12\,\mu R^2)$

$\Lambda_b = 6\,\mu U_b R/(C^2 P_o)$

$\Lambda_j = 6\,\mu U_j R/(C^2 P_o)$

$\epsilon = e/C$

$\alpha = A\,(R/C)$

$\beta = B\,(R/C)$

$Re^* = \rho h^3 \nabla p/\,\mu^2$

$Re_o^* = \rho C^3 P_o/(R\,\mu^2)$

$\Lambda_r = \rho C^6 P_o/(288\,A_o^2 C_d^2\,\mu^2)$

$= (Re_o^*/288)\,(C^3 R/A_o^2 C_d^2)$

$\Lambda_e = K_e\,(Re_o^* C/288\,R)$,

the dimensionless film thickness is now written for the cylindrical geometry:

$$h = h_o - (\varepsilon_x + z\beta)\cos\theta - (\varepsilon_y - z\alpha)\sin\theta$$

$$\frac{\partial h}{\partial \tau} = -\left(\frac{\partial \varepsilon_x}{\partial \tau} + z\frac{\partial \beta}{\partial \tau}\right)\cos\theta - \left(\frac{\partial \varepsilon_y}{\partial \tau} - z\frac{\partial \alpha}{\partial \tau}\right)\sin\theta \qquad \textbf{(14)}$$

and for the face geometry:

$$h = h_o + \epsilon_z - \beta\zeta\cos\theta + \alpha\zeta\sin\theta$$

$$\frac{\partial h}{\partial \tau} = \frac{\partial \epsilon_z}{\partial \tau} - \frac{\partial \beta}{\partial \tau}\zeta\cos\theta + \frac{\partial \alpha}{\partial \tau}\zeta\sin\theta \qquad \textbf{(15)}$$

Equations (3), (4) and (5) become:

$$\frac{(f_j Re_j + f_b Re_b)}{2} u = -12h^2 \frac{\partial p}{\partial \theta} + (Re_j f_j \Lambda_j + Re_b f_b \Lambda_b)$$

$$\frac{(f_j Re_j + f_b Re_b)}{2} v = -12h^2 \frac{\partial p}{\partial z} \tag{16}$$

$$\frac{\partial}{\partial \theta}(uh) + \frac{\partial}{\partial z}(vh) + \frac{\partial h}{\partial \tau} = 0 \tag{17}$$

$$Re_i = \frac{Re_o^* h}{12} \sqrt{(u - 2\Lambda_i)^2 + v^2}, \quad i = j, b \tag{18}$$

Equations (6) and (7) remained unaltered, as they were already dimensionless.

The dimensionless form of the boundary conditions now become:

At the circumferential ends, either:

$$p(\zeta, \theta_s) = 0 \text{ and } p(\zeta, \theta_e) = 0$$

or:

$$p(\zeta, \theta_s) = p(\zeta, \theta_e) \text{ and } u(\zeta, \theta_s) = u(\zeta, \theta_e).$$

when periodic boundary conditions are present.

At the left end:

$$p(-L/D, \theta) = p_l - \Lambda_e v_n^2,$$

and at the right end either:

$$p(L/D, \theta) = p_r - \Lambda_e v_n^2$$

or:

$$v(0, \theta) = 0.$$

At pocket boundaries: $p(z, \theta) = p_p - \Lambda_e v_n^2$

where:

$$v_n = \begin{cases} \mathbf{v}\cdot\hat{\mathbf{n}}, & \mathbf{v}\cdot\hat{\mathbf{n}} > 0 \\ 0, & \mathbf{v}\cdot\hat{\mathbf{n}} \le 0 \end{cases} \tag{19}$$

$$\mathbf{v} \equiv u\,\hat{\mathbf{e}}_z + v\,\hat{\mathbf{e}}_\theta$$

Equations (12) and (13) governing the external pressurization become:

$$p_s - p_p = sgn(q_r)\,\Lambda_r q_r^2 \tag{20}$$

$$q_r = \oint_{S_p} h\ \mathbf{v}\cdot\hat{\mathbf{n}}\ ds + \int_{A_p} \frac{\partial h}{\partial \tau}\ d\theta\, dz \tag{21}$$

2.2 Solution of film pressures

Discretization of the seal surface is done by using a rectangular grid, with **M** lines in the meridional direction and **N** lines in the circumferential direction. The grid lines are separated by variable increments. The pressure distribution is represented by discrete values at the grid points located at the intersections of the grid lines. There must be grid lines coincident with the boundaries of the seal surface and with the pocket boundaries. Using the cell method [4], a control area or cell is centered at each grid point and extending half way to the neighboring grid lines, as shown by the shaded area in Figure 7. The grid points are noted by the solid circles and have grid coordinates i,j. The film thickness is evaluated at the corners of the cell (denoted by the shaded circles marked h_1, h_2, h_3, and h_4) located at the geometric centers of the rectangles formed by the grid lines. This staggered configuration allows a discontinuous film thickness to be treated, as occurs, for example in a seal with a Rayleigh-step. Circumferential and meridional components of velocity are also associated with each of the four cell corners.

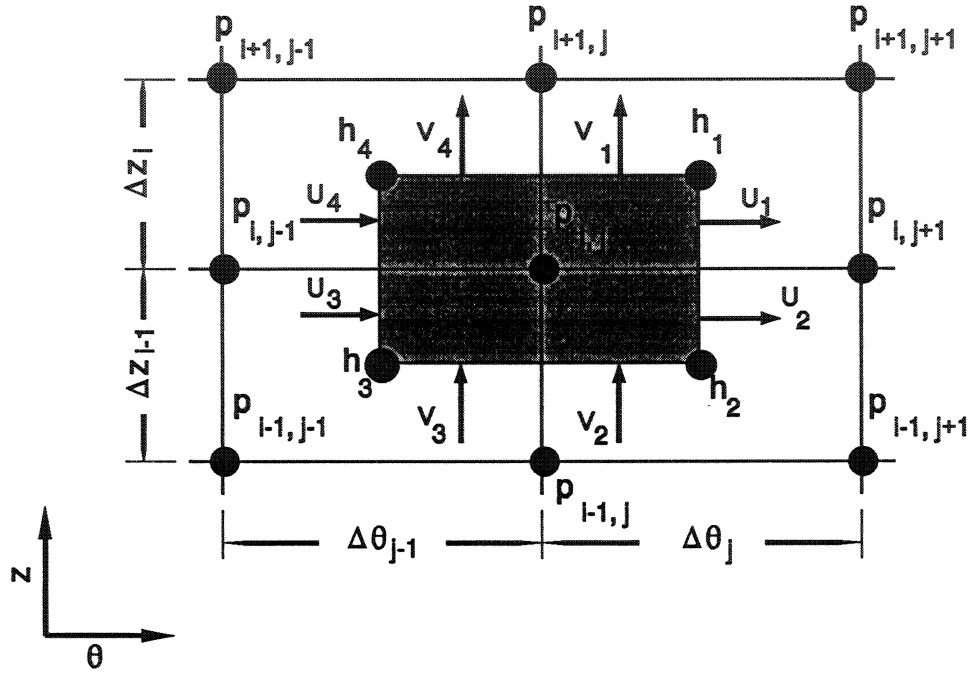

Figure 7 Flow control area about grid point i,j.

Using the divergence theorem, the continuity equation may be integrated over the cell to give:

$$-\oint_{S_c} h\,\mathbf{v}\cdot\hat{\mathbf{n}}\,dS = \int_{A_c} \frac{\partial h}{\partial \tau}\,dA \tag{22}$$

where A_c and S_c are the cell area and perimeters, respectively. The left hand side of the above equation is the sum of the flows out of the cell while the right hand side is the rate of change of the cell volume. The finite-difference form of this equation is:

$$\begin{aligned} F_{i,j} = {} & \frac{\Delta z_i}{2}(u_1 h_1 - u_4 h_4) + \frac{\Delta z_{i-1}}{2}(u_2 h_2 - u_3 h_3) + \\ & + \frac{\Delta \theta_j}{2}(v_1 h_1 - v_2 h_2) + \frac{\Delta \theta_{j-1}}{2}(v_4 h_4 - v_3 h_3) - \\ & - \frac{1}{4}\frac{\partial h_{i,j}}{\partial \tau}(\Delta z_i + \Delta z_{i-1})(\Delta \theta_j + \Delta \theta_{j-1}) = 0 \end{aligned} \tag{23}$$

where $F_{i,j}$ is the error in satisfying continuity of flow in the cell centered at i,j. Although the time rate of change of film thickness has been evaluated at the center of the cell, it could have alternatively been evaluated at each of the four cell corners.

When the grid point falls on a pressurized boundary, such as a pocket or seal end, the film pressure error is:

$$\begin{aligned} F_{i,j} &= p_b - p_{i,j} - \Lambda_e \max(0, v_n)^2 = 0 \\ v_n &= \frac{\Sigma_{i,j}}{s_b h_{i,j}} \end{aligned} \tag{24}$$

where p_b is the dimensionless boundary pressure[4], v_n is the mean velocity of the flow that crosses the portion of the boundary perimeter that intersects the

4 P_l/P_o, P_r/P_o or P_p/P_o.

cell, and $\Sigma_{i,j}$ represents the sum of the appropriate terms in equation (23) contributing to the cell flow. Figure 8 shows an example of the cell i,j located at the right bottom corner of a pocket. In this case, the mean velocity would be evaluated as:

$$v_n = \left[\frac{\Delta z_l}{2}(u_1 h_1) + \frac{\Delta z_{l-1}}{2}(u_2 h_2 - u_3 h_3) + \frac{\Delta \theta_j}{2}(v_1 h_1 - v_2 h_2) - \frac{\Delta \theta_{j-1}}{2}(v_3 h_3) - \right.$$

$$\left. - \frac{\partial h_{l,j}}{\partial \tau} \frac{(\Delta z_l + \Delta z_{l-1})\Delta \theta_j + \Delta z_{l-1}\Delta \theta_{j-1}}{4} \right] \div \left[\frac{(\Delta \theta_{j-1} + \Delta z_l) h_{l,j}}{2} \right] \tag{25}$$

Equations (23) and (24) represent the finite-difference form of the continuity equation that must be solved for the pressures. The eight components of velocity used in these equations are functions of the nine pressures at or neighboring grid point i,j, and are evaluated as described in section 2.3. Following the procedure described in reference 2, these highly nonlinear equations can be solved using the Newton-Raphson iteration method [15]. The procedure is started with an initially guessed or previously calculated pressure distribution, $\mathbf{p}_{i,j}$. The error function $\mathbf{F}_{ij}$ is then linearized about this guess in order to obtain a better approximation to the pressures $\mathbf{p}_{i,j}^{\mathbf{new}}$:

$$F_{ij} + \sum_{\substack{k=i-1,i+1 \\ l=j-1,j+1}} \frac{\partial F_{ij}}{\partial P_{kl}} \left(P_{kl}^{new} - P_{kl} \right) = 0 \tag{26}$$

where a forward difference or a central difference may optionally be used to numerically evaluate the partial derivatives. Pressures without the superscript **new** relate to the previous or "old" approximation. If we introduce the column vector $\{\mathbf{p}_j^{\mathbf{new}}\}$ as the **M** new pressures at the **j**th column of grid points, Equation (26) may be written:

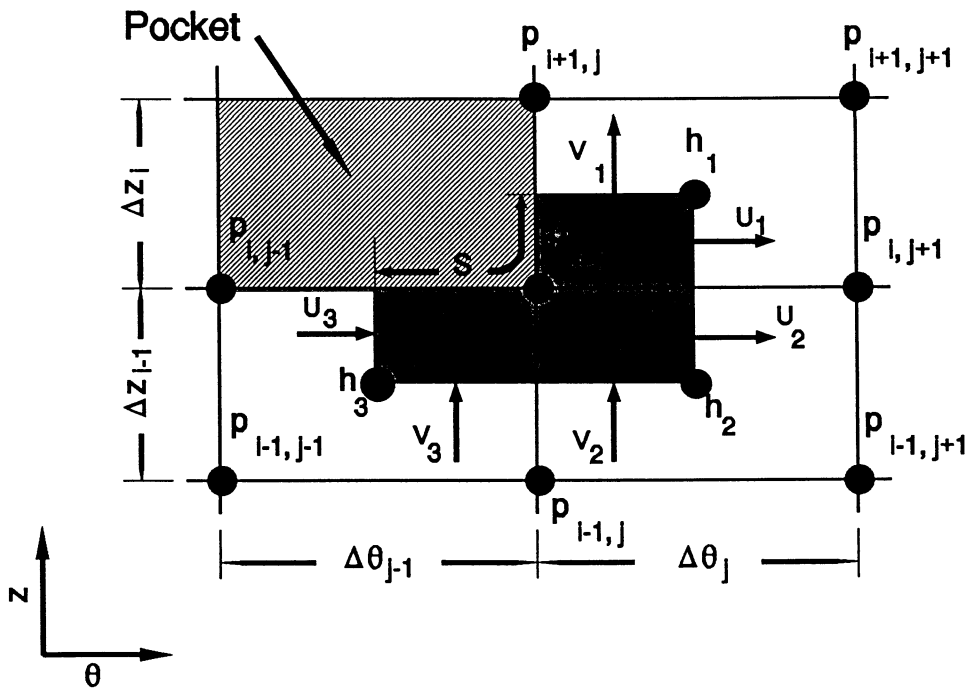

Figure 8 Example of cell at corner of pocket.

$$[C^j]\{p_j^{new}\} + [E^j]\{p_{j-1}^{new}\} + [D^j]\{p_{j+1}^{new}\} = \{R^j\} \quad , \tag{27}$$

where $[C^j]$, $[E^j]$ and $[D^j]$ are tri-diagonal matrices whose interior elements are:

$$C^j_{i,i+k} = \frac{\partial F_{ij}}{\partial p_{i+k,j}} \ , \quad E^j_{i,i+k} = \frac{\partial F_{ij}}{\partial p_{i+k,j-1}} \ , \quad D^j_{i,i+k} = \frac{\partial F_{ij}}{\partial p_{i+k,j+1}} \ , \quad k = -1,0,1 \ ; \quad i = 2,\ldots,M-1$$

The interior elements of the column vector $\{R^j\}$ are:

$$R_i^j = \sum_{k=-1}^{1} \left(C^j_{i,i+k} p_{i+k,j} + E^j_{i,i+k} p_{i+k,j-1} + D^j_{i,i+k} p_{i+k,j+1} \right) - F_{ij} \quad .$$

The set of linear equations (27) that result for the next guess of pressure distribution is in a form suitable for solution by the column method which is described in detail in References 4 and 5. This method makes use of the banded nature of the equations in order to minimize computer time.

2.3 Solution of flow velocity

The momentum equations (16) are used in order to evaluate the velocity components from the pressure gradients. These equations may be rewritten in the generic form:

$$G_u\left[\frac{\partial p}{\partial \theta}, u, v\right] \equiv \frac{f_j Re_j + f_b Re_b}{2} u + 12h^2 \frac{\partial p}{\partial \theta} - \left(Re_j f_j \Lambda_j + Re_b f_b \Lambda_b\right) = 0,$$
$$G_v\left[\frac{\partial p}{\partial z}, u, v\right] \equiv \frac{f_j Re_j + f_b Re_b}{2} v + 12h^2 \frac{\partial p}{\partial z} = 0, \tag{28}$$

where the Reynolds numbers used to evaluate the friction factors are based on the *magnitude* of the local fluid velocity relative to each surface:

$$Re_j = \frac{Re_o^* h}{12}\sqrt{(u-2\Lambda_j)^2 + v^2},$$
$$Re_b = \frac{Re_o^* h}{12}\sqrt{(u-2\Lambda_b)^2 + v^2}, \tag{29}$$

The dependence of the friction factors on velocity components orthogonal to each momentum direction couples the two momentum equations. Figure 9 is a schematic of the rectangular region between meridional grid lines i and i+1 and circumferential grid lines j and j+1. In order to preserve continuity, it is essential that the same equation be used to evaluate the velocity components for adjacent cells. That is, the velocity u_1 out of the shaded cell centered at i,j must have the same value as the velocity u_4 into the cell centered at i,j+1. (See Fig. 7). This value is designated as u^- in the figure. Similarly, the velocity v_1 out of the cell i,j must be the same as v_2 into the cell at i+1,j, and is designated as v^-. This is achieved by using the average of the two corresponding orthogonal

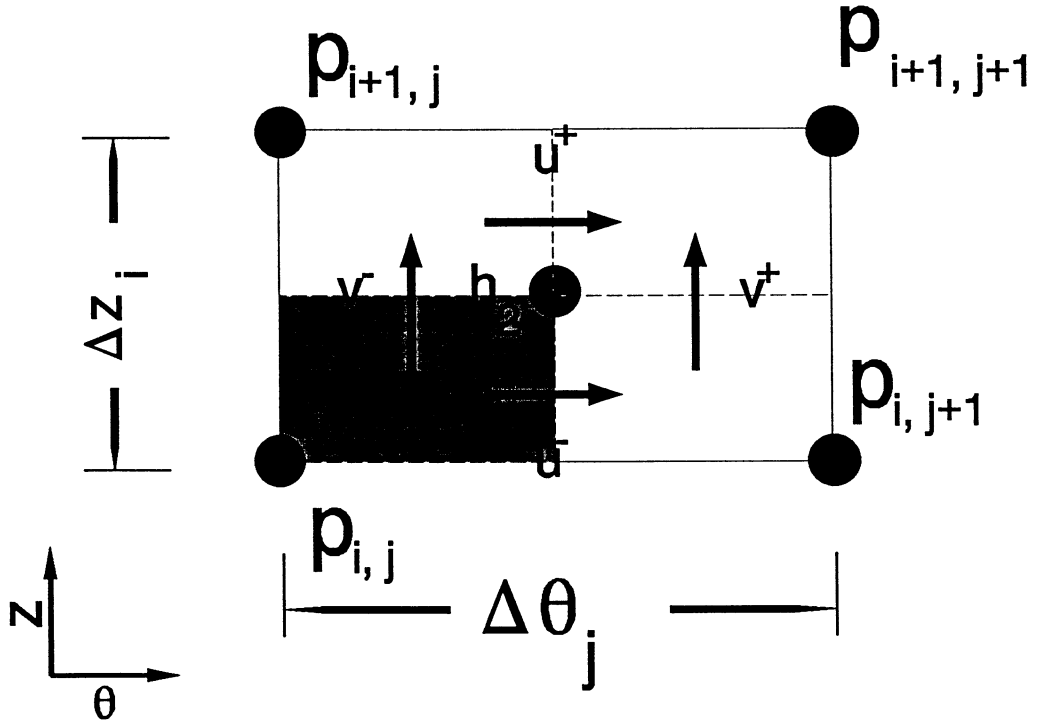

Figure 9 Schematic of rectangular region between grid lines.

components. Thus, the component u^- is determined by the u-momentum equation:

$$G_u\left[\frac{p_{i,j+1}-p_{i,j}}{\Delta\theta_j},\ u^-,\ \frac{v^-+v^+}{2}\right] = 0 \tag{30}$$

while the component v^- is determined by the v-momentum equation:

$$G_v\left[\frac{p_{i+1,j}-p_{i,j}}{\Delta z_i},\ \frac{u^-+u^+}{2},\ v^-\right] = 0 \tag{31}$$

Similarly, u^+ and v^+ are determined by:

$$\begin{aligned} G_u\left[\frac{p_{i+1,j+1}-p_{i+1,j}}{\Delta\theta_j}, u^+, \frac{v^-+v^+}{2}\right] &= 0 \\ G_v\left[\frac{p_{i+1,j+1}-p_{i,j+1}}{\Delta z_i}, \frac{u^-+u^+}{2}, v^+\right] &= 0 \end{aligned} \tag{32}$$

Equations (30), (31) and (32) are four coupled equations that determine the velocity components from the four pressures at the corners of the rectangle between grid lines and must be solved simultaneously. This is done using an inner Newton-Raphson iteration loop. By performing the differentiation of the error functions (G_u, G_v, ...) with respect to the four unknown velocities, analytically instead of numerically, significant computer time is saved. If the velocities have not been previously calculated initial guesses may be obtained from equations (8) assuming laminar flow. Once the iterations for the velocities have converged, their values are saved to provide a good starting guess for the next time they must be calculated.

One simplification is possible by assuming that the friction factors are constant within the rectangular region and the Reynolds numbers are based on the

averaged flow velocity components, $\frac{1}{2}(u^- + u^+)$ and $\frac{1}{2}(v^- + v^+)$. Although this does not uncouple the four equations, it requires less number of evaluations of the square root in equation (18). Since this assumption saves some computer time without introducing significant errors, it was chosen as the default program option (**IFRIC=3**). However, occasionally when the grid is not very fine and the pressure gradients vary rapidly, the iterations will diverge and the more rigorous formulation, which uses distinct friction factors for each of the four momentum equations, should be used with the **IFRIC=4** option.

If the surfaces are smooth and the housing is stationary so that the continuity equation takes the form of equation (10), the simpler formulation described in detail in Reference 2 may be used by selecting the option **IFRIC=0**, resulting in significant reduction in computer time.

2.4 Fluid film load, moment and torque

The forces and moments on the rotor generated by the fluid film pressure distribution are obtained by integration of the pressure distribution over the cylindrical seal surface:

$$\begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} = \int_{-L}^{L} \int_{\theta_s}^{\theta_e} P \begin{Bmatrix} \cos\theta \\ \sin\theta \\ -Z\sin\theta \\ Z\cos\theta \end{Bmatrix} R d\theta \, dZ \tag{33}$$

The dimensionless form of this equation is written:

$$\begin{Bmatrix} f_x \\ f_y \\ m_x \\ m_y \end{Bmatrix} = \int_{-\frac{L}{D}}^{\frac{L}{D}} \int_{\theta_s}^{\theta_e} p \begin{Bmatrix} \cos\theta \\ \sin\theta \\ -z\sin\theta \\ z\cos\theta \end{Bmatrix} d\theta \, dz \tag{34}$$

For the face geometry, the differential of forces and moments are given by

$$d\begin{Bmatrix} F_z \\ M_x \\ M_y \end{Bmatrix} = p\begin{Bmatrix} 1 \\ -r\sin\theta \\ r\cos\theta \end{Bmatrix} dA \tag{35}$$

where the pressure p is a function of r and θ and

$$dA = r\,dr\,d\theta \tag{36}$$

The pressure in the rectangular region $\theta_j<\theta<\theta_{j+1}$, $R_i<r<R_{i+1}$ can be expressed most accurately as a bilinear function of the coordinates as:

$$p(r,\theta) = a_1 + a_2 r + a_3 \theta + a_4 r\theta \tag{37}$$

where the coefficients are functions of the values of the pressure at the four corners of the rectangle:

$$\begin{aligned}
a_1 &= \frac{(p_{i,j} R_{i+1} - p_{i+1,j} R_i)\theta_{j+1} - (p_{i,j+1} R_{i+1} - p_{i+1,j+1} R_i)\theta_j}{(R_{i+1} - R_i)\ (\theta_{j+1} - \theta_j)} \\
a_2 &= \frac{p_{i,j+1} R_{i+1} - p_{i+1,j+1} R_i - p_{i,j} R_{i+1} + p_{i+1,j} R_i}{(R_{i+1} - R_i)\ (\theta_{j+1} - \theta_j)} \\
a_3 &= \frac{(p_{i+1,j} - p_{i,j})\theta_{j+1} - (p_{i+1,j+1} - p_{i,j+1})\theta_j}{(R_{i+1} - R_i)\ (\theta_{j+1} - \theta_j)} \\
a_4 &= \frac{p_{i+1,j+1} - p_{i,j+1} - p_{i+1,j} + p_{i,j}}{(R_{i+1} - R_i)\ (\theta_{j+1} - \theta_j)}
\end{aligned} \tag{38}$$

The contribution to the fluid film forces and moments corresponding to the rectangle is then obtained by integrating equation (37):

$$\Delta\begin{Bmatrix} F_z \\ M_x \\ M_y \end{Bmatrix} = \int_{\theta_j}^{\theta_{j+1}} \int_{R_i}^{R_{i+1}} \begin{Bmatrix} a_1 r + a_2 r^2 + a_3 r\theta + a_4 r^2\theta \\ (-a_1 r^2 - a_2 r^3 - a_3 r^2\theta - a_4 r^3\theta)\sin\theta \\ (a_1 r^2 + a_2 r^3 + a_3 r^2\theta + a_4 r^3\theta)\cos\theta \end{Bmatrix} dr\,d\theta \tag{39}$$

to obtain:

$$\Delta\begin{Bmatrix} F_z \\ M_x \\ M_y \end{Bmatrix} = \begin{bmatrix} \mathfrak{I}_R^1\mathfrak{I}_\theta^0 & \mathfrak{I}_R^2\mathfrak{I}_\theta^0 & \mathfrak{I}_R^1\mathfrak{I}_\theta^1 & \mathfrak{I}_R^2\mathfrak{I}_\theta^1 \\ -\mathfrak{I}_R^2\mathfrak{I}_\theta^0 & -\mathfrak{I}_R^3\mathfrak{I}_\theta^0 & -\mathfrak{I}_R^2\mathfrak{I}_s^1 & -\mathfrak{I}_R^3\mathfrak{I}_s^1 \\ \mathfrak{I}_R^2\mathfrak{I}_\theta^0 & \mathfrak{I}_R^3\mathfrak{I}_\theta^0 & \mathfrak{I}_R^2\mathfrak{I}_c^1 & \mathfrak{I}_R^3\mathfrak{I}_c^1 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{Bmatrix} \tag{40}$$

where

$$\begin{aligned} \mathfrak{I}_c^n &\equiv \int_{\theta_j}^{\theta_{j+1}} \theta^n \cos\theta \, d\theta = \left[\cos^n\theta - \theta^n \sin\theta \right]_{\theta_j}^{\theta_{j+1}}, \\ \mathfrak{I}_s^n &\equiv \int_{\theta_j}^{\theta_{j+1}} \theta^n \sin\theta \, d\theta = \left[\sin^n\theta - \theta^n \cos\theta \right]_{\theta_j}^{\theta_{j+1}}, \\ \mathfrak{I}_\theta^n &\equiv \int_{\theta_j}^{\theta_{j+1}} \theta^n \, d\theta = \frac{\theta_{j+1}^{n+1} - \theta_j^{n+1}}{n+1}, \\ \mathfrak{I}_R^n &\equiv \int_{r_i}^{r_{i+1}} r^n \, dr = r^n \, dr = \frac{R_{i+1}^{n+1} - R_i^{n+1}}{n+1}. \end{aligned} \tag{41}$$

For the cylindrical geometry,

$$d\begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} = p\begin{Bmatrix} -\cos\theta \\ -\sin\theta \\ z\sin\theta \\ -z\cos\theta \end{Bmatrix} R\,d\theta\,DZ \tag{42}$$

The pressure in the rectangle ($\theta_j<\theta<\theta_{j+1}, z_i<z<z_{i+1}$) can be expressed as a linear function of the coordinates:

$$p(z,\theta) = a_1 + a_2 z + a_3\theta + a_4 z\theta \tag{43}$$

where the coefficients are functions of the values of the pressure at the four corners of the rectangle:

$$\begin{aligned}
a_1 &= \frac{(p_{i,j} z_{i+1} - p_{i+1,j} z_i)\theta_{j+1} - (p_{i,j+1} z_{i+1} - p_{i+1,j+1} z_i)\theta_j}{(z_{i+1} - z_i)\ (\theta_{j+1} - \theta_j)} \\
a_2 &= \frac{p_{i,j+1} z_{i+1} - p_{i+1,j+1} z_i - p_{i,j} z_{i+1} + p_{i+1,j} z_i}{(z_{i+1} - z_i)\ (\theta_{j+1} - \theta_j)} \\
a_3 &= \frac{(p_{i+1,j} - p_{i,j})\theta_{j+1} - (p_{i+1,j+1} - p_{i,j+1})\theta_j}{(z_{i+1} - z_i)\ (\theta_{j+1} - \theta_j)} \\
a_4 &= \frac{p_{i+1,j+1} - p_{i,j+1} - p_{i+1,j} + p_{i,j}}{(z_{i+1} - z_i)\ (\theta_{j+1} - \theta_j)}
\end{aligned} \tag{44}$$

Substituting equations (43) & (44) allows integration of (42) over the rectangle:

$$\Delta \begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} = R \int_{\theta_j}^{\theta_{j+1}} \int_{z_i}^{z_{i+1}} \begin{Bmatrix} -(a_1 + a_2 z + a_3 \theta + a_4 z\theta)\cos\theta \\ -(a_1 + a_2 z + a_3 \theta + a_4 z\theta)\sin\theta \\ (a_1 z + a_2 z^2 + a_3 z\theta + a_4 z^2 \theta)\sin\theta \\ -(a_1 z + a_2 z^2 + a_3 z\theta + a_4 z^2 \theta)\cos\theta \end{Bmatrix} dz\, d\theta \qquad (45)$$

Defining:

$$\mathfrak{I}_z^n \equiv \int_{z_i}^{z_{i+1}} z^n \, dz = \frac{z_{i+1}^{n+1} - z_i^{n+1}}{n+1} \qquad (46)$$

yields:

$$\Delta \begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} = \begin{bmatrix} -\mathfrak{I}_z^0 \mathfrak{I}_c^0 & -\mathfrak{I}_z^1 \mathfrak{I}_c^0 & -\mathfrak{I}_z^0 \mathfrak{I}_c^1 & -\mathfrak{I}_z^1 \mathfrak{I}_c^1 \\ -\mathfrak{I}_z^0 \mathfrak{I}_s^0 & -\mathfrak{I}_z^1 \mathfrak{I}_s^0 & -\mathfrak{I}_z^0 \mathfrak{I}_s^1 & -\mathfrak{I}_z^1 \mathfrak{I}_s^1 \\ \mathfrak{I}_z^1 \mathfrak{I}_s^0 & \mathfrak{I}_z^2 \mathfrak{I}_s^0 & \mathfrak{I}_z^1 \mathfrak{I}_s^1 & \mathfrak{I}_z^2 \mathfrak{I}_s^1 \\ -\mathfrak{I}_z^1 \mathfrak{I}_c^0 & -\mathfrak{I}_z^2 \mathfrak{I}_c^0 & -\mathfrak{I}_z^1 \mathfrak{I}_c^1 & -\mathfrak{I}_z^2 \mathfrak{I}_c^1 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{Bmatrix} \qquad (47)$$

The differential of torque transmitted from the housing to the rotor is given by the cross product of the position vector $\vec{r}$ and the shear traction vector acting on the housing $\vec{t}$:

$$\vec{T} = T\hat{e}_z = \iint_{A_f} \vec{r} \times \vec{t}\, dA$$

$$= R \iint_{A_f} \hat{e}_r \times (\bar{\tau} \bullet \hat{e}_r)\, dA \tag{48}$$

$$T = \frac{P_o R^2}{2C_o} \iint_{A_f} \{ h\frac{\partial p}{\partial \theta} - \frac{f_j R_j (u-2\Lambda_j) - f_b R_b (u-2\Lambda_b)}{72h} \}\, d\theta\, dZ$$

For laminar regime, $f_j Re_j = f_b Re_b = 12$, and the equation simplifies to:

$$T = \frac{P_o R^2}{2C_o} \iint_{A_f} \{ h\frac{\partial p}{\partial \theta} - \frac{\Lambda_j - \Lambda_b}{3h} \}\, d\theta\, dZ \tag{49}$$

The power loss due to the difference in velocities across the two surfaces is obtained by doting this torque with the relative velocity:

$$P = T(\omega_b - \omega_j)$$

$$= \frac{P_o R^2}{2C_o} \iint_{A_f} \{ h\frac{\partial p}{\partial \theta} - \frac{f_j R_j (u-2\Lambda_j) - f_b R_b (u-2\Lambda_b)}{72h} \} (\Lambda_j - \Lambda_b)\, d\theta\, dZ \tag{50}$$

2.5 Stiffness and damping coefficients

Defining **W** to be a generalized vector of forces and moments generated by the fluid film pressure and $\vec{r}$ to be a generalized vector of lateral and angular displacements:

$$W = \begin{Bmatrix} f_x \\ f_y \\ m_x \\ m_y \end{Bmatrix} \quad r = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \alpha \\ \beta \end{Bmatrix} \quad \dot{r} = \frac{\partial}{\partial \tau} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \alpha \\ \beta \end{Bmatrix} \tag{51}$$

the matrices of stiffness and damping coefficients can be written:

$$k_{ij} = -\frac{\partial W_i}{\partial r_j} \qquad b_{ij} = -\frac{\partial W_i}{\partial \dot{r}_j} \tag{52}$$

where the subscripts i and j range over x, y, α and β. These coefficients are evaluated by numerical differentiation of **W**, using a forward difference. For example:

$$K_{y\alpha} = \frac{F_y(\epsilon_x, \epsilon_y, \alpha + \delta, \beta) - F_y(\epsilon_x, \epsilon_y, \alpha, \beta)}{\delta} \tag{53}$$

2.6 Solution of rotor position and pocket pressures

If the rotor position is specified, equation (51) is used to solve for the fluid film forces and moments in terms of the calculated pressure field. Similarly, if the pocket pressures are specified, equation (12) is used to solve for the orifice size in terms of the supply pressure and calculated pocket flow.

On the other hand, if externally applied loads and moments on the rotor **(f_{xg}, f_{yg}, m_{xg} and m_{yg})** are specified they must be balanced by the fluid film forces to maintain static equilibrium. Similarly, once the orifice size is specified, equation

(12) must be satisfied by the pressure in each pocket. The global set of equations that must be satisfied by the rotor displacements and pocket pressures are:

$$
\begin{aligned}
f_x(\mathbf{r}) &= -f_{xg} \\
f_y(\mathbf{r}) &= -f_{yg} \\
m_x(\mathbf{r}) &= -m_{xg} \\
m_y(\mathbf{r}) &= -m_{yg} \\
p_s - p_{p1} &= sng(q_{r1})\,\Lambda_{r1}(q_{r1})^2, \quad \textit{for pocket } 1, \\
p_s - p_{p2} &= sng(q_{r2})\,\Lambda_{r2}(q_{r2})^2, \quad \textit{for pocket } 2, \textit{ etc.}
\end{aligned}
\tag{54}
$$

The vector $\mathbf{r}$ can now be redefined to include the pocket pressures and a generalized vector of errors in forces, moments and pocket pressures $\mathbf{W_e}$ can be defined:

$$
\mathbf{r} = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \alpha \\ \beta \\ p_{p1} \\ p_{p2} \\ \vdots \end{Bmatrix} \qquad \mathbf{W_e} = \begin{Bmatrix} f_x + f_{xg} \\ f_y + f_{yg} \\ m_x + m_{xg} \\ m_y + m_{yg} \\ p_s - p_{p1} - sgn(q_{r1})\,\Lambda_{r2}(q_{r1})^2 \\ p_s - p_{p2} - sgn(q_{r2})\,\Lambda_{r2}(q_{r2})^2 \\ \vdots \end{Bmatrix}
\tag{55}
$$

Solution of the global equations is performed by Newton-Raphson iterations, as follows:

$$
\mathbf{W_e} + \left[\frac{\partial \mathbf{W_e}}{\partial \mathbf{r}}\right]\left(\mathbf{r}^{new} - \mathbf{r}\right) = 0
\tag{56}
$$

where, as before, the superscript **new** indicates the newer values of the vector $\mathbf{r}$.

3.0 PROGRAM USAGE AND INPUT DESCRIPTION

3.1 Program Usage

Using an editor, the user prepares an input file such as *fname.*inp, as described in section **3.2**. The extension must be "INP" although the filename is arbitrary. This input file must be copied to IFACE.INP *fname*, without extension. Must appear as the first line in the input file.

Execution is started by entering the command:

IFACE

The program will write iteration diagnostics to the screen to show the progress of the calculations. Screen output need not be saved, since iteration diagnostics are also written to *file fname.*itr described below.

Once execution is finished, the user may review the results by editing, browsing or printing the output file, called *fname.*out. Other files created by the execution are:

*fname.*itr — A copy of screen output, including iteration history.

*fname.*hpf — Pressure, film thickness and velocity distributions for subsequent plotting by program PLOT3D as described in section **4.2**.

*fname.*888 — Binary file storing the pressure and velocity distributions. This file may be used to restart calculations by a subsequent run. See description of variables **READP** and **IREADP.**

3.2 Input description

All the input is in NAMELIST format. The input for each case to be run starts with "&INPUTS" and ends with an ampersand, "&". In between, the variables and arrays are assigned their values. Variable assignments are delimited by blanks or commas. The namelist field must be kept within columns 2 and 80 of the file. Text outside of the namelist fields is ignored.

Additional cases may be specified following each other as desired. The program will read a namelist &INPUTS for each case to be run. The program will continue to loop, reading the namelist for a case and executing it, until it reaches the end of file or until a namelist with ISTOP = 1 is read. The case with ISTOP = 1 will not be executed. Any variables not specified within a namelist will retain the values specified or calculated[5] in the previous case. Variables not specified on the first case will have the default value.

In order to input arrays, either the specific indices of the elements are specified or the elements are entered in order. For example, the following three specifications are equivalent:

M1(1)=3, M1(2)=6, M1(3)=3, M1(4)=6,

M1= 3, M1(2)=6, 3, 6,

M1= 3, 6, 3, 6,

---

5 positon variables EX, EY, ALFA, BETA and/or pocket pressures PPOCK are calculated by the program when FXG, FYG, MXG, MYG and/or DORIF are specified.

For arrays with two indices, the first index can be assumed to increase by one when more than one element is specified. The second index should always be specified. For example, the following two specifications are equivalent:

DELTA(1,3) = 0.001, DELTA(2,3) = 0.002, DELTA(3,3) = 0.003,

DELTA(1,3) = 0.001, 0.002, 0.003,

Table 1 Units for variables

Symbol		English units	SI units
L	length	inches	m
F	force	Lb_f	N
T	time	sec	sec

The units of the input variables are indicated in brackets after their description, e.g., $[F/L^2]$, in terms of force units [F], length units [L], and time units [T]. Table 1 gives the values of these units depending on the system of units being used. This is followed by any limits and default values.

INPUT VARIABLES	Description
FNAME	Name of output and other files produced, without extension. Must be first line of input file.
TITLE	Character string, consisting of any string of up to 80 characters within quotes. (Default='Program IFACE') For example: TITLE='Test of program IFACE'
UNITS='ENGLISH'	Labeling in output file will use English units (Default)
='SI'	Labeling in output file will use SI units Note that the program calculations are not affected by this input, since a consistent set of units is used.

GEOMETRY DESCRIPTION:

IFACE=0	Cylindrical seal geometry (Default)
=0	Face seal geometry.
CREF	Reference clearance (i.e., at concentric aligned position) [L] (0 < CREF) (Default* = 0)[6]. Operating clearance for face seals.

6 Variables which default to zero but must have a non-zero value are required input for the 1st case to be run and are marked with a "*".

RADIUS	Outer radius of seal surface [L] (0 < RADIUS) (Default* = 0)
LENGTH	Meridional extent of seal surface. This is the cylindrical seal length or the outer minus inner radius for a face seal. [L] (0 < LENGTH) (Default* = 0)
ROUGHJ	Roughness of rotor surface [L] (0 ≥ ROUGHJ) (Default = 0)
ROUGHB	Roughness of housing surface [L] (0≥ ROUGHB) (Default = 0)
ISYM=0	For modeling the full seal. Boundary at z = L/2 (i = M) has a specified pressure. (Default)
=1	For modeling half of the seal. Boundary at z = L/2 (i = M) is a seal line of symmetry. Only applicable to cylindrical seals (IFACE=0).
IPER=0	For specified pressure boundary conditions at the circumferential start and end of the model.
=1	For modeling periodic boundary conditions at the circumferential start and end of the model. See also discussion under description of variable PCAV. (Default)
TS,TE	Circumferential start and end of the model (Degrees). (Defaults: TS = 0, TE = 360). (TS < TE)
NPADS	If at the concentric aligned position, the seal geometry consists of one "pad" repeated a number of times around the circumference, the user need only to specify the geometry for

the first pad and set NPADS > 1. The program will generate the inputs for subsequent pads assuming that the next one begins at the same circumferential position where the last one ended. If this option (NPADS > 1) is used, all other program inputs (N,TS,TE,NPOCK,DELTA,etc.) should refer only to the first pad. (Default: NPADS = 0).

FLUID DESCRIPTION:

RHO Lubricant mass density $[F\text{-}T^2/L^4]$ ($0 \leq$ RHO) (Default* = 0)

XMU Lubricant-viscosity $[F\text{-}T/L^2]$ ($0 <$ XMU) (Default* = 0)

OPERATING & BOUNDARY CONDITIONS:

RPMJ Speed of rotor surface [RPM] ($0 \leq$ RPMJ) (Default = 0)

RPMB Speed of housing surface [RPM] ($0 \leq$ RPMB) (Default = 0)

PCAV Lubricant cavitation vapor pressure. With non-periodic bondary conditions trailing-end film cavitation will be calculated (P = PCAV with zero slope). When a periodic boundary condition is used, PCAV should be set equal to a large negative number, such that all of the resulting film pressures are larger than PCAV since film reformation problem is not performed. When IPER = 1, the program will first calculate the pressure distribution and then set any pressure less than PCAV equal to it. $[F/L^2]$ (Default = 0)

PL1,PR1 Boundary pressures at the inner and outer radii (left and right ends for the cylindrical geometry), respectively, at the start of the model (θ = TS). [F/L^2] (Default = 0)

PL2,PR2 Boundary pressures at the inner and outer radii (left and right ends for the cylindrical geometry), respectively, at the end of the model (θ = TE). These values are only used when IPER=0. [F/L^2] (Default = 0). At grid points in between these pressures, a linear interpolation is performed.

EX,EY,ALFA,BETA Dimensionless lateral and angular displacements of rotor with respect to the housing. EX, EY are components of eccentricity ratio and are therefore dimensionless. The eccentricity ratio is the eccentricity of the rotor relative to the housing at Z = 0 divided by the reference clearance, CREF. ALFA, BETA are the components of the rotation of the rotor relative to the housing, scaled by (2*LENGTH/CREF), so that rotor to housing contact occurs when $ALFA^2+BETA^2$ is unity.

All four quantities default to 0 and are restricted to:

$$EX^2 + EY^2 + ALFA^2 + BETA^2 < 1$$

It is recommended that non-zero values of radial and/or angular displacements be specified as initial guesses when the external forces and/or moments are specified.

ALFA and BETA must be zero if ISYM=1, since that is the only way that the pressure distribution will be symmetric about the Z=0 plane.

FXG,FYG,

MXG,MYG External forces and moments applied to the rotor. (All four quantities default to -999. indicating that their value was not specified). If not specified the program will assume that the analysis is to be performed at the rotor position specified by EX,EY,ALFA,BETA. If specified, the program will perform iterations to find the rotor position. As explained in more detail below, the user may specify the radial position independently of the angular position.

If FXG,FYG are specified, the program will calculate the radial rotor position, using the input values of EX,EY as initial guesses while retaining the specified angular rotor position. Specification of FXG alone assumes that FYG is zero and vice versa.

Similarly, if MXG,MYG are specified, the program will calculate the angular position using the input values of ALFA and BETA as initial guesses while retaining the specified radial rotor position. Specification of MXG alone assumes that MYG is zero and vice versa.

If all four variables (FXG, FYG, MXG, and MYG) are specified, the program will calculate the rotor position using the input values of EX, EY, ALFA and BETA as initial guesses.

For a face seal, EX refers to the *axial* eccentricity ratio and FXG refers to the externally applied *axial* force, while EY and MYG are ignored. Since a positive axial eccentricity increases the film thickness, the film thickness of an aligned rotor face seal will be CREF (1+ EX).

Since the moments resulting from a pressure distribution that is symmetric about the Z=0 plane are zero, MXG and MYG must not be specified if ISYM=1.

EXD,EYD, ALFAD,BETAD Radial and angular velocities of rotor with respect to housing. The program calculates the damping coefficients internally by incrementing these velocities by TOL(1) and dividing the resulting perturbations in the forces and moments by this increment. These quantities are rarely used for steady state calculations, and should be left equal to zero. They are described in the input for calculating performance at prescribed *finite* rotor velocities. [T^{-1}] (Default = 0)

POCKET PARAMETERS:

NPOCK Number of pockets (Default = 0) ($0 \leq NPOCK \leq 20$ and $1 \leq k \leq NPOCK$)

M1(k),M2(k) Meridional integer coordinates at the start and end of pockets. (Default = 0) ($1 \leq M1(k) \leq M2(k) \leq M$)

N1(k),N2(k) Circumferential integer coordinates at the start and end of pockets. (Default = 0) ($1 \leq N1(k) \leq N2(k) \leq N$)

PPOCK(k) Pocket pressure. [F/L^2] (Default = 0)

PSUP Supply pressure [F/L^2] In case both rotor and housing speeds are zero, a positive value should be prescribed for PSUP even if no pockets are specified, since the program will use this value for the internal pressure scale. (Default* = 0)

DORIF Orifice diameter. Set equal to zero to calculate its value based on specified pocket pressure. If DORIF is non-zero, the array of pocket pressures PPOCK(k) should be specified but will only be used as an initial estimate of the k-th pocket pressures) [L] (Default = 0) ($0 \leq$ DORIF)

CD Coefficient of discharge for flow through orifice (Default = 0.6) ($0 <$ CD)

VARIABLE GRID SPECIFICATIONS

M,N Grid mesh size in the meridional and circumferential directions. (Defaults: M = 5, N = 11) ($2 \leq M \leq 91$, $2 \leq N \leq 201$)

DZT(i) Array of meridional coordinate increments (M-1 values). If DZT(1) is not specified or zero, the program will use an equal spacing meridionally. (Default = 0) ($1 \leq i \leq N-1$)

DTH(j) Array of circumferential coordinate increments (N-1 values). If DTH(1) is not specified or zero, the program will use an equal spacing circumferentially. (Default = 0) ($1 \leq j \leq M-1$)

Only the ratios between the coordinate increments is used, since the dimensions of the seal are specified separately by the variables RADIUS, LENGTH, TS and TE. For this reason, the units used for the increments are irrelevant.

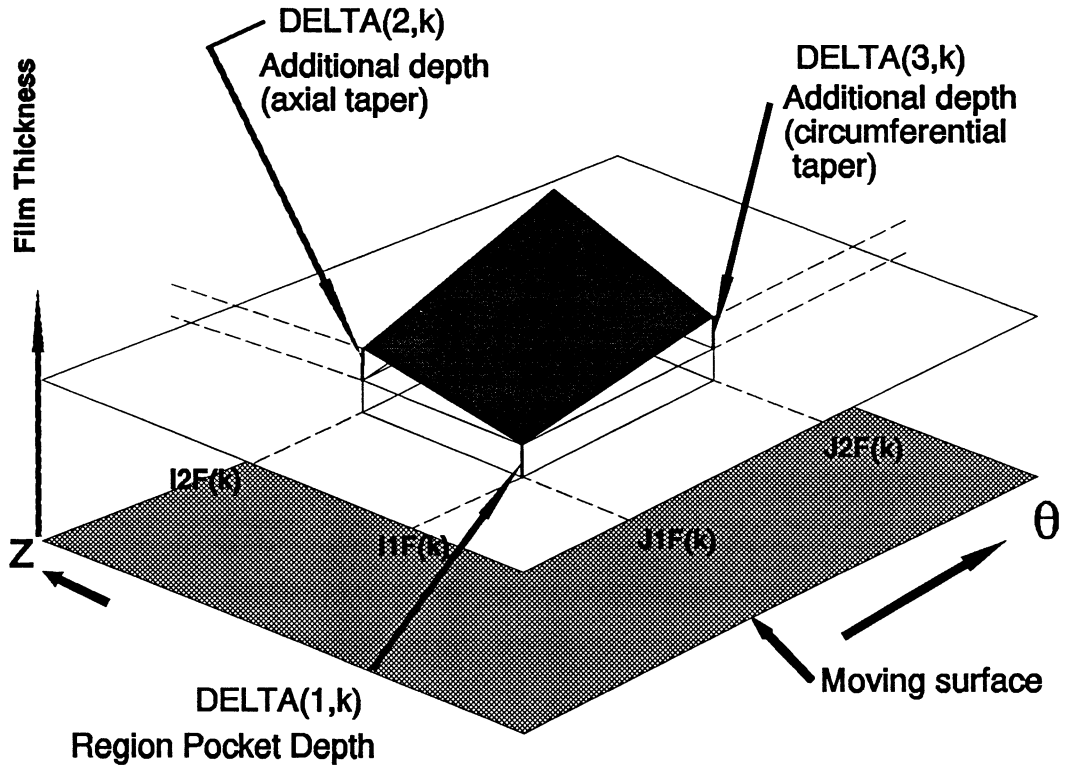

Figure 10 Arbitrary film thickness specification

ARBITRARY FILM & PRESSURE SPECIFICATIONS

A number of rectangular regions may be specified in which additional clearance or a fixed pressure is specified. Figure 10 illustrates the variables describing the k-th region ($1 \leq k \leq 40$).

I1F(k),I2F(k) Meridional integer coordinates at the start and end of the k-th region (Default = 0)

J1F(k),J2F(k) Circumferential integer coordinates at the start and end of the k-th region (Default = 0)

DELTA(1,k) Region depth for: I1F(k) < i < I2F(k), J1F(k) < j < j2F(k) (Default = 0)

DELTA(2,k) Additional depth at i = I2F(k). (Use this for meridional taper). (Default = 0)

DELTA(3,k) Additional depth* at j = J2F(k). (Use this for circumferential taper) (Default = 0)

DELTA(4,k) Region preload ratio. This ratio is defined as the maximum decrease in film thickness divided by the reference clearance (CREF). Normally a preloaded region will extend across the seal length with: I1F=1,I2F=M. (Default = 0)

DELTA(5,k) Specified constant pressure within the region. (Do not use this for an externally pressurized pocket: instead use PPOCK with DORIF = 0). A value of -999. means that the pressure is not specified in the k-th region. (Default = -999.) $[F/L^2]$

Positive values of DELTA(1,k), DELTA(2,k) and DELTA(3,k) indicate increased film thickness beyond CREF, while a positive value of DELTA(4,k) indicates a decrease in film thickness.

If I2F(k) = I1F(k), the region is a circumferential line; if J2F(k) = J1F(k), the region is a meridional line, and If both are true the specification is valid only at a grid point. If I2F(k) = 0 it is assumed equal to I1F(k). If J2F(k) = 0 it is assumed equal to J1F(k).

OFFSET Circumferential offset of location of maximum decrease in film thickness of preloaded regions (Degrees). By default, preloaded regions specified by DELTA(4,k) above have the maximum decrease in film thickness at the middle of the region, between meridional grid lines J1F(k) and J2F(k). This variable allows the user to shift this location. (Default = 0)

PROGRAM CONTROLS

There are three nested iteration loops:

1. The inner-most iteration loop is for velocity components within each of the four corners of a cell.

2. The middle iteration loop is for the pressure distribution.

3. The outer iteration loop is to calculate rotor position and pocket pressures.

There are three controls for each of the iteration loops (k = 1,2,3):

ECR(k) Error criteria that must be achieved before iteration stops. (Defaults = 10^{-10}, 10^{-8} and 10^{-6})

NIT(k) Maximum number of iterations (Defaults = 21, 21, 10)

TOL(k) Tolerance used to evaluate partial derivative of error with respect to the unknown variables. TOL(1) is not used since the differentiations are performed analytically for the inner-most iteration loop. (Defaults = 0, -10^{-6} and 10^{-4})

If $|P_{i,j}| > 1.e\text{-}6$, $|TOL(2)*P_{i,j}|$ is used, else $|TOL(2)|$ is used. Use a positive value for a forward difference or a negative value for a central difference.

MAXDIT Maximum number of consecutive diverging iterations allowed before the program stops (Defaults to 2).

IFRICT= 3	New analysis (Rough, based on Moody formula) (Default)
= 0	Previous analysis (Smooth,based on Ng-Elrod Linearized Turbulence). This friction model has been used successfully for a number of years at MTI. Although it may not account for surface roughness effects, it is accurate and will reduce computation time significantly. Do not use this with inertia pressure drop from pressurized seal ends (i.e., XKE>0 and non-zero PL1 or PR1).
= 4	Refined new analysis (Under this option, the program will average the orthogonal components of velocity).
XKE	Film entrance loss coefficient (dimensionless). This coefficient expresses the pressure loss as a fraction of the dynamic pressure based on the film velocity. (Default = 1.0)
ISTIFF = 0	to bypass stiffness calculations (Default)
= 2	to calculate all[7] stiffness and damping coefficients
= 1	to calculate all stiffness coefficients
=-1	to calculate lateral stiffness coefficients
=-2	to calculate lateral stiffness and damping coefficients

7 lateral and angular

Only the lateral coefficients can be calculated with a symmetric model (ISYM=1).

IREADP A positive value will cause the program to read the pressures and velocity fields from a binary file generated by a previous run. (Default = 0)

READP Character variable defining the name of the binary file to be read. (Defaults to fname.888, where fname is the filename of the input file)

ISAVEP If this variable is non zero, the program will save the pressure and velocity fields in a file fname.888, where fname is the filename of the input file. A negative value causes file to be rewound before saving. (Default = 8)

ISTOP = 0 To run current case. (Default)

= 1 to indicate that the previous input case was the last to be run. This is accomplished by the following line:

```
&INPUTS ISTOP=1&
```

Although the program will also stop when reaching the end of the file, the above line allows the user to store other namelist cases following it without the program attempting to run them.

Table 2 Variables that may be varied as parameters.

1	CREF =	.0000000	2	CD =	.6000000	3	DORIF =	.0000000
4	RADIUS=	.0000000	5	TS =	.0000000	6	TE =	360.0000
7	LENGTH=	.0000000	8	RHO =	.0000000	9	XMU =	.0000000
10	OFFSET=	.0000000	11	RPMJ =	.0000000	12	RPMB =	.0000000
13	ROUGHJ=	.0000000	14	ROUGHB=	.0000000	15	.....=	.0000000
16	.....=	.0000000	17	EX =	.0000000	18	EY =	.0000000
19	ALFA =	.0000000	20	BETA =	.0000000	21	EXD =	.0000000
22	EYD =	.0000000	23	ALFAD =	.0000000	24	BETAD =	.0000000
25	FXG =	-999.0000	26	FYG =	-999.0000	27	MXG =	-999.0000
28	MYG =	-999.0000	29	ECR(1)=	1.0000000E-10	30	ECR(2)=	1.0000000E-08
31	ECR(3)=	1.0000000E-06	32	TOL(1)=	.0000000	33	TOL(2)=	-1.0000000E-06
34	TOL(3)=	1.0000000E-04	35	PR1 =	.0000000	36	PL1 =	.0000000
37	PR2 =	.0000000	38	PL2 =	.0000000	39	PCAV =	.0000000
40	PSUP =	.0000000	41	XKE =	1.000000			

PARAMETRIC EVALUATION:

The five variables below allow the user to run a number of cases, by varying one of the variables in Table 2. This table also gives the default values of these parameters.

IPAR Number of the input variable in Table 2 that will be varied as a parameter. For example, use IPAR = 11 to vary RPMJ. See table at end of program output. (Default = 0)

PAR1 First value of parameter

PAR2 Last value of parameter

PARINC Increment for parameter. (Do not set this value if NPAR is specified) (Default = 0)

NPAR Number of values the parameter will take (negative to use logarithmic scale). NPAR will be calculated from PAR1, PAR2 and PARINC if NPAR = 0 and PARINC>0. (Default = 0)

For example, the following line of input will cause the program to run 10 cases, changing the axial eccentricity ratio (EX) from 0.0 to 0.9 in increments of 0.1:

IPAR=17, PAR1=0.0, PAR2=0.9, PARINC=0.1,

while the following line will vary the rotor speed (RPMJ) from 1,000 to 100,000 over 6 intervals in a logarithmic scale:

IPAR=20, PAR1=1.E3, PAR2=1.E5, NPAR=-7,

DIAGNOSTICS CONTROLS:

KDIAG = 0 No diagnostics are written. (Default)

= 5 To write all the namelist &INPUTS to output file

= 8 To output pressures every iteration

IRESET = 0	To use the pressure distribution from the previous case as the initial guess. (Default)
= 1	To reset the pressure distribution guess to zero. Use this when changing the size of the grid (M, N, ...) from the previous case or when the pressure distribution from the previous case is to be discarded.

4.0 OUTPUT DESCRIPTION

4.1 Text

The first part of the output file consists of the time, date, filename (*fname*) and an identical copy of the input file. This part is terminated by a long horizontal line. The second part of the output consists of the key input variables as interpreted by the program described in English with their corresponding units. Seal dimensionless quantities (Λ_b, Λ_j, Re^*, Re_o^*, and Λ_r, Λ_e) discussed in section **2.1** are also listed. This part is also terminated by a long horizontal line. The last part of the output consists of the results as follows:

The pressure distribution is first given in tabular form, with the meridional coordinate direction increasing from left to right and the circumferential coordinate direction increasing from top to bottom.

This is followed by the rotor position (components of eccentricity and misalignment ratios) as well as the forces and moments acting on the rotor. The rotor position should match exactly the values specified, unless the external forces and moments were specified. The forces and moments generated by the film pressure should match closely the negative of the externally applied values specified (Fxg, Fyg, etc) when the outer loop iterations have converged.

This is followed by the maximum film pressure and minimum film thickness, identified by the integer coordinates where they occur.

If NPOCK>0, this is followed by the orifice diameter as well as the pressures and volumetric flows through each pocket, as well as a sum of these flows.

The dynamic stiffness and damping coefficients, when requested, are printed as a matrix where the column corresponds to the displacement or rotation and the row corresponds to the force or moment. The units for any given stiffness or damping value will be the force unit given at the end of its row divided by the displacement unit given at the top of its column.

The last part of the results gives the volumetric flows at the boundaries of the seal model as well as the torque and power loss.

Note that all quantities (forces, flows, dynamic coefficients, etc.) refer to the full seal length, even if only half is modeled with a symmetric right-hand boundary (ISYM = 1).

Additional second and third parts of the output just described above are repeated for subsequent cases, also separated by long horizontal lines. Listings of output files generated by IFACE are given in Appendix A and discussed in Section 5 under sample problems.

4.2 Graphics

The user may examine graphically the film thickness or pressure distributions by running the three dimensional plotting program PLOT3D, by running the batch file (PLOT) provided:

PLOT *fname*

This program is completely interactive and self-explanatory. It will run in either DOS rev. 4.0 or above or in an OS2 DOS full window. Most of the inputs involve 1-key stroke and are described in the menu that is always written to the screen when in text mode. The user simply hits the return key to continue viewing plots.

The space bar toggles between graphics and text screens, while the escape key ends the program.

Support is provided for VGA monitors and HP LaserJet Series II printer in 150 DPI resolution. The printer files (1.PIC, 2.PIC,...) are produced when the user hits "p" from the graphics screen. They are automatically copied to the printer and erased by the batch file.

Table 3 Summary of sample cases

Case	Mesh size MxN	Variables specified	Variables calculated	NPADS	run time (sec)	features
1	5x11	EX, ALFA			3.75	variable grid, DELTA(1,1)
2A	5x31	FXG, MXG, MYG	EX,ALFA, BETA	3	125	prescribed force & moments, DELTA(5,1)
3A	7x41	PPOCK	DORIF, K,B	4	404	4-pocket, calculation of orifice & coefficients
3B	7x41	DORIF, EX,BETA	PPOCK	4	352	4-pocket, prescribed displacements
3C	7x41	DORIF, FXG, MXG,MYG	PPOCK, EX, ALFA,BETA	4	566	4-pocket, prescribed force & moments, pressures read
13	9x37		K, B	4	1093	preloaded pads, roughness multiple cases, DELTA(4,1)
17	9x65	ALFA		8	103	8 Rayleigh steps
15A	10x61	PPOCK	DORIF, K,B	4	2115	4-pocket with XKE=1
15B	10x61	DORIF, EX, MXG, MYG	ALFA,BETA, PPOCK	4	1368	4-pocket finding angular position, pressures read

5.0 SAMPLE PROBLEMS

A number of sample problems have been prepared to demonstrate the behavior and various features of the computer program. They are intended primarily for illustration and do not necessarily represent recommended seal designs. Table 3 summarizes the mesh size, approximate execution times (on a 33Mz 486 PC) as well as a list of what variables where specified and solved[8] for in the outer iteration loop.

The complete input file is included at the top of the output file for each case. Listings of output (.out) and screen output (.itr) files for the sample problems are given in Appendix A. The filenames used in these samples all used the prefix "iface" (e.g., Sample 1 uses *fname* = IFACE1, and so on).

8 K and B indicate calculation of stiffness and damping coefficients.

Sample **1** uses a coarse mesh, variable in both directions, to represent a 50° sector with a film thickness that is tapered circumferentially by 1 mil. This sample demonstrates how different input variables control the film thickness distribution. DELTA(1,1) increases the film from the reference clearance (CREF) to 2 mils. DELTA(3,1) then decreases the film thickness by 1 mil over the circumferential extent. The axial eccentricity ratio (EX= -0.1) decreases the clearance distribution by 10% of CREF. The model is located in the first quadrant, so the resulting pressure distribution produces a positive moment about the x axis and a negative one about the y axis. The resulting film thickness distribution is shown in Figure 11 and the pressure is shown in Figure 12.

Sample **2A** specifies a geometry that is repeated circumferetially every 120° using NPADS=3. A zero pressure is specified at the first two grid lines of each pad (DELTA(5,1)=0 for j=1,2) while the rest of the pad's film thickness is tapered with DELTA(1,2). The ouput shows how the program automatically increases N from 11 to 31 and generates the corresponding specifications for $j \geq 11$. The prescribed external force and moments were obtained from the negative of the results of a similar case at $\epsilon_z=0.2$, $\alpha=0.5$ and $\beta=0$. In sample 2A, the program iterates on the position, starting from zero[9] guess values, and converges on $\epsilon_z=0.2$, $\alpha=0.500002$, and a near zero β in 4 outer loop iterations. The resulting film thickness distribution is shown in Figure 13 and the pressure is shown in Figure 14.

Samples 3A, 3B and 3C are used to illustrate the steps that would be used in calculating the performance of a hydrostatically supported, 4-pocket face seal. A variable mesh is used to describe the geometry of ¼ of the circumference between $\theta=0$ and 90 degrees from the x-axis (TS,TE). One pocket with a supply pressure of 1000 psi is centered on the section modeled (NPOCK,M1,N1,M2,N2). Pressures

9 since EX, ALFA or BETA were not prescribed.

of 100 and 200 psi are prescribed at the inner and outer radii (PL1, PR1). Periodic circumferential boundary conditions and 4 pads are specified to generate the geometry in the remaining three quadrants (IPER=1, NPADS=4).

In sample **3A**, sizing of the orifice diameter is performed with pocket pressures at 500 psi and an aligned rotor (PPOCK). Although the ¼ model corresponding to one pocket would be sufficient for the orifice calculation, the full model was required in this case in order to calculate the stiffness and damping coefficients (ISTIFF=2). The output indicates an orifice diameter of 0.069 inches, a total flowrate of 9 in^3/s, and a fluid film axial force of 7,376 lbf. The direct axial stiffness is $K_{zz}=12.7x10^6$ lb/in and the direct angular stiffness and damping coefficients are $33.2x10^6$ lb-in/rad and $29.6x10^3$ lb-in/rad.

In sample **3B**, the fluid film forces are calculated for prescribed orifice diameters of 0.068 inches, an axial eccentricity ratio[10] of 20% and a misalignment ratio of 50% about the y-axis (DORIF, EX, BETA). The pocket pressures converge in 4 iterations. The pressure increases in pockets 1 and 4 and decreases in 2 and 3. The fluid film axial force inreases to 7,932 lbf, with resulting moments of -287 and -5,216 in-lb about the x and y axes, respectively. The resulting film thickness and pressure distributions are shown in Figure 15 and Figure 16, respectively.

In sample 3C, the external force and moment are prescribed equal to the negative of the fluid film forces calculated in sample 3B (FXG, MXG, MYG). The initial guess for pocket and film pressure distributions were read from the values saved previouly in sample case 3A (IREAPD, READP). Although convergence is also achieved in 4 outer loop iterations, it takes more time to execute (572 versus 360 seconds) because the program must now simultaneously iterate on three position variables as well as the four pocket pressures.

---

10 prescribing EX=0.2 with CREF=0.001 is analogous to prescribing CREF=0.0012 with EX=0.0 .

Sample 13 illustrates multiple NAMELIST inputs in the same run. The model consists of 4 preloaded pads, each with a preload ratio of 50% and a circumferential offset of 10 degrees (DELTA(4,1), OFFSET). The first NAMELIST input prescribes a roughness of 0.02 mils to both surfaces while the second and third inputs have smooth housing and rough rotor, and viceversa (ROUGHB, ROUGHJ). The last NAMELIST restores smooth surfaces for both housing and rotor. The resulting film thickness is shown in Figure 17; the pressure distribution is shown in Figure 18. Table 4 illustrates the effects of surface roughness on the torque and direct stiffness coefficients. It is noted that roughness of the housing alone can increase the stiffnesses by 43 to 52% with less than 18% increase in torque, while roughness of the rotor alone decreases the stiffnesses with equivalent increase in torque.

Table 4 Effect of roughness on torque and direct stiffnesses

roughness (mils)		torque	K_{zz}	$K_{\alpha\alpha} = K_{\beta\beta}$
rotor	housing	(in-lb)	(10^8lb/in)	(10^8lb-in/rad)
0.02	0.02	2,900	245	1,956
0.02	0.00	2,354	158	1,153
0.00	0.02	2,366	263	2,035
0.00	0.00	2,006	184	1,337

Sample 17 illustrates a hydroynamically supported face seal. The sealed pressure at the inner radius is 1000 psi higher than the outer radius (PL1). Eight Rayleigh steps are equally sapced along the circumference and are fed from the inner radius by a deep radial groove. A misalignment ratio of 50% is specified about the x axis. The resulting film thickness is shown in Figure 19 and the pressure distribution is shown in Figure 20.

Sample 15A and 15B are similar to 3A and 3C, respectively, but with a finer mesh, which takes significantly longer execution times (2116 and 1702 sec). The resulting film thickness and pressure distributions are shown in Figure 21 and Figure 22.

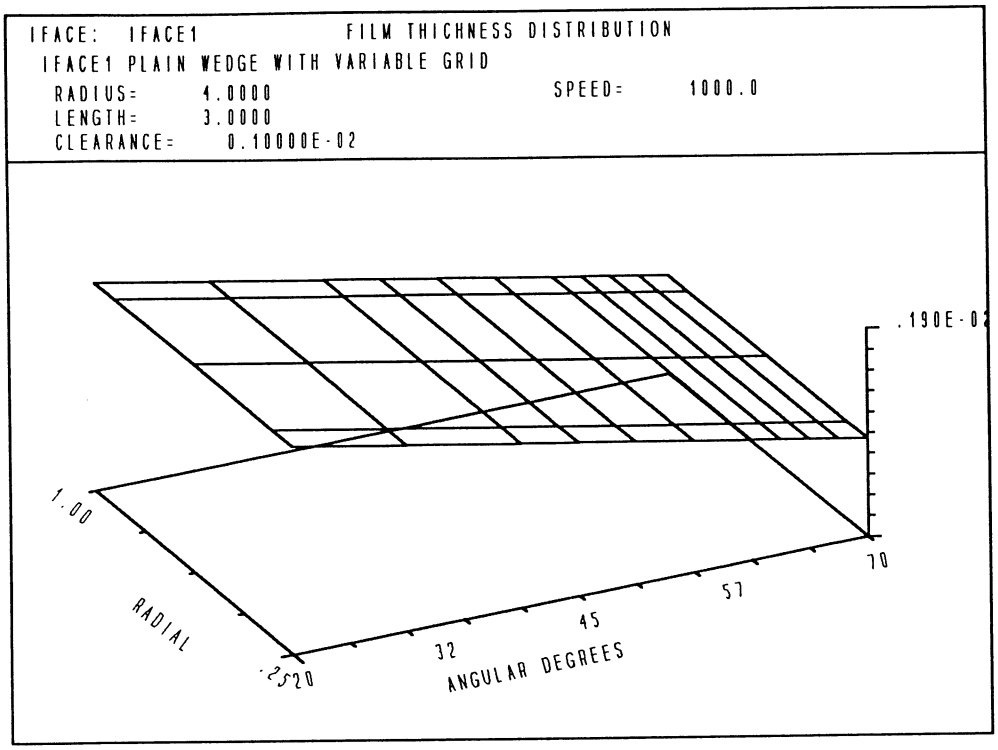

Figure 11 Film thickness distribution for sample 1.

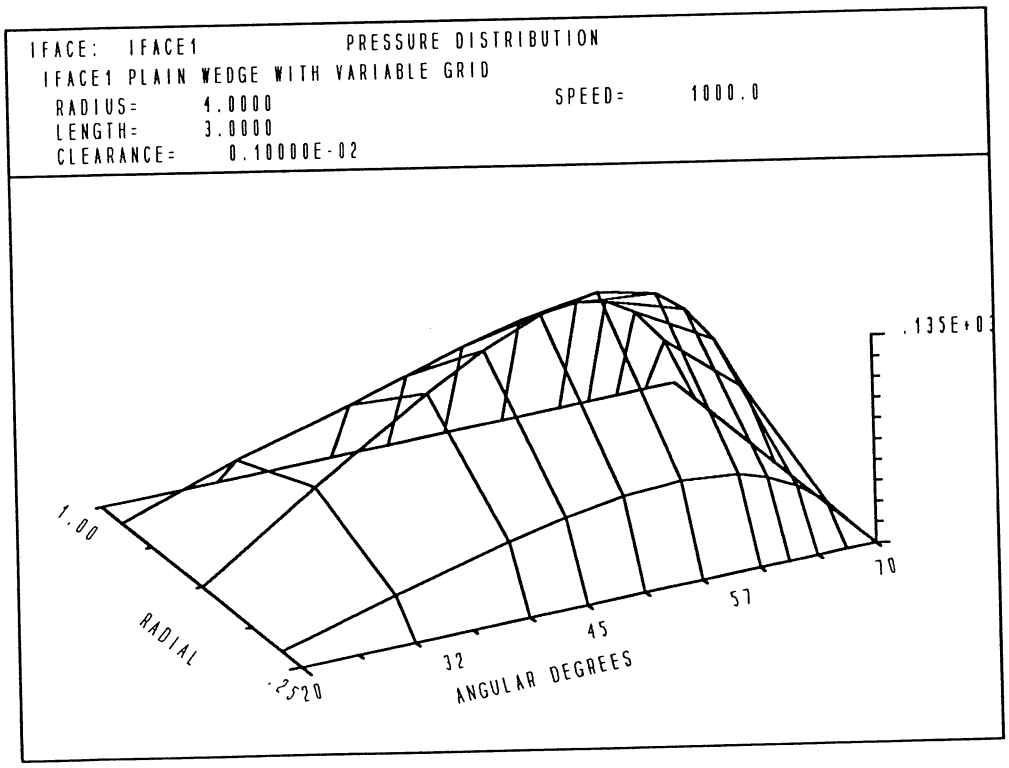

Figure 12 Pressure distribution for sample 1.

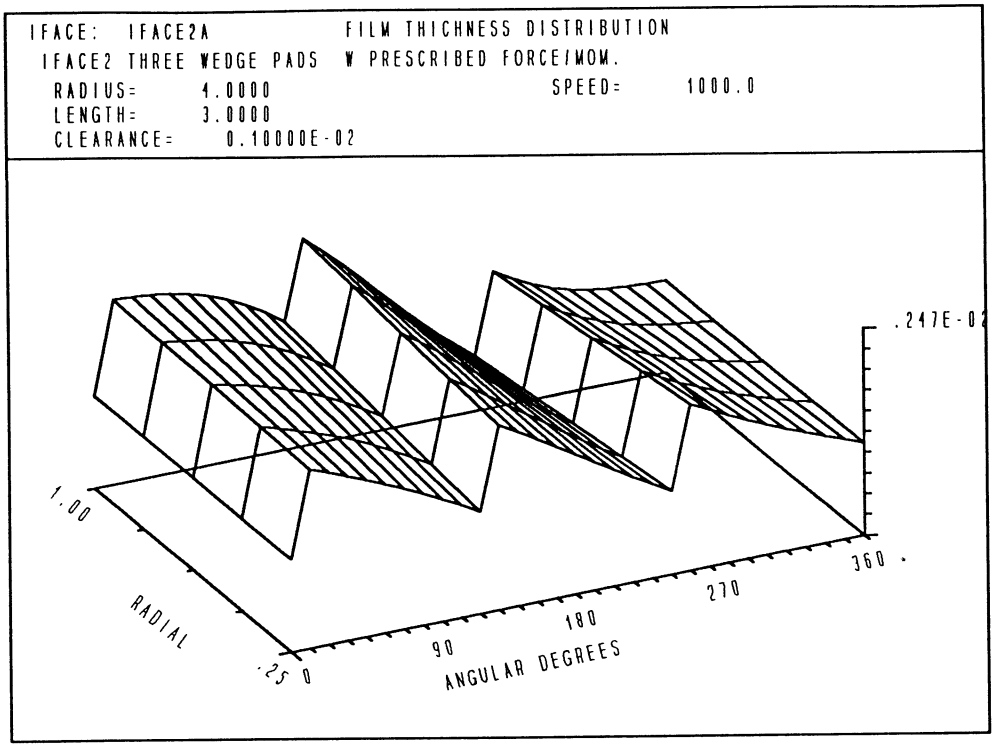

Figure 13 Film thickness distribution for sample 2A.

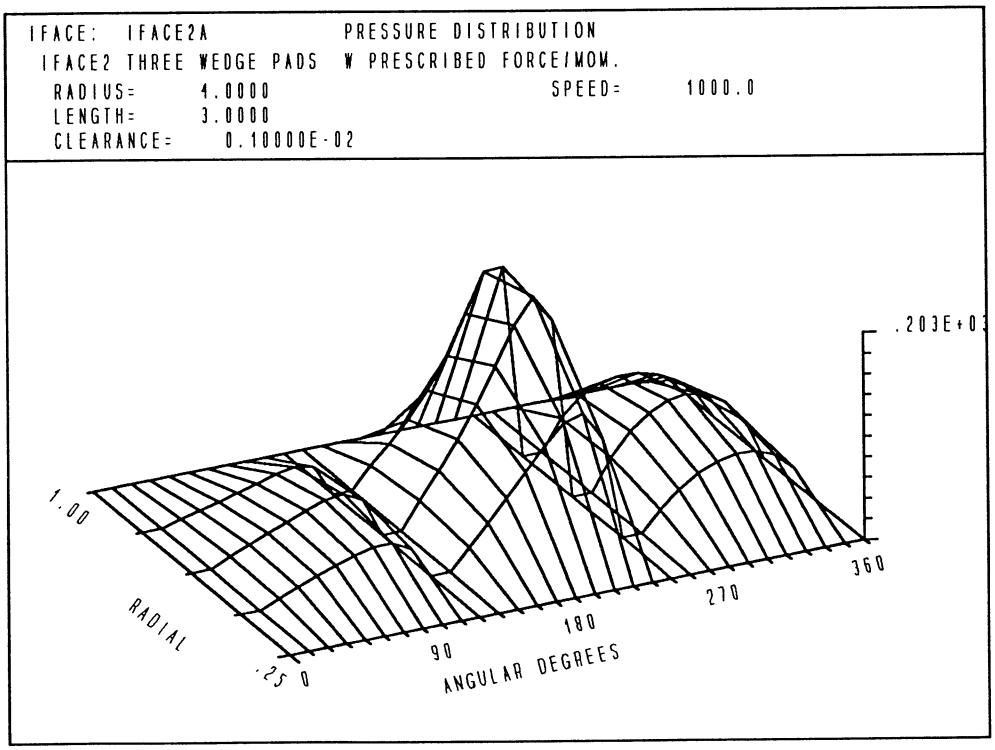

Figure 14 Pressure distribution for sample 2A.

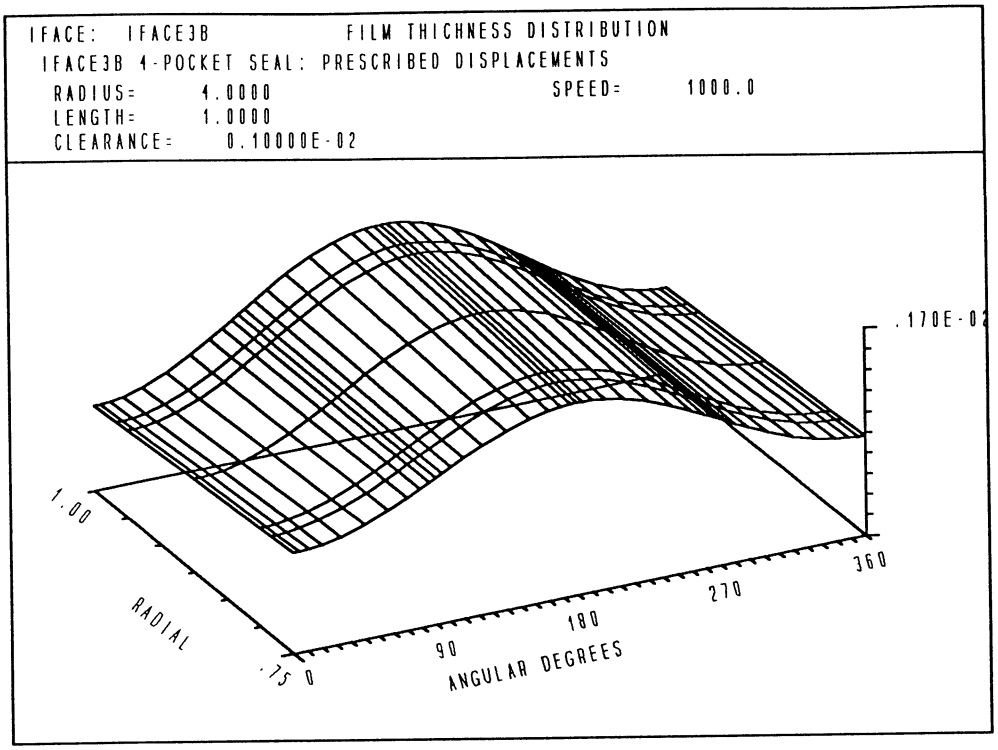

Figure 15 Film thickness distribution for sample 3B

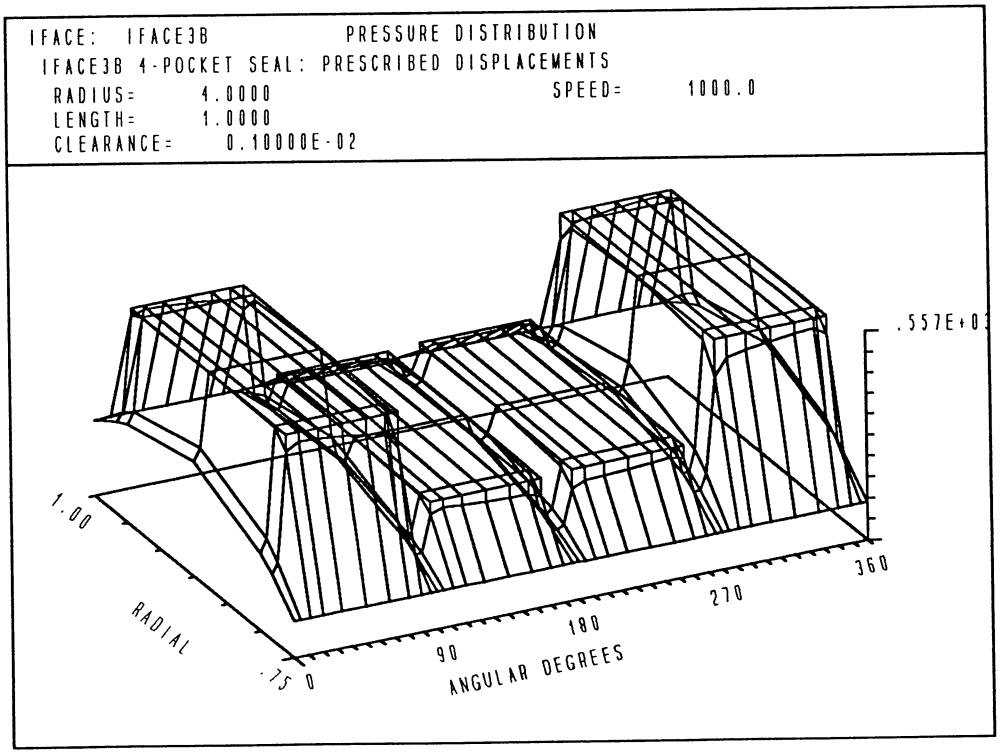

Figure 16 Pressure distribution for sample 3B.

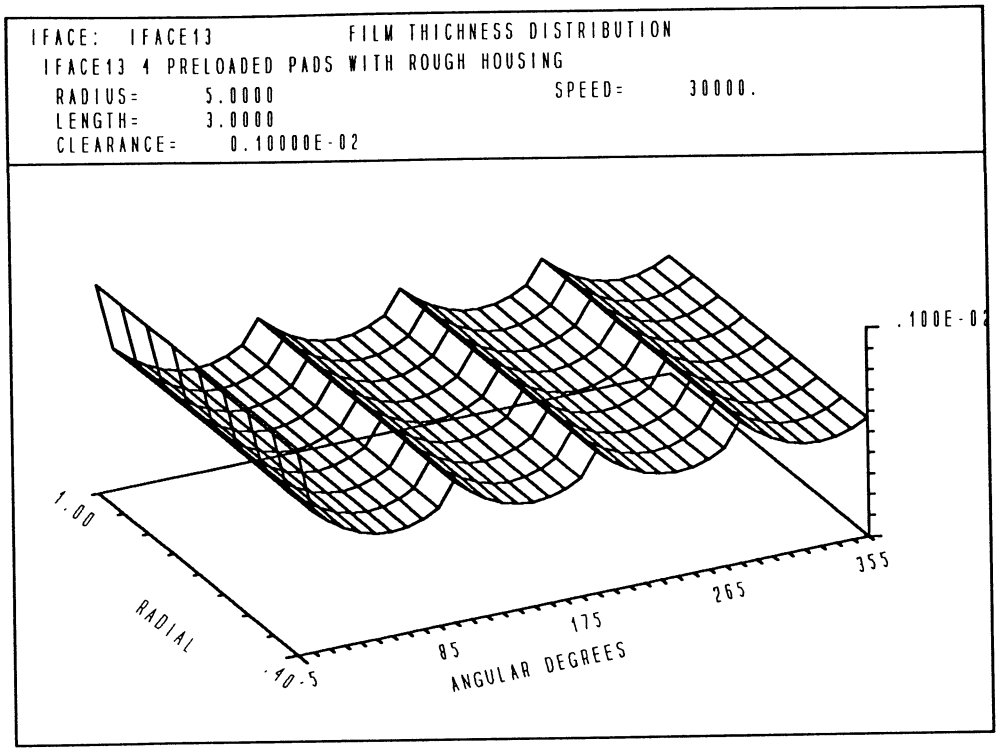

Figure 17 Film thickness distribution for sample 13.

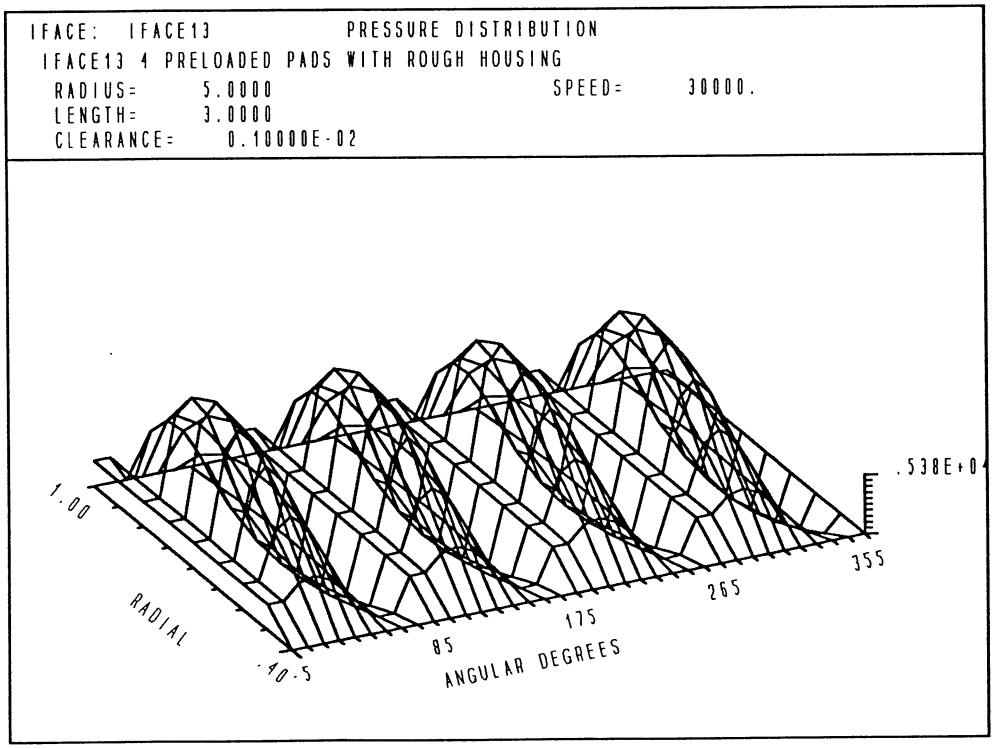

Figure 18 Pressure distribution for sample 13.

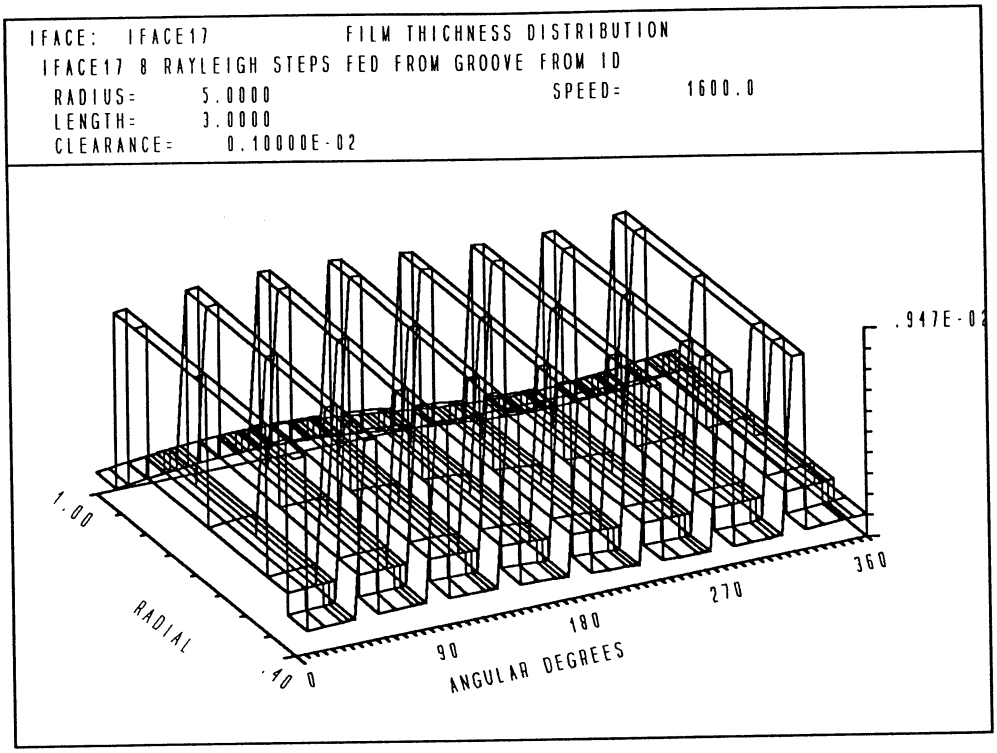

Figure 19 Film thickness distribution for sample 17.

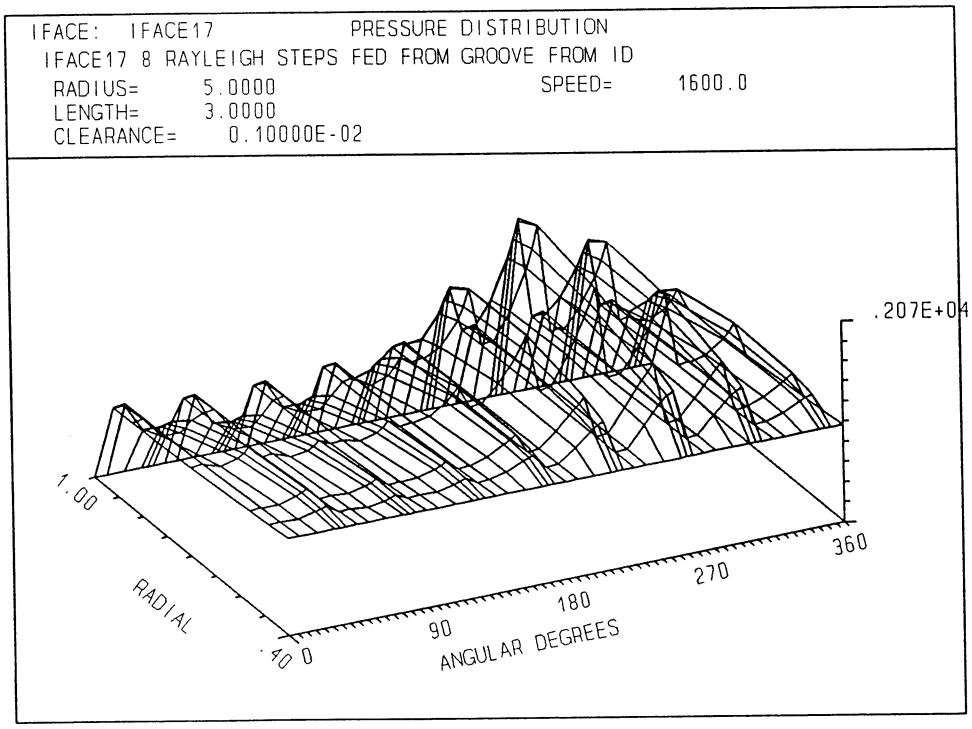

Figure 20 Pressure distribution for sample 17.

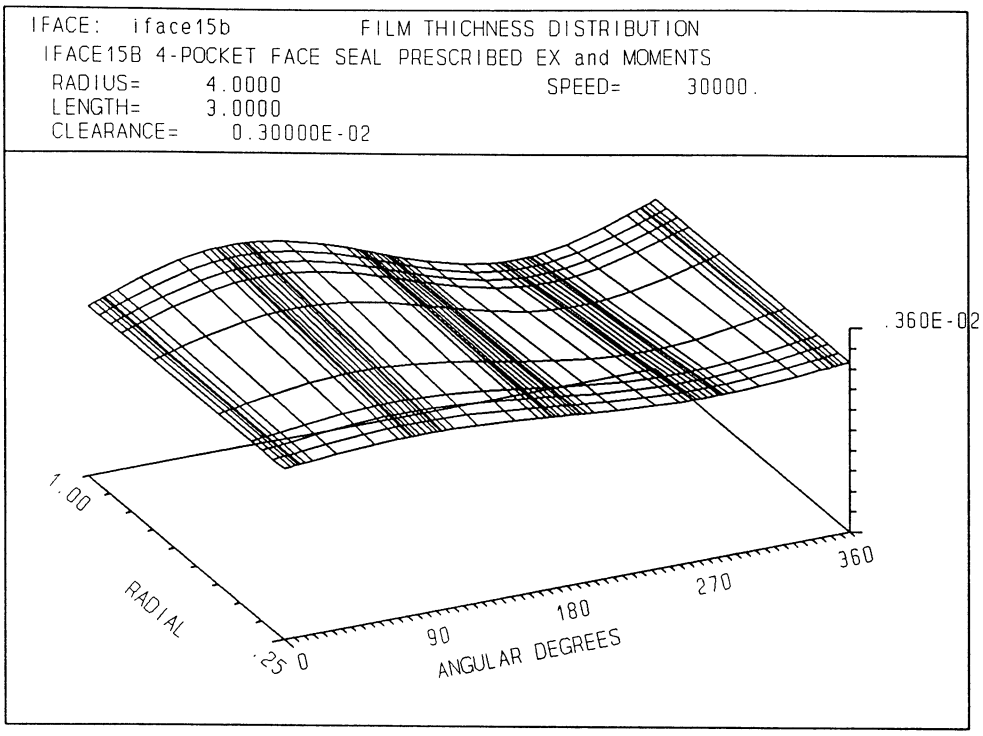

Figure 21 Film thickness distribution for sample 15B.

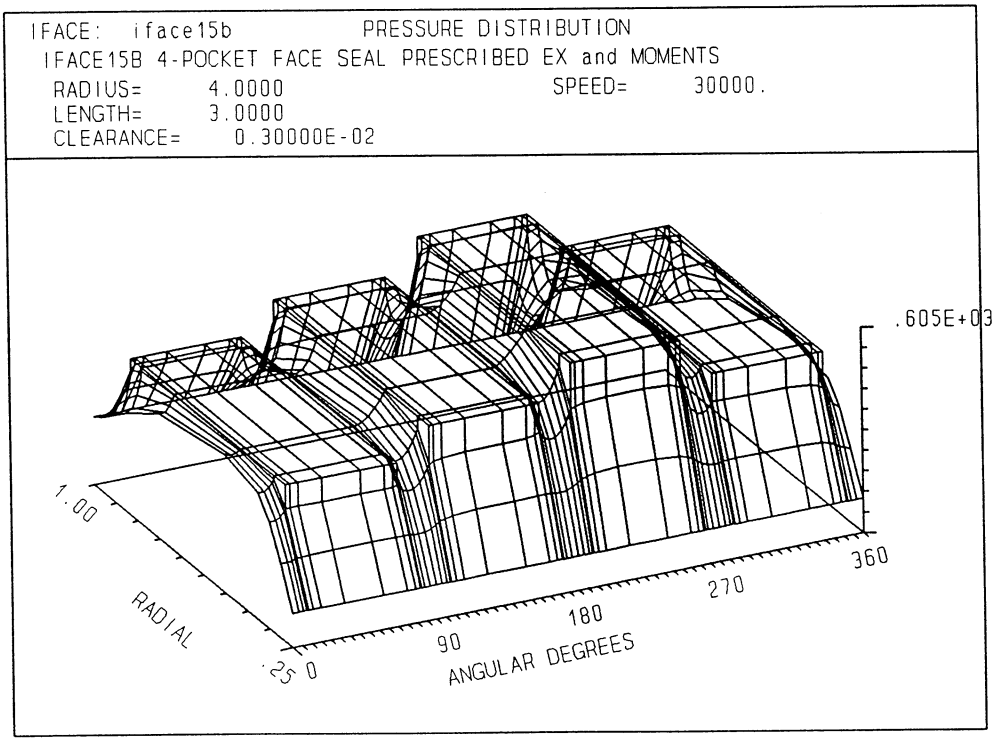

Figure 22 Pressure distribution for sample 15B.

6.0 VERIFICATION

During its development for cylindrical seals capability (as the code ICYL documented in reference 1) IFACE has been compared with the results of two other MTI computer codes as well as currently published data. The first comparison was against a generic bearing program with many similar capabilities (GBEAR) based on the turbulent lubrication theory of Ng and Pan. A second comparison against a laminar bearing program (GASBEAR) was used to verify the calculations of moments and angular coefficients. Finally, comparison were made against calculations published by San Andrés in Reference [17]. (See Reference 1 for comparisons).

The first of the MTI computer codes is GBEAR which is fully described in Reference 2. This program is based on the turbulent lubrication theory of Ng and Pan[14], and does not include surface roughness, housing rotation or calculation of misalignment coefficients. It includes inertia pressure drop at exit from pockets but not from the seal ends.

Calculations were made with a 90° seal sector at an eccentricity ratio of 0.5 and with a pocket at its center with a prescribed pressure ratio of 0.5. Table 5 shows a comparison of pocket flow, orifices size, force, and stiffness and damping coefficients. As expected, comparisons of GBEAR against ICYL with the same friction model (IFRIC=0) yielded nearly identical results. With the new friction model that includes surface roughness effects, ICYL calculates lower torque(-32%), lower pocket flow (-13%) and orifice size (-7%), and force components(-6%). Very good agreement in the stiffness coefficients (-4%), and slightly higher damping coefficients(+13%) are obtained.

Table 5 Comparison against GBEAR.

	GBEAR	ICYL IFRIC=0	ICYL IFRIC=3	ICYL IFRIC=4
Recess flow (in^3/s)	25.75	25.21	20.931	22.316
Orifice diam. (in)	0.0833	0.0820	0.0752	0.0776
Torque (lb-in)	14.38	14.32	8.791	9.771
Power (Lb-in/s)	45,171	44,971	27,617	30,696
Fx (Lb)	3,694	3,358	3,352	3,477
Fy (Lb)	-3,488	-3,122	-3,083	-3,346
Kxx (10^6 Lb/in)	2.352	2.267	2.329	2.344
Kxy (10^6 Lb/in)	-1.461	-1.378	-1.280	-1.397
Kyx (10^6 Lb/in)	-1.998	-1.874	-1.871	-1.961
Kyy (10^6 Lb/in)	1.573	1.481	1.406	1.564
Bxx (Lb/in)	232.08	234.79	269.01	274.46
Bxy (Lb/in)	-175.53	-175.87	-194.38	-199.65
Byx (Lb/in)	-174.78	-174.10	-192.40	-200.56
Byy (Lb/in)	173.87	173.79	187.57	196.53

Other comparisons against GBEAR in the laminar regime and without pockets yielded identical results.

A second MTI computer code with the fluid compressibility turned off (GASBEAR) was used to verify the calculation of the 24 stiffness and damping coefficients which involve rotor misalignment. GASBEAR was written for use in conjunction with plain journal bearings and cylindrical seals and does not treat turbulence or pressurized pockets. The comparison, in the laminar regime and with the same finite difference mesh, yielded identical coefficients.

More details on these comparisons are found in reference 1.

7.0 OPERATING ENVIRONMENT

7.1 Compilation and memory requirements

The computer code IFACE was written using the WATCOM FORTRAN compiler under ver. 2.0 of IBM's OS/2 operating system. The source program is compiled and linked with the following two commands:

```
WFC386  /4 /FPI87 /MF /OX /ERRORFILE *.FOR
WLINK.EXE  SYS OS2V2 PMCOMPATIBLE NAME ICYL1.EXE *.OBJ
```

7.2 Error messages

Following are descriptions of the error messages produced by the program. If the error number is positive, the program execution stops with a FORTRAN message of: "Return code 1" to the user's screen. If the error number is negative, the program execution continues with the next case in the input file. The fields underlined in the descriptions below are variable and depend on the program inputs. The output messages are written to the output file, except when an input file is not found (error number 11), in which case the message is written to the user screen.

The following error messages, without assigned numbers, occur during I/O to the saved pressure distribution files (ISAVEP>0 or IREADP>0):

Error number	Description
1	FORTRAN error number: 6511 reading namelist namelist variable name not found. The user should carefully check the names of each variable specified in the namelist, and if the problem reoccurs, place arrays after variables

2	Variable out of range the following variable:XXXXX has a value outside of program limits Consult program documentation.
3	NEGATIVE FILM THICKNESS REQUESTED BY THE FOLLOWING VALUES OF EX, EY, ALFA, BETA: SUGGESTED USER ACTION: o REDUCE THE SPECIFIED APPLIED FORCES/MOMENTS o REDUCE THE SPECIFIED ECCENTRICITY/MISALIGNMENT This warns the user that the prescribed displacements and/or misalignments exceed allowable limits and should be reduced. If this message occurs during iterations for rotor position, the new guess is outside of the domain limited by that of solid contact with he housing, and either the applied forces/moments should be reduced or increased more slowly from previous cases.
-4	*** WARNING *** ***ITERATION LIMIT:NIT(2)=_____ reached in iteration for pressure distribution Occurs when the Newton-Raphson iteration procedure for finding the pressure distribution does not converge to within a relative error of ECR(2) in NIT(2) iterations. RECOMMENDED USER ACTION: Increase NIT(2), ECR(2), or try using the more refined velocity component calculations with IFRIC=4. If this fails, try using a finer grid.
-5	*** WARNING *** NIT(3)=_____ Maximum variable Y error =_____ Maximum equation error =_____ Maximum number of outer iteration loop reached. Occurs when the Newton-Raphson iteration procedure for finding the rotor position and pocket pressures does not converge to within a relative error of ECR(3) in NIT(3) iterations. RECOMMENDED USER ACTION: Increase NIT(3), ECR(3), or try a different guess for position and/or pocket pressures.
6	Consecutive diverging iterations RECOMMENDED USER ACTION: Increase MAXDIT. If preceded by: MAXIMUM ERROR=_____ it is in the outer iterations for position and pocket pressures, and the user should try changing rotor displacements or applied forces more gradually. If preceded by: dpmax=_____ it is in the iterations for pressure and the user should try to refine the mesh.

7	Moments cannot be specified with ISYM=1
9	u,v iteration limit reached NIT(1) NUMBER OF ITERATIONS: NIT(1)=____ ERROR CRITERIA: ECR(1)=_____ Try: increasing NIT(1) or increasing ECR(1), or using the more refined velocity component calculations with IFRIC=4.
-10	*** ALLOCATION ERROR: REQUESTED MEMORY= DDDDDDD EXCEEDS: DDDDD Decrease M or N, or use version of program with larger MAXMEM
11	Input file not found: XXXXXX.inp or Input file not specified Return code 1
14	Internal error in program Zero flow in pocket i1= 1 This error should not normally occur. If it does, check to see if inputs are correct.
16	DETERMINANT=0 at J=_____ This error would occur in the highly unlikely event that a singular matrix was encountered during the column method solution for the pressures.
	Error writing to file:XXXXXX The user should check that sufficient disk space is available.
	Error or EOF reading from file:XXXXX
	Mismatch in mesh size M, N, NPOCK=_____ Previously saved file:_____ has: MFILE, NFILE, NPOCKF=_____ The user should check that the mesh size, number of pockets and their location match with the case that generated the saved file.

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APPENDIX A

Input and Output Listings
for Sample Problems

```
06/01/1993  10:18        Filename: IFACE1.OUT                                  Page   1

Incompressible FACE seal program (IFACE) 06/01/93  10:18:35   iface1

&INPUTS
TITLE= 'IFACE1 PLAIN WEDGE WITH VARIABLE GRID'
CREF=   0.001,      RHO=   1.0E-4,      EX=   -0.1,
RADIUS= 4.,         XMU=   1.0E-6,      PCAV=  -1000,
LENGTH= 3.,         RPMJ=  1000,        PSUP=  100.,
TS=     20,         XKE=   0.0,
TE=     70.,        IFACE=  1,         IPER=0,
M=      5,          N=     11,          UNITS= 'ENGLISH',
I1F=1, I2F= 5,      J1F=1, J2F=11,      DELTA(1,1)= 0.001, 0.0, -0.001,
DTH= 0.2, 0.2, 0.1, 0.1, 0.1, 0.1, 0.05, 0.05, 0.05, 0.05,
DZT= 0.1, 0.4, 0.4, 0.1,
&

IFACE1 PLAIN WEDGE WITH VARIABLE GRID

Input values:

Seal Type: Face seal
Outer Radius =   4.0000     inches
inner Radius =   1.0000     inches
Clearance =  1.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =   1000.0     r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Inertia pressure drop coefficient = 0.00000E+00

                         Inside      Outside radius
Pressure at top    =  0.00000E+00 0.00000E+00 psi
Pressure at bottom =  0.00000E+00 0.00000E+00 psi
Viscosity =  1.00000E-06 psi-sec
Density =  1.00000E-04 lb-s**2/in**4

Number of radial grid intervals =            4
Number of circumferential grid intervals =  10

   K  I1F  I2F  J1F  J2F DELTA(1,K) DELTA(2,K) DELTA(3,K) DELTA(4,K) DELTA(5,K)

   1    1    5    1   11   0.001000   0.000000  -0.001000   0.000000    -999.00

Pressure scale P0=  100.00     psi
Dimensionless parameters:
   Speed of rotor surface            XLj=  100.53
   Speed of housing surface          XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 0.00000E+00
   Couette Reynolds numbers          RE0=  41.888
   Poisseuille Reynolds numbers      RE0S=  2.5000

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components

                          Outputs:
Pressure, psi
            1             2             3             4             5
   1  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   2  0.0000000E+00   20.23748       49.27116       25.24620       0.0000000E+00
   3  0.0000000E+00   38.89298       94.26752       44.50680       0.0000000E+00
   4  0.0000000E+00   46.78228       113.9580       55.66090       0.0000000E+00
   5  0.0000000E+00   52.56619       128.9920       66.39350       0.0000000E+00
   6  0.0000000E+00   54.66607       135.4524       75.45857       0.0000000E+00
   7  0.0000000E+00   50.39166       126.3423       78.64873       0.0000000E+00
   8  0.0000000E+00   44.42464       112.0863       75.04895       0.0000000E+00
   9  0.0000000E+00   34.86971       88.55113       64.36269       0.0000000E+00
```

```
06/01/1993  10:18        Filename: IFACE1.OUT                                  Page   2

   10  0.0000000E+00   20.57713       52.59522       41.91374       0.0000000E+00
   11  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00

                          x              y              z
Eccentricity ratio=                                  -0.10000
Misalignment ratio=    1.27323-313    1.27323-313
Axial force       =                                   358.85      lbs
Moment components =     734.78        -627.04                     in-lb

                         Location
Maximum pressure       (  3,  6)=     135.45     psi
Minimum film thickness (  1, 11)=    9.00000E-04 inches

Radial flow from inside=   -3.20265E-02 in**3/sec
Radial flow  to outside=    0.13002     in**3/sec
Circumferential flow at start =    0.59424     in**3/sec
Circumferential flow at   end =    0.43219     in**3/sec
Overall flow error  =    1.18424E-16 in**3/sec
Torque about z-axis =     6.3153     in-lb
Power loss          =     375.62     in-lb/sec

Pressures & velocities written to file:  iface1.888
IFACE Analysis Completed 06/01/93  10:18:38      3.75 SEC
```

```
        Pressure Iter.No.  1, Max.change @ (  3,  6)=    1.35452
        Pressure Iter.No.  2, Max.change @ (  3,  9)=   2.716931E-10
 Pressures & velocities written to file:  iface1.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

```
Incompressible FACE seal program (IFACE) 06/01/93  10:23:18   iface2a

&INPUTS
TITLE= 'IFACE2 THREE WEDGE PADS  W PRESCRIBED FORCE/MOM.'
CREF=   0.001,      RHO=   1.0E-4,      FXG=-1719.6, MXG=1237.5, MYG=-1483.9,
RADIUS= 4.,         XMU=   1.0E-6,      PCAV=  -1000,
LENGTH= 3.,         RPMJ=  1000,        PSUP=  100.,
TS=      0,         XKE=   0.0,         NPADS=3,
TE=    120.,        IFACE=  1,          IPER=1,
M=       5,         N=     11,          UNITS= 'ENGLISH',
I1F(1)=1, I2F(1)= 5, J1F(1)=1, J2F(1)= 2, DELTA(5,1)= 0.000,
I1F(2)=1, I2F(2)= 5, J1F(2)=2, J2F(2)=11, DELTA(1,2)= 0.001, 0.0, -0.001,
&
The above values of FXG,MXG, and MYG
are the negative of the results obtained with:
EX= 0.1,   ALFA= 0.5,

IFACE2 THREE WEDGE PADS  W PRESCRIBED FORCE/MOM.

Input values:

Seal Type: Face seal
Outer Radius =   4.0000      inches
inner Radius =   1.0000      inches
Clearance =  1.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =   1000.0      r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient = 0.00000E+00

                          Inside      Outside radius
Pressure at top     =  0.00000E+00 0.00000E+00 psi
Viscosity =  1.00000E-06 psi-sec
Density =  1.00000E-04 lb-s**2/in**4

Number of radial grid intervals =            4
Number of circumferential grid intervals =  30

   K  I1F  I2F  J1F  J2F DELTA(1,K) DELTA(2,K) DELTA(3,K) DELTA(4,K) DELTA(5,K)

   1    1    5    1    2  0.000000   0.000000   0.000000   0.000000       0.00
   2    1    5    2   11  0.001000   0.000000  -0.001000   0.000000    -999.00
   3    1    5   11   12  0.000000   0.000000   0.000000   0.000000       0.00
   4    1    5   12   21  0.001000   0.000000  -0.001000   0.000000    -999.00
   5    1    5   21   22  0.000000   0.000000   0.000000   0.000000       0.00
   6    1    5   22   31  0.001000   0.000000  -0.001000   0.000000    -999.00

Pressure scale P0=  100.00      psi
Dimensionless parameters:
   Speed of rotor surface              XLj=  100.53
   Speed of housing surface            XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 0.00000E+00
   Couette Reynolds numbers            RE0=  41.888
   Poisseuille Reynolds numbers        RE0S=  2.5000

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components

                          Outputs:
Pressure, psi
              1             2             3             4             5
   1  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   2  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
```



```
   3  0.0000000E+00   8.276738      9.205321      5.861961      0.0000000E+00
   4  0.0000000E+00   15.53583      16.97681      10.60403      0.0000000E+00
   5  0.0000000E+00   22.32026      24.31379      15.19337      0.0000000E+00
   6  0.0000000E+00   28.85371      31.71293      20.08612      0.0000000E+00
   7  0.0000000E+00   34.87410      39.10677      25.39472      0.0000000E+00
   8  0.0000000E+00   39.28985      45.48159      30.70627      0.0000000E+00
   9  0.0000000E+00   39.48393      47.82522      34.27645      0.0000000E+00
  10  0.0000000E+00   29.97834      38.59455      30.36495      0.0000000E+00
  11  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
  12  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
  13  0.0000000E+00   20.45370      26.69652      20.64481      0.0000000E+00
  14  0.0000000E+00   40.63004      52.08231      38.75252      0.0000000E+00
  15  0.0000000E+00   61.37902      78.92604      58.49271      0.0000000E+00
  16  0.0000000E+00   83.09807      109.2425      82.59397      0.0000000E+00
  17  0.0000000E+00   104.9407      143.6210      113.1009      0.0000000E+00
  18  0.0000000E+00   123.3140      179.0608      150.2982      0.0000000E+00
  19  0.0000000E+00   128.9255      202.8940      187.2213      0.0000000E+00
  20  0.0000000E+00   101.3228      177.0093      188.0678      0.0000000E+00
  21  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
  22  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
  23  0.0000000E+00   19.74134      30.96412      29.54107      0.0000000E+00
  24  0.0000000E+00   35.59172      52.86041      46.49258      0.0000000E+00
  25  0.0000000E+00   47.46466      67.35516      55.94869      0.0000000E+00
  26  0.0000000E+00   55.39043      75.50166      59.77873      0.0000000E+00
  27  0.0000000E+00   59.20326      77.76761      58.84196      0.0000000E+00
  28  0.0000000E+00   58.22737      73.97688      53.61283      0.0000000E+00
  29  0.0000000E+00   50.80692      62.83550      43.95090      0.0000000E+00
  30  0.0000000E+00   33.53161      40.80813      28.06736      0.0000000E+00
  31  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00

                          x             y             z
Eccentricity ratio=                                   0.10000
Misalignment ratio=     0.50002       6.75807E-06
Axial force        =                                  1719.6      lbs
Moment components =    -1237.5        1483.9                      in-lb

                          Location
Maximum pressure        (  3, 19)=     202.89      psi
Minimum film thickness  (  5, 21)=    6.66979E-04 inches

Radial flow from inside=   -0.14340     in**3/sec
Radial flow  to outside=    0.36633     in**3/sec
Overall flow error  =    -0.50974     in**3/sec
Torque about z-axis =      40.119     in-lb
Power loss          =      2492.2     in-lb/sec

Pressures & velocities written to file:  iface2a.888
IFACE Analysis Completed 06/01/93  10:25:23    125.43 SEC
```

```
      ----Current position----
        Ez              ALFA            BETA
     0.00000E+00    1.27323-313    1.27323-313
Calculations at current position...
          Pressure Iter.No.  1, Max.change @ (  3, 29)=    1.13768
          Pressure Iter.No.  2, Max.change @ (  3, 27)=  -5.664521E-10
      ----Equation errors-----
        Ez              ALFA            BETA
     9.56347E-02    0.19336        -0.23186
      Max.Error for BETA    eqn.=    0.23186

Calculation of Position and/or Pocket Pressures...

 Position Iter.No.  1
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
      ----New position----
        Ez              ALFA            BETA
     3.80086E-02    0.40826        -7.27796E-02
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  4, 20)=    1.21538
          Pressure Iter.No.  2, Max.change @ (  4, 19)=   5.254739E-10
      ----Equation errors-----
        Ez              ALFA            BETA
     0.12275        2.80030E-02    2.88100E-02
      Max.Error for Ez      eqn.=    0.12275     previous=    0.23186

 Position Iter.No.  2
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
      ----New position----
        Ez              ALFA            BETA
     9.32557E-02    0.48753        -9.10168E-03
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3, 18)=  -0.173209
          Pressure Iter.No.  2, Max.change @ (  4, 18)=   7.199707E-11
      ----Equation errors-----
        Ez              ALFA            BETA
     1.10689E-02    3.96317E-03    2.19338E-03
      Max.Error for Ez      eqn.=    1.10689E-02 previous=    0.12275

 Position Iter.No.  3
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
      ----New position----
        Ez              ALFA            BETA
     9.99109E-02    0.49982        -1.20747E-04
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3,  9)=  -1.840254E-02
          Pressure Iter.No.  2, Max.change @ (  4,  3)=  -1.225720E-11
      ----Equation errors-----
        Ez              ALFA            BETA
     1.31573E-04    6.67114E-05    1.36874E-05
      Max.Error for Ez      eqn.=    1.31573E-04 previous=    1.10689E-02

 Position Iter.No.  4
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
```



```
      ----New position----
        Ez              ALFA            BETA
     0.10000        0.50002        6.75807E-06
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3,  9)=  -2.668667E-04
          Pressure Iter.No.  2, Max.change @ (  4,  4)=  -2.118306E-13
      ----Equation errors-----
        Ez              ALFA            BETA
    -3.11966E-08    3.08009E-08   -1.49675E-08
      Max.Error for Ez      eqn.=    3.11966E-08 previous=    1.31573E-04
 Pressures & velocities written to file:  iface2a.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

Incompressible FACE seal program (IFACE) 06/01/93 10:54:37 iface3a

```
&INPUTS
TITLE= 'IFACE3A 4-POCKET FACE SEAL: CALCULATION OF DORIF'
CREF=   0.001,     RHO=   1.0E-3,     EX=    0.0,      Fxg= -999.,
RADIUS= 4.,        XMU=   1.0E-6,     ALFA=  0.0,      Mxg= -999.,
LENGTH= 1.,        RPMJ=  1000.,      BETA=  0.0,      Myg= -999.,
TS=      0,        RPMB=  0.0,        PCAV=  -1.E9,
TE=     90.,       XKE=   1.0,        PL1=  100.,      PR1= 200.,
IFACE=  1,         ISTIFF= 2,         NPADS=4,
M=      7,         N=     11,
ISYM=   0,         IPER=   1,
MAXDIT= 4,         IREADP= 0,
DZT=  .1, .05, .30, .30, .05, .1,
DTH=  4, 6, 8, 12, 15, 15, 12, 8, 6, 4,
NPOCK=  1,         PSUP= 1000.,       CD= 0.6,
M1=   2,     N1=   3,                 DORIF=0.,
M2=   6,     N2=   9,                 PPOCK= 500.,
&END
```

```
IFACE3A 4-POCKET FACE SEAL: CALCULATION OF DORIF

Input values:

Seal Type: Face seal
Outer Radius =   4.0000      inches
inner Radius =   3.0000      inches
Clearance =  1.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =   1000.0      r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient =  1.0000

                          Inside      Outside radius
Pressure at top     =   100.00      200.00      psi
Viscosity =  1.00000E-06 psi-sec
Density =  1.00000E-03 lb-s**2/in**4

Number of radial grid intervals =            6
Number of circumferential grid intervals =  40

Data for   4 pressurized pockets:
Supply pressure =   1000.0      psi
Discharge Coeff. = 0.60000

Pocket        radial            Circumferential     Pressure
Number    Start   End             Start   End       (psi            )
 1                2     6          3     9            500.00
 2                2     6         13    19            500.00
 3                2     6         23    29            500.00
 4                2     6         33    39            500.00

Pressure scale P0=  1000.0      psi
Dimensionless parameters:
   Speed of rotor surface            XLj=  10.053
   Speed of housing surface          XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 2.17014E-04
   Couette Reynolds numbers          REO=  418.88
   Poisseuille Reynolds numbers      REOS=  250.00

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components
Orifice diameter calculated:
DORIF=        0.069166827961722
```


Outputs:

Pressure, psi	1	2	3	4	5
	6	7			
1	100.0000	173.3799	203.8801	288.4654	248.0758
	233.5175	200.0000			
2	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
3	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
4	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
5	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
6	100.0000	464.0455	500.0000	500.0000	500.0000
	477.6885	200.0000			
7	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
8	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
9	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
10	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
11	100.0000	173.3799	203.8801	288.4654	248.0758
	233.5175	200.0000			
12	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
13	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
14	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
15	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
16	100.0000	464.0455	500.0000	500.0000	500.0000
	477.6885	200.0000			
17	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
18	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
19	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
20	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
21	100.0000	173.3799	203.8801	288.4654	248.0758
	233.5175	200.0000			
22	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
23	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
24	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
25	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
26	100.0000	464.0455	500.0000	500.0000	500.0000
	477.6885	200.0000			
27	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
28	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
29	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
30	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			

31	100.0000	173.3799	203.8801	288.4654	248.0758
	233.5175	200.0000			
32	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
33	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
34	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
35	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
36	100.0000	464.0455	500.0000	500.0000	500.0000
	477.6885	200.0000			
37	100.0000	464.0453	500.0000	500.0000	500.0000
	477.6884	200.0000			
38	100.0000	463.9320	500.0000	500.0000	500.0000
	477.6454	200.0000			
39	100.0000	438.0385	491.5832	499.1188	494.9120
	458.7915	200.0000			
40	100.0000	200.1899	238.7022	321.4773	275.3406
	253.7685	200.0000			
41	100.0000	173.3799	203.8801	288.4654	248.0758
	233.5175	200.0000			

	x	y	z	
Eccentricity ratio=			0.00000E+00	
Misalignment ratio=	0.00000E+00	0.00000E+00		
Axial force =			9376.1	lbs
Moment components =	2.90544E-11	-2.05391E-12		in-lb

	Location		
Maximum pressure	(3, 4)=	500.00	psi
Minimum film thickness	(1, 1)=	1.00000E-03	inches

Pressurized Pockets: Orifice diameter = 6.91668E-02 inches

Pocket Number	Pressure (psi)	Flow (in**3/sec)
1	500.00	2.2544
2	500.00	2.2544
3	500.00	2.2544
4	500.00	2.2544
	Total=	9.0177

Radial flow from inside=	-4.5751	in**3/sec
Radial flow to outside=	4.4426	in**3/sec
Overall flow error =	2.88516E-11	in**3/sec
Torque about z-axis =	12.872	in-lb
Power loss =	1086.2	in-lb/sec

Dynamic Coefficients (Force unit / displacement unit)

Disp.	z inches	inches	α radians	β radians	Force unit
Kz	1.27149E+07	0.00000E+00	-160.05	-1955.0	lbs
Kα	-106.23	0.00000E+00	3.32080E+07	1.55030E+06	in-lb
Kβ	-106.44	0.00000E+00	-1.54696E+06	3.32034E+07	in-lb
Bz	10817.	0.00000E+00	1.9515	-7.78368E-02	lbs-sec
Bα	46.896	0.00000E+00	29579.	2.0827	in-lb-sec
Bβ	293.72	0.00000E+00	0.46166	29579.	in-lb-sec

Pressures & velocities written to file: iface3a.888
IFACE Analysis Completed 06/01/93 11:01:21 403.87 SEC

```
          Pressure Iter.No.  1, Max.change @ (  4, 10)=   0.172089
          Pressure Iter.No.  2, Max.change @ (  2, 19)=  -4.771839E-03
          Pressure Iter.No.  3, Max.change @ (  2, 23)=  -2.854674E-05
          Pressure Iter.No.  4, Max.change @ (  2,  3)=  -8.184021E-10

Calculation of Stiffness and/or Damping Coefficients

Calculating Stiffness Coefficients...Perturbing displacement:z
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.50000         0.50000         0.50000         0.50000
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     -2.68283E-04    -2.68283E-04    -2.68283E-04    -2.68283E-04
       Max.Error for PPOCK  1eqn.=    2.68283E-04
       Max.Error for PPOCK  3eqn.=    4.88470E-08 previous=    2.68283E-04

Calculating Stiffness Coefficients...Perturbing displacement:α
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.49993         0.49993         0.49993         0.49993
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      1.08987E-04     1.20564E-04     4.27247E-04     4.15678E-04
       Max.Error for PPOCK  3eqn.=    4.27247E-04
       Max.Error for PPOCK  2eqn.=    1.43618E-08 previous=    4.27247E-04

Calculating Stiffness Coefficients...Perturbing displacement:β
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.49996         0.49996         0.50004         0.50004
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      3.06744E-04    -1.15629E-05    -3.06862E-04     1.15781E-05
       Max.Error for PPOCK  3eqn.=    3.06862E-04
       Max.Error for PPOCK  3eqn.=    5.47655E-08 previous=    3.06862E-04

Calculating Damping Coefficients...B Perturbing velocity    :z
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.50004         0.49996         0.49996         0.50004
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     -1.48603E-04     1.58182E-04     1.46561E-04    -1.60190E-04
       Max.Error for PPOCK  4eqn.=    1.60190E-04
       Max.Error for PPOCK  4eqn.=    2.24770E-08 previous=    1.60190E-04

Calculating Damping Coefficients...B Perturbing velocity    :α
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.50000         0.50000         0.50000         0.50000
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      4.03348E-07     4.32621E-07     1.56040E-06     1.53175E-06
       Max.Error for PPOCK  3eqn.=    1.56040E-06
       Max.Error for PPOCK  3eqn.=    1.75715E-10 previous=    1.56040E-06

Calculating Damping Coefficients...B Perturbing velocity    :β
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.50000         0.50000         0.50000         0.50000
```



```
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      1.13276E-06     6.60477E-11    -1.13254E-06     1.50048E-10
       Max.Error for PPOCK  1eqn.=    1.13276E-06
       Max.Error for PPOCK  3eqn.=    1.11494E-10 previous=    1.13276E-06
 Pressures & velocities written to file:  iface3a.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

Incompressible FACE seal program (IFACE) 06/01/93 11:15:07 iface3b

```
&INPUTS
TITLE= 'IFACE3B 4-POCKET SEAL: PRESCRIBED DISPLACEMENTS'
CREF=   0.001,      RHO=   1.0E-3,      EX=    0.2,
RADIUS= 4.,         XMU=   1.0E-6,      ALFA=  0.0,
LENGTH= 1.,         RPMJ=  1000.,       BETA=  0.5,
TS=      0,         RPMB=  0.0,         PCAV=  -1.E9,
TE=     90.,        XKE=   1.0,         PL1=  100.,      PR1= 200.,
IFACE=  1,          ISTIFF= 0,          NPADS=4,
M=      7,          N=     11,
ISYM=   0,          IPER=   1,
MAXDIT= 4,          IREADP= 0,
DZT=  .1, .05, .30, .30, .05, .1,
DTH=  4, 6, 8, 12, 15, 15, 12, 8, 6, 4,
NPOCK=  1,          PSUP= 1000.,        CD= 0.6,
M1=   2,     N1=    3,                  DORIF=0.068,
M2=   6,     N2=    9,                  PPOCK= 500.,
&END
```

IFACE3B 4-POCKET SEAL: PRESCRIBED DISPLACEMENTS

Input values:

```
Seal Type: Face seal
Outer Radius =    4.0000      inches
inner Radius =    3.0000      inches
Clearance =  1.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =    1000.0      r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient =  1.0000

                          Inside      Outside radius
Pressure at top     =    100.00       200.00      psi
Viscosity =  1.00000E-06 psi-sec
Density =  1.00000E-03 lb-s**2/in**4

Number of radial grid intervals =            6
Number of circumferential grid intervals =  40

Data for   4 pressurized pockets:
Orifice diameter =  6.80000E-02 inches
Supply pressure =    1000.0      psi
Discharge Coeff. = 0.60000

Pocket        radial            Circumferential     Pressure
Number     Start   End              Start   End     (psi            )
 1                 2     6          3     9           500.00
 2                 2     6         13    19           500.00
 3                 2     6         23    29           500.00
 4                 2     6         33    39           500.00

Pressure scale P0=  1000.0      psi
Dimensionless parameters:
   Speed of rotor surface            XLj=  10.053
   Speed of housing surface          XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 2.17014E-04
   Couette Reynolds numbers          RE0=  418.88
   Poisseuille Reynolds numbers      REOS=  250.00

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components
```


Outputs:

Pressure, psi	1	2	3	4	5
	6	7			
1	100.0000	176.5186	208.9401	306.3695	262.4044
	243.9733	200.0000			
2	100.0000	205.7694	246.3324	340.0217	291.8575
	266.3645	200.0000			
3	100.0000	494.1063	535.7906	538.5263	537.9547
	519.8716	200.0000			
4	100.0000	514.6059	538.8821	538.8821	538.8821
	529.4975	200.0000			
5	100.0000	510.8794	538.8821	538.8821	538.8821
	527.0733	200.0000			
6	100.0000	504.5271	538.8821	538.8821	538.8821
	522.6334	200.0000			
7	100.0000	495.9725	538.8821	538.8821	538.8821
	516.1405	200.0000			
8	100.0000	486.2862	538.8821	538.8821	538.8821
	508.3541	200.0000			
9	100.0000	445.4965	516.0673	535.8303	524.4434
	475.7237	200.0000			
10	100.0000	189.3451	223.9883	298.2845	263.4180
	245.2058	200.0000			
11	100.0000	150.1719	171.3629	235.1437	220.5734
	214.2451	200.0000			
12	100.0000	151.9956	172.6548	225.1476	218.0059
	212.8586	200.0000			
13	100.0000	251.2923	278.6840	282.7676	282.1088
	273.1511	200.0000			
14	100.0000	260.6001	282.9920	282.9920	282.9920
	276.8112	200.0000			
15	100.0000	257.1346	282.9920	282.9920	282.9920
	275.4145	200.0000			
16	100.0000	253.5090	282.9920	282.9920	282.9920
	273.9026	200.0000			
17	100.0000	250.4473	282.9920	282.9920	282.9920
	272.5819	200.0000			
18	100.0000	248.2700	282.9920	282.9920	282.9920
	271.6422	200.0000			
19	100.0000	234.8177	268.8391	281.9606	278.5348
	264.7579	200.0000			
20	100.0000	147.9440	167.1800	216.8766	215.1879
	210.9942	200.0000			
21	100.0000	137.9263	153.9955	205.8033	207.6245
	205.5179	200.0000			
22	100.0000	149.0616	168.7302	219.1676	216.5756
	211.9787	200.0000			
23	100.0000	238.7509	274.1881	288.2761	284.1931
	269.0250	200.0000			
24	100.0000	252.6475	289.4501	289.4501	289.4501
	276.5063	200.0000			
25	100.0000	254.9349	289.4501	289.4501	289.4501
	277.5624	200.0000			
26	100.0000	258.1554	289.4501	289.4501	289.4501
	279.0504	200.0000			
27	100.0000	261.9751	289.4501	289.4501	289.4501
	280.7603	200.0000			
28	100.0000	265.6336	289.4501	289.4501	289.4501
	282.3463	200.0000			
29	100.0000	256.2307	285.1827	289.3445	288.5680
	278.4100	200.0000			
30	100.0000	163.0213	188.0402	250.7936	233.4747
	224.0128	200.0000			
31	100.0000	163.2697	189.7000	266.4257	239.0481

	227.5231	200.0000			
32	100.0000	203.1858	243.3126	330.2524	283.0634
	259.3925	200.0000			
33	100.0000	458.2363	533.0099	554.3290	541.4860
	488.8919	200.0000			
34	100.0000	500.5569	557.1096	557.1096	557.1096
	523.5067	200.0000			
35	100.0000	510.9027	557.1096	557.1096	557.1096
	532.0249	200.0000			
36	100.0000	520.0646	557.1096	557.1096	557.1096
	539.1541	200.0000			
37	100.0000	526.8828	557.1096	557.1096	557.1096
	544.0434	200.0000			
38	100.0000	530.8875	557.1096	557.1096	557.1096
	546.7180	200.0000			
39	100.0000	509.1278	553.6828	556.7208	556.0617
	536.2099	200.0000			
40	100.0000	210.1919	252.4502	349.3792	298.7597
	271.4886	200.0000			
41	100.0000	176.5186	208.9401	306.3695	262.4044
	243.9733	200.0000			

	x	y	z	
Eccentricity ratio=			0.20000	
Misalignment ratio=	0.00000E+00	0.50000		
Axial force =			7932.0	lbs
Moment components =	-286.84	-5216.0		in-lb

	Location		
Maximum pressure	(3, 34)=	557.11	psi
Minimum film thickness	(7, 1)=	7.00000E-04	inches

Pressurized Pockets: Orifice diameter = 6.80000E-02 inches

Pocket Number	Pressure (psi)	Flow (in**3/sec)
1	538.88	2.0926
2	282.99	2.6094
3	289.45	2.5976
4	557.11	2.0508
	Total=	9.3503

Radial flow from inside=	-5.2991	in**3/sec
Radial flow to outside=	4.0513	in**3/sec
Overall flow error =	0.00000E+00	in**3/sec
Torque about z-axis =	11.618	in-lb
Power loss =	983.21	in-lb/sec

Pressures & velocities written to file: iface3b.888
IFACE Analysis Completed 06/01/93 11:20:59 352.07 SEC

```
      ----Current position----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     0.50000         0.50000         0.50000         0.50000
Calculations at current position...
          Pressure Iter.No.  1, Max.change @ (  4, 30)=   0.184339
          Pressure Iter.No.  2, Max.change @ (  2, 23)=  -2.938523E-02
          Pressure Iter.No.  3, Max.change @ (  2, 23)=  -2.458237E-03
          Pressure Iter.No.  4, Max.change @ (  2, 23)=  -1.626175E-05
          Pressure Iter.No.  5, Max.change @ (  6, 23)=  -8.812883E-10
      ----Equation errors-----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     0.12013         -3.3770         -3.2120         0.17035
      Max.Error for PPOCK  2eqn.=     3.3770

Calculation of Position and/or Pocket Pressures...

 Position Iter.No.  1
          Calculate Partial Derivitives of Errors...
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     0.54013         0.32165         0.32684         0.55978
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3, 14)=  -0.178353
          Pressure Iter.No.  2, Max.change @ (  6, 17)=  -1.283854E-02
          Pressure Iter.No.  3, Max.change @ (  6, 18)=  -2.534619E-04
          Pressure Iter.No.  4, Max.change @ (  6, 19)=  -1.971768E-07
          Pressure Iter.No.  5, Max.change @ (  6, 19)=  -2.627343E-13
      ----Equation errors-----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
    -3.62334E-03    -0.46984        -0.44676        -7.95935E-03
      Max.Error for PPOCK  2eqn.=     0.46984     previous=     3.3770

 Position Iter.No.  2
          Calculate Partial Derivitives of Errors...
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     0.53889         0.28572         0.29203         0.55712
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3, 14)=  -3.592358E-02
          Pressure Iter.No.  2, Max.change @ (  6, 18)=  -1.033092E-03
          Pressure Iter.No.  3, Max.change @ (  6, 19)=  -2.485020E-06
          Pressure Iter.No.  4, Max.change @ (  6, 19)=  -4.601702E-11
      ----Equation errors-----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
    -5.54396E-06    -3.07334E-02    -2.85745E-02    -1.52594E-05
      Max.Error for PPOCK  2eqn.=     3.07334E-02 previous=     0.46984

 Position Iter.No.  3
          Calculate Partial Derivitives of Errors...
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     0.53888         0.28301         0.28947         0.55711
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3, 14)=  -2.713078E-03
```



```
          Pressure Iter.No.  2, Max.change @ (  6, 18)=  -7.031706E-06
          Pressure Iter.No.  3, Max.change @ (  6, 19)=  -1.453321E-10
      ----Equation errors-----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
    -1.08466E-07    -2.08540E-04    -1.81504E-04    -9.67027E-09
      Max.Error for PPOCK  2eqn.=     2.08540E-04 previous=     3.07334E-02

 Position Iter.No.  4
          Calculate Partial Derivitives of Errors...
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     0.53888         0.28299         0.28945         0.55711
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3, 14)=  -1.864624E-05
          Pressure Iter.No.  2, Max.change @ (  6, 18)=  -3.367660E-10
      ----Equation errors-----
        PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
    -6.96308E-10    -9.21573E-08    -6.56357E-08    -1.07370E-11
      Max.Error for PPOCK  2eqn.=     9.21573E-08 previous=     2.08540E-04
 Pressures & velocities written to file:  iface3b.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

```
Incompressible FACE seal program (IFACE) 06/14/93  09:23:22   iface3c

&INPUTS
TITLE= 'IFACE3C 4-POCKET SEAL: PRESCRIBED FORCE & MOM.'
CREF=   0.001,     RHO=   1.0E-3,     EX=    0.0,      Fxg=-7932.0,
RADIUS= 4.,        XMU=   1.0E-6,     ALFA=  0.0,      Mxg= 286.84,
LENGTH= 1.,        RPMJ=  1000.,      BETA=  0.0,      Myg= 5216.0,
TS=      0,        RPMB=  0.0,        PCAV=  -1.E9,
TE=     90.,       XKE=   1.0,        PL1=  100.,      PR1= 200.,
IFACE=  1,         ISTIFF= 0,         NPADS=4,
M=      7,         N=     11,
ISYM=   0,         IPER=   1,
MAXDIT= 4,         IREADP= 1,         READP='IFACE3A.888',
DZT=  .1, .05, .30, .30, .05, .1,
DTH=  4, 6, 8, 12, 15, 15, 12, 8, 6, 4,
NPOCK=  1,         PSUP= 1000.,       CD= 0.6,
M1=   2,     N1=   3,                 DORIF=0.068,
M2=   6,     N2=   9,                 PPOCK= 500.,
&END

IFACE3C 4-POCKET SEAL: PRESCRIBED FORCE & MOM.

Input values:

Seal Type: Face seal
Outer Radius =   4.0000      inches
inner Radius =   3.0000      inches
Clearance =  1.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =   1000.0      r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient =  1.0000

                              Inside      Outside radius
Pressure at top     =   100.00      200.00      psi
Viscosity =  1.00000E-06 psi-sec
Density =  1.00000E-03 lb-s**2/in**4

Number of radial grid intervals =            6
Number of circumferential grid intervals =  40

Data for   4 pressurized pockets:
Orifice diameter =  6.80000E-02 inches
Supply pressure =   1000.0      psi
Discharge Coeff. = 0.60000

Pocket        radial            Circumferential     Pressure
Number     Start   End            Start   End      (psi              )
 1                 2     6         3      9          500.00
 2                 2     6        13     19          500.00
 3                 2     6        23     29          500.00
 4                 2     6        33     39          500.00

Pressure scale P0=  1000.0      psi
Dimensionless parameters:
   Speed of rotor surface              XLj=  10.053
   Speed of housing surface            XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 2.17014E-04
   Couette Reynolds numbers            RE0=  418.88
   Poisseuille Reynolds numbers        RE0S=  250.00

 Friction formula based on Moody diagram (Nelson)
 Newton-Raphson itertions for velocity components
Pressures & velocities read from file: IFACE3A.888
```


Outputs:

Pressure, psi	1	2	3	4	5
	6	7			
1	100.0000	176.5186	208.9401	306.3694	262.4042
	243.9732	200.0000			
2	100.0000	205.7695	246.3324	340.0216	291.8574
	266.3643	200.0000			
3	100.0000	494.1057	535.7902	538.5260	537.9544
	519.8710	200.0000			
4	100.0000	514.6054	538.8818	538.8818	538.8818
	529.4971	200.0000			
5	100.0000	510.8789	538.8818	538.8818	538.8818
	527.0728	200.0000			
6	100.0000	504.5268	538.8818	538.8818	538.8818
	522.6330	200.0000			
7	100.0000	495.9722	538.8818	538.8818	538.8818
	516.1402	200.0000			
8	100.0000	486.2861	538.8818	538.8818	538.8818
	508.3539	200.0000			
9	100.0000	445.4967	516.0673	535.8300	524.4433
	475.7237	200.0000			
10	100.0000	189.3452	223.9884	298.2847	263.4181
	245.2059	200.0000			
11	100.0000	150.1721	171.3632	235.1442	220.5737
	214.2453	200.0000			
12	100.0000	151.9959	172.6553	225.1483	218.0063
	212.8589	200.0000			
13	100.0000	251.2937	278.6856	282.7693	282.1104
	273.1525	200.0000			
14	100.0000	260.6017	282.9936	282.9936	282.9936
	276.8127	200.0000			
15	100.0000	257.1362	282.9936	282.9936	282.9936
	275.4160	200.0000			
16	100.0000	253.5106	282.9936	282.9936	282.9936
	273.9041	200.0000			
17	100.0000	250.4489	282.9936	282.9936	282.9936
	272.5834	200.0000			
18	100.0000	248.2717	282.9936	282.9936	282.9936
	271.6436	200.0000			
19	100.0000	234.8192	268.8408	281.9622	278.5364
	264.7593	200.0000			
20	100.0000	147.9445	167.1805	216.8774	215.1884
	210.9945	200.0000			
21	100.0000	137.9266	153.9959	205.8039	207.6248
	205.5181	200.0000			
22	100.0000	149.0620	168.7308	219.1683	216.5761
	211.9790	200.0000			
23	100.0000	238.7524	274.1899	288.2777	284.1947
	269.0263	200.0000			
24	100.0000	252.6491	289.4517	289.4517	289.4517
	276.5077	200.0000			
25	100.0000	254.9365	289.4517	289.4517	289.4517
	277.5639	200.0000			
26	100.0000	258.1570	289.4517	289.4517	289.4517
	279.0518	200.0000			
27	100.0000	261.9767	289.4517	289.4517	289.4517
	280.7618	200.0000			
28	100.0000	265.6351	289.4517	289.4517	289.4517
	282.3478	200.0000			
29	100.0000	256.2321	285.1843	289.3461	288.5696
	278.4114	200.0000			
30	100.0000	163.0216	188.0406	250.7942	233.4751
	224.0131	200.0000			

31	100.0000	163.2698	189.7001	266.4259	239.0482
	227.5232	200.0000			
32	100.0000	203.1858	243.3126	330.2524	283.0633
	259.3925	200.0000			
33	100.0000	458.2363	533.0097	554.3285	541.4857
	488.8918	200.0000			
34	100.0000	500.5566	557.1090	557.1090	557.1090
	523.5063	200.0000			
35	100.0000	510.9022	557.1090	557.1090	557.1090
	532.0244	200.0000			
36	100.0000	520.0640	557.1090	557.1090	557.1090
	539.1534	200.0000			
37	100.0000	526.8821	557.1090	557.1090	557.1090
	544.0427	200.0000			
38	100.0000	530.8868	557.1090	557.1090	557.1090
	546.7172	200.0000			
39	100.0000	509.1269	553.6822	556.7202	556.0611
	536.2090	200.0000			
40	100.0000	210.1919	252.4501	349.3789	298.7593
	271.4884	200.0000			
41	100.0000	176.5186	208.9401	306.3694	262.4042
	243.9732	200.0000			

	x	y	z	
Eccentricity ratio=			0.20000	
Misalignment ratio=	2.44566E-08	0.49999		
Axial force =			7932.0	lbs
Moment components =	-286.84	-5216.0		in-lb

	Location		
Maximum pressure	(3, 34)=	557.11	psi
Minimum film thickness	(7, 1)=	7.00004E-04	inches

Pressurized Pockets: Orifice diameter = 6.80000E-02 inches

Pocket Number	Pressure (psi)	Flow (in**3/sec)
1	538.88	2.0926
2	282.99	2.6094
3	289.45	2.5976
4	557.11	2.0508
	Total=	9.3503

Radial flow from inside=	-5.2991	in**3/sec
Radial flow to outside=	4.0513	in**3/sec
Overall flow error =	-1.18424E-15	in**3/sec
Torque about z-axis =	11.618	in-lb
Power loss =	983.21	in-lb/sec

Pressures & velocities written to file: iface3c.888
IFACE Analysis Completed 06/14/93 09:32:33 551.03 SEC

```
Pressures & velocities read from file: IFACE3A.888

      ----Current position----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     0.00000E+00     0.00000E+00     0.00000E+00     0.50000          0.50000
        PPOCK  3        PPOCK  4
     0.50000         0.50000
Calculations at current position...
          Pressure Iter.No.  1, Max.change @ (  3, 34)=   1.533954E-07
          Pressure Iter.No.  2, Max.change @ (  6, 13)=  -4.884981E-15
      ----Equation errors-----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     9.02592E-02     4.48187E-03     8.14999E-02    -3.52125E-02    -3.52113E-02
        PPOCK  3        PPOCK  4
    -3.52113E-02    -3.52125E-02
      Max.Error for Ez       eqn.=    9.02592E-02

Calculation of Position and/or Pocket Pressures...

 Position Iter.No.  1
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     9.95296E-02     2.63549E-03     0.30884         0.54163          0.28045
        PPOCK  3        PPOCK  4
     0.29253         0.55371
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  3, 14)=  -0.219552
          Pressure Iter.No.  2, Max.change @ (  6, 18)=  -2.701061E-02
          Pressure Iter.No.  3, Max.change @ (  6, 19)=  -2.425082E-03
          Pressure Iter.No.  4, Max.change @ (  6, 19)=  -3.118671E-05
          Pressure Iter.No.  5, Max.change @ (  6, 19)=  -3.737899E-09
      ----Equation errors-----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     7.66290E-04     1.92072E-04     6.48025E-04    -4.96548E-03      0.40723
        PPOCK  3        PPOCK  4
     0.37145         5.66117E-04
      Max.Error for PPOCK  2eqn.=    0.40723      previous=    9.02592E-02

 Position Iter.No.  2
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     0.23786         1.29339E-03     0.56658         0.53704          0.28556
        PPOCK  3        PPOCK  4
     0.28756         0.55898
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  2, 24)=  -2.254654E-02
          Pressure Iter.No.  2, Max.change @ (  2, 23)=  -1.335448E-03
          Pressure Iter.No.  3, Max.change @ (  2, 23)=  -9.450817E-06
          Pressure Iter.No.  4, Max.change @ (  2, 23)=  -3.808311E-10
      ----Equation errors-----
```



```
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
    -1.73868E-04     8.75452E-05    -6.66458E-05    -8.71594E-03    -0.24027
        PPOCK  3        PPOCK  4
    -0.17132        -8.69281E-03
      Max.Error for PPOCK  2eqn.=    0.24027      previous=    0.40723

 Position Iter.No.  3
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     0.20312         5.24471E-04     0.50560         0.53852          0.28342
        PPOCK  3        PPOCK  4
     0.28910         0.55748
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  2, 24)=   6.036533E-03
          Pressure Iter.No.  2, Max.change @ (  2, 23)=  -7.197765E-05
          Pressure Iter.No.  3, Max.change @ (  2, 23)=  -2.498401E-08
          Pressure Iter.No.  4, Max.change @ (  2, 23)=  -2.359224E-15
      ----Equation errors-----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
    -9.36814E-06     1.73291E-06    -3.21092E-06    -5.28773E-04    -2.10360E-02
        PPOCK  3        PPOCK  4
    -1.05463E-02    -5.36344E-04
      Max.Error for PPOCK  2eqn.=    2.10360E-02 previous=    0.24027

 Position Iter.No.  4
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
      ----New position----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     0.20002         1.14655E-05     0.50004         0.53888          0.28300
        PPOCK  3        PPOCK  4
     0.28945         0.55712
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  2,  9)=   6.970676E-04
          Pressure Iter.No.  2, Max.change @ (  2, 23)=  -7.943409E-07
          Pressure Iter.No.  3, Max.change @ (  2, 23)=  -2.919748E-12
      ----Equation errors-----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
    -1.07876E-07    -3.69063E-09    -2.61935E-08    -6.70286E-06    -2.23071E-04
        PPOCK  3        PPOCK  4
    -3.92574E-05    -6.43507E-06
      Max.Error for PPOCK  2eqn.=    2.23071E-04 previous=    2.10360E-02

 Position Iter.No.  5
          Calculate Partial Derivitives of Errors...
          Perturbing Ez
          Perturbing ALFA
          Perturbing BETA
          Perturbing PPOCK  1
          Perturbing PPOCK  2
          Perturbing PPOCK  3
          Perturbing PPOCK  4
```

```
      ----New position----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
     0.20000         2.44566E-08     0.49999         0.53888         0.28299
        PPOCK  3        PPOCK  4
     0.28945         0.55711
Calculations at new position...
          Pressure Iter.No.  1, Max.change @ (  2,  9)=   9.265861E-06
          Pressure Iter.No.  2, Max.change @ (  2, 23)=  -9.280468E-11
      ----Equation errors-----
        Ez              ALFA            BETA            PPOCK  1        PPOCK  2
    -5.40166E-11    -3.13297E-11    1.68858E-11    -2.42458E-08    -5.80078E-08
        PPOCK  3        PPOCK  4
     6.21394E-09    -2.90375E-08
      Max.Error for PPOCK  2eqn.=    5.80078E-08 previous=    2.23071E-04
 Pressures & velocities written to file:  iface3c.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

Incompressible FACE seal program (IFACE) 06/04/93 11:59:29 iface13

```
&INPUTS
TITLE= 'IFACE13 4 PRELOADED PADS WITH SURFACES ROUGH',   PL1=1000., PR1=5000.,
CREF=   0.001,      RHO=   1.0E-4,      LENGTH= 3.,       ROUGHJ=0.00002,
RADIUS= 5.,         XMU=   1.0E-7,      RPMJ= 30000,      ROUGHB=0.00002,
TS=     -5,         TE=     85.,        PCAV=-1.E6,       IPER=   0, NPADS=4,
IFACE=  1,          ALFA=0.0, ISTIFF= 2, M=      9,       N=     10,
I1F(1)=2, I2F(1)=9,  J1F(1)=1, J2F(1)= 2, DELTA(5,1)=  5000,  XKE=0.,
I1F(2)=1, I2F(2)=9,  J1F(2)=2, J2F(2)=10, DELTA(4,2)=   0.5,  OFFSET=10.,
I1F(3)=2, I2F(3)=9, J1F(3)=37, J2F(3)=37, DELTA(5,3)=  5000,
&END

&INPUTS ROUGHB=0.00002, ROUGHJ=0.00000,
TITLE= 'IFACE13 4 PRELOADED PADS WITH ROUGH HOUSING'
&END

&INPUTS ROUGHB=0.00000, ROUGHJ=0.00002,
TITLE= 'IFACE13 4 PRELOADED PADS WITH ROUGH ROTOR'
&END

&INPUTS ROUGHB=0.00000, ROUGHJ=0.00000,
TITLE= 'IFACE13 4 PRELOADED PADS WITH BOTH SURFACES SMOOTH'
&END
```

IFACE13 4 PRELOADED PADS WITH SURFACES ROUGH

Input values:

```
Seal Type: Face seal
Outer Radius =   5.0000      inches
inner Radius =   2.0000      inches
Clearance =  1.00000E-03 inches
Rotor Roughness =  2.00000E-05 inches
Housing Roughness =  2.00000E-05 inches
Rotor Angular Velocity =   30000.      r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Inertia pressure drop coefficient = 0.00000E+00

                          Inside      Outside radius
Pressure at top     =   1000.0      5000.0     psi
Pressure at bottom =  0.00000E+00 0.00000E+00 psi
Viscosity =  1.00000E-07 psi-sec
Density =  1.00000E-04 lb-s**2/in**4

Number of radial grid intervals =            8
Number of circumferential grid intervals =  36
```

K	I1F	I2F	J1F	J2F	DELTA(1,K)	DELTA(2,K)	DELTA(3,K)	DELTA(4,K)	DELTA(5,K)
1	2	9	1	2	0.000000	0.000000	0.000000	0.000000	5000.00
2	1	9	2	10	0.000000	0.000000	0.000000	0.500000	-999.00
3	2	9	37	37	0.000000	0.000000	0.000000	0.000000	5000.00
4	2	9	10	11	0.000000	0.000000	0.000000	0.000000	5000.00
5	1	9	11	19	0.000000	0.000000	0.000000	0.500000	-999.00
6	2	9	19	20	0.000000	0.000000	0.000000	0.000000	5000.00
7	1	9	20	28	0.000000	0.000000	0.000000	0.500000	-999.00
8	2	9	28	29	0.000000	0.000000	0.000000	0.000000	5000.00
9	1	9	29	37	0.000000	0.000000	0.000000	0.500000	-999.00

```
Pressure scale P0=  5000.0      psi
Dimensionless parameters:
   Speed of rotor surface              XLj=  9.4248
   Speed of housing surface            XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 0.00000E+00
```



```
Couette Reynolds numbers          REO=  15708.
Poisseuille Reynolds numbers      REOS=  10000.

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components
```

Outputs:

Pressure, psi	1	2	3	4	5
	6	7	8	9	
1	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
2	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
3	1000.000	4413.812	6640.979	8400.081	9599.493
	10110.64	9725.484	8148.730	5000.000	
4	1000.000	4193.107	6929.267	9213.104	10750.16
	11317.90	10717.87	8701.955	5000.000	
5	1000.000	3599.011	5996.031	8084.598	9559.450
	10143.23	9688.390	8033.636	5000.000	
6	1000.000	2677.136	4272.421	5719.305	6835.885
	7411.079	7337.143	6561.331	5000.000	
7	1000.000	1689.747	2333.580	2948.886	3517.359
	4002.522	4389.015	4709.319	5000.000	
8	1000.000	1046.701	939.9813	851.8207	913.1398
	1236.287	1917.624	3110.737	5000.000	
9	1000.000	1498.069	1218.010	896.8400	718.1866
	808.3309	1346.309	2624.842	5000.000	
10	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
11	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
12	1000.000	4413.812	6640.979	8400.081	9599.493
	10110.64	9725.484	8148.730	5000.000	
13	1000.000	4193.107	6929.267	9213.104	10750.16
	11317.90	10717.87	8701.955	5000.000	
14	1000.000	3599.011	5996.031	8084.598	9559.450
	10143.23	9688.390	8033.636	5000.000	
15	1000.000	2677.136	4272.421	5719.305	6835.885
	7411.079	7337.143	6561.331	5000.000	
16	1000.000	1689.747	2333.580	2948.886	3517.359
	4002.522	4389.015	4709.319	5000.000	
17	1000.000	1046.701	939.9813	851.8207	913.1398
	1236.287	1917.624	3110.737	5000.000	
18	1000.000	1498.069	1218.010	896.8400	718.1866
	808.3309	1346.309	2624.842	5000.000	
19	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
20	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
21	1000.000	4413.812	6640.979	8400.081	9599.493
	10110.64	9725.484	8148.730	5000.000	
22	1000.000	4193.107	6929.267	9213.104	10750.16
	11317.90	10717.87	8701.955	5000.000	
23	1000.000	3599.011	5996.031	8084.598	9559.450
	10143.23	9688.390	8033.636	5000.000	
24	1000.000	2677.136	4272.421	5719.305	6835.885
	7411.079	7337.143	6561.331	5000.000	
25	1000.000	1689.747	2333.580	2948.886	3517.359
	4002.522	4389.015	4709.319	5000.000	
26	1000.000	1046.701	939.9813	851.8207	913.1398
	1236.287	1917.624	3110.737	5000.000	
27	1000.000	1498.069	1218.010	896.8400	718.1866
	808.3309	1346.309	2624.842	5000.000	
28	1000.000	5000.000	5000.000	5000.000	5000.000

	5000.000	5000.000	5000.000	5000.000	
29	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
30	1000.000	4413.888	6641.090	8400.207	9599.618
	10110.75	9725.560	8148.769	5000.000	
31	1000.000	4193.338	6929.606	9213.485	10750.53
	11318.21	10718.10	8702.073	5000.000	
32	1000.000	3599.641	5996.943	8085.607	9560.420
	10144.05	9688.977	8033.939	5000.000	
33	1000.000	2678.910	4274.847	5721.901	6838.311
	7413.084	7338.557	6562.056	5000.000	
34	1000.000	1695.213	2340.165	2955.419	3523.134
	4007.092	4392.143	4710.900	5000.000	
35	1000.000	1065.511	957.9857	867.3075	925.4358
	1245.269	1923.460	3113.608	5000.000	
36	1000.000	1569.958	1265.464	927.9546	738.0187
	820.7207	1353.657	2628.294	5000.000	
37	0.0000000E+00	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	

	x	y	z	
Eccentricity ratio=			0.00000E+00	
Misalignment ratio=	0.00000E+00	1.27323-313		
Axial force =			3.42216E+05	lbs
Moment components =	-67.918	-115.01		in-lb

	Location		
Maximum pressure	(6, 31)=	11318.	psi
Minimum film thickness	(1, 7)=	5.00000E-04	inches

Radial flow from inside= -7.9850 in**3/sec
Radial flow to outside= 2.6094 in**3/sec
Circumferential flow at start = 16.493 in**3/sec
Circumferential flow at end = 8.7372 in**3/sec
Overall flow error = -2.8383 in**3/sec
Torque about z-axis = 2900.3 in-lb
Power loss = 6.22887E+06 in-lb/sec

Dynamic Coefficients (Force unit / displacement unit)

Disp.	z inches	inches	α radians	β radians	Force unit
Kz	2.44782E+08	0.00000E+00	-1.12385E+05	-4.71910E+05	lbs
Kα	-46346.	0.00000E+00	1.95677E+09	1.02990E+10	in-lb
Kβ	-1.38023E+05	0.00000E+00	-1.02986E+10	1.95792E+09	in-lb
Bz	8.10649E+05	0.00000E+00	-55.608	-128.22	lbs-sec
Bα	-68.794	0.00000E+00	6.96057E+06	1680.7	in-lb-sec
Bβ	-108.59	0.00000E+00	-1341.2	6.96086E+06	in-lb-sec

Pressures & velocities written to file: iface13.888
IFACE13 4 PRELOADED PADS WITH ROUGH HOUSING

Input values:

Seal Type: Face seal
Outer Radius = 5.0000 inches
inner Radius = 2.0000 inches
Clearance = 1.00000E-03 inches
Rotor Roughness = 0.00000E+00 inches
Housing Roughness = 2.00000E-05 inches
Rotor Angular Velocity = 30000. r/min.
Housing Angular Velocity = 0.00000E+00 r/min.
Inertia pressure drop coefficient = 0.00000E+00

Inside Outside radius

Pressure at top = 1000.0 5000.0 psi
Pressure at bottom = 0.00000E+00 0.00000E+00 psi
Viscosity = 1.00000E-07 psi-sec
Density = 1.00000E-04 lb-s**2/in**4

Number of radial grid intervals = 8
Number of circumferential grid intervals = 36

K	I1F	I2F	J1F	J2F	DELTA(1,K)	DELTA(2,K)	DELTA(3,K)	DELTA(4,K)	DELTA(5,K)
1	2	9	1	2	0.000000	0.000000	0.000000	0.000000	5000.00
2	1	9	2	10	0.000000	0.000000	0.000000	0.500000	-999.00
3	2	9	37	37	0.000000	0.000000	0.000000	0.000000	5000.00
4	2	9	10	11	0.000000	0.000000	0.000000	0.000000	5000.00
5	1	9	11	19	0.000000	0.000000	0.000000	0.500000	-999.00
6	2	9	19	20	0.000000	0.000000	0.000000	0.000000	5000.00
7	1	9	20	28	0.000000	0.000000	0.000000	0.500000	-999.00
8	2	9	28	29	0.000000	0.000000	0.000000	0.000000	5000.00
9	1	9	29	37	0.000000	0.000000	0.000000	0.500000	-999.00

Pressure scale P0= 5000.0 psi
Dimensionless parameters:
Speed of rotor surface XLj= 9.4248
Speed of housing surface XLb= 0.00000E+00
Inertia pressure drop coefficient XLI= 0.00000E+00
Couette Reynolds numbers REO= 15708.
Poisseuille Reynolds numbers REOS= 10000.

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components

Outputs:

Pressure, psi	1	2	3	4	5
	6	7	8	9	
1	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
2	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
3	1000.000	3977.897	5764.477	7116.813	8067.750
	8510.778	8288.010	7204.465	5000.000	
4	1000.000	3621.444	5763.134	7494.190	8702.113
	9240.762	8914.554	7557.174	5000.000	
5	1000.000	3123.694	5008.090	6595.428	7736.801
	8293.951	8110.139	7046.061	5000.000	
6	1000.000	2425.746	3733.690	4884.829	5776.003
	6309.412	6405.235	5984.620	5000.000	
7	1000.000	1696.610	2331.164	2927.276	3474.982
	3948.473	4346.352	4687.474	5000.000	
8	1000.000	1272.767	1393.415	1524.483	1742.395
	2091.506	2661.081	3586.757	5000.000	
9	1000.000	1808.958	1822.658	1778.987	1778.746
	1901.609	2326.709	3276.201	5000.000	
10	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
11	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
12	1000.000	3977.897	5764.477	7116.813	8067.750
	8510.778	8288.010	7204.465	5000.000	
13	1000.000	3621.444	5763.134	7494.190	8702.113
	9240.762	8914.554	7557.174	5000.000	
14	1000.000	3123.694	5008.090	6595.428	7736.801
	8293.951	8110.139	7046.061	5000.000	
15	1000.000	2425.746	3733.690	4884.829	5776.003
	6309.412	6405.235	5984.620	5000.000	

16	1000.000	1696.610	2331.164	2927.276	3474.982
	3948.473	4346.352	4687.474	5000.000	
17	1000.000	1272.767	1393.415	1524.483	1742.395
	2091.506	2661.081	3586.757	5000.000	
18	1000.000	1808.958	1822.658	1778.987	1778.746
	1901.609	2326.709	3276.201	5000.000	
19	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
20	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
21	1000.000	3977.897	5764.477	7116.813	8067.750
	8510.778	8288.010	7204.465	5000.000	
22	1000.000	3621.444	5763.134	7494.190	8702.113
	9240.762	8914.554	7557.174	5000.000	
23	1000.000	3123.694	5008.090	6595.428	7736.801
	8293.951	8110.139	7046.061	5000.000	
24	1000.000	2425.746	3733.690	4884.829	5776.003
	6309.412	6405.235	5984.620	5000.000	
25	1000.000	1696.610	2331.164	2927.276	3474.982
	3948.473	4346.352	4687.474	5000.000	
26	1000.000	1272.767	1393.415	1524.483	1742.395
	2091.506	2661.081	3586.757	5000.000	
27	1000.000	1808.958	1822.658	1778.987	1778.746
	1901.609	2326.709	3276.201	5000.000	
28	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
29	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
30	1000.000	3977.976	5764.591	7116.938	8067.871
	8510.881	8288.084	7204.504	5000.000	
31	1000.000	3621.679	5763.477	7494.571	8702.479
	9241.070	8914.776	7557.288	5000.000	
32	1000.000	3124.337	5009.012	6596.434	7737.753
	8294.748	8110.706	7046.353	5000.000	
33	1000.000	2427.565	3736.150	4887.420	5778.386
	6311.355	6406.592	5985.312	5000.000	
34	1000.000	1702.164	2337.764	2933.720	3480.591
	3952.861	4349.329	4688.968	5000.000	
35	1000.000	1291.374	1410.952	1539.349	1754.067
	2099.977	2666.548	3589.428	5000.000	
36	1000.000	1877.572	1866.579	1807.402	1797.014
	1913.111	2333.471	3279.358	5000.000	
37	0.0000000E+00	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	

	x	y	z	
Eccentricity ratio=			0.00000E+00	
Misalignment ratio=	6.02986-309	2.12200-313		
Axial force =			3.19916E+05	lbs
Moment components =	-64.275	-104.48		in-lb

	Location		
Maximum pressure	(6, 31)=	9241.1	psi
Minimum film thickness	(1, 7)=	5.00000E-04	inches

Radial flow from inside=	-8.3883	in**3/sec
Radial flow to outside=	2.1593	in**3/sec
Circumferential flow at start =	14.904	in**3/sec
Circumferential flow at end =	7.9732	in**3/sec
Overall flow error =	-3.6172	in**3/sec
Torque about z-axis =	2354.2	in-lb
Power loss =	5.02069E+06	in-lb/sec

Dynamic Coefficients (Force unit / displacement unit)

Disp.	z inches	inches	α radians	β radians	Force unit

Kz	1.58335E+08	0.00000E+00	37598.	-2.29525E+05	lbs
Kα	-589.81	0.00000E+00	1.15324E+09	7.27113E+09	in-lb
Kβ	-6693.1	0.00000E+00	-7.27103E+09	1.15397E+09	in-lb
Bz	6.76422E+05	0.00000E+00	-72.109	-169.18	lbs-sec
Bα	-71.502	0.00000E+00	5.77195E+06	1122.0	in-lb-sec
Bβ	-136.95	0.00000E+00	-699.73	5.77235E+06	in-lb-sec

Pressures & velocities written to file: iface13.888
IFACE13 4 PRELOADED PADS WITH ROUGH ROTOR

Input values:

Seal Type: Face seal
Outer Radius = 5.0000 inches
inner Radius = 2.0000 inches
Clearance = 1.00000E-03 inches
Rotor Roughness = 2.00000E-05 inches
Housing Roughness = 0.00000E+00 inches
Rotor Angular Velocity = 30000. r/min.
Housing Angular Velocity = 0.00000E+00 r/min.
Inertia pressure drop coefficient = 0.00000E+00

	Inside	Outside radius	
Pressure at top =	1000.0	5000.0	psi
Pressure at bottom =	0.00000E+00	0.00000E+00	psi

Viscosity = 1.00000E-07 psi-sec
Density = 1.00000E-04 lb-s**2/in**4

Number of radial grid intervals = 8
Number of circumferential grid intervals = 36

K	I1F	I2F	J1F	J2F	DELTA(1,K)	DELTA(2,K)	DELTA(3,K)	DELTA(4,K)	DELTA(5,K)
1	2	9	1	2	0.000000	0.000000	0.000000	0.000000	5000.00
2	1	9	2	10	0.000000	0.000000	0.000000	0.500000	-999.00
3	2	9	37	37	0.000000	0.000000	0.000000	0.000000	5000.00
4	2	9	10	11	0.000000	0.000000	0.000000	0.000000	5000.00
5	1	9	11	19	0.000000	0.000000	0.000000	0.500000	-999.00
6	2	9	19	20	0.000000	0.000000	0.000000	0.000000	5000.00
7	1	9	20	28	0.000000	0.000000	0.000000	0.500000	-999.00
8	2	9	28	29	0.000000	0.000000	0.000000	0.000000	5000.00
9	1	9	29	37	0.000000	0.000000	0.000000	0.500000	-999.00

Pressure scale P0= 5000.0 psi
Dimensionless parameters:

Speed of rotor surface	XLj= 9.4248
Speed of housing surface	XLb= 0.00000E+00
Inertia pressure drop coefficient	XLI= 0.00000E+00
Couette Reynolds numbers	REO= 15708.
Poisseuille Reynolds numbers	REOS= 10000.

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components

Outputs:

Pressure, psi

	1	2	3	4	5
	6	7	8	9	
1	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
2	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
3	1000.000	4452.467	6621.209	8265.159	9297.000

	9690.847	9284.950	7828.724	5000.000	
4	1000.000	4261.857	6947.088	9121.805	10489.59
	10900.35	10255.35	8366.242	5000.000	
5	1000.000	3690.924	6066.037	8077.863	9434.603
	9895.534	9374.088	7791.543	5000.000	
6	1000.000	2768.676	4370.608	5774.794	6816.161
	7318.873	7205.578	6447.792	5000.000	
7	1000.000	1769.635	2449.447	3065.687	3607.202
	4054.535	4420.668	4726.036	5000.000	
8	1000.000	1116.625	1064.252	1004.189	1069.303
	1395.848	2091.627	3246.740	5000.000	
9	1000.000	1552.840	1319.085	1017.156	860.4861
	1020.331	1612.572	2832.873	5000.000	
10	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
11	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
12	1000.000	4452.467	6621.209	8265.159	9297.000
	9690.847	9284.950	7828.724	5000.000	
13	1000.000	4261.857	6947.088	9121.805	10489.59
	10900.35	10255.35	8366.242	5000.000	
14	1000.000	3690.924	6066.037	8077.863	9434.603
	9895.534	9374.088	7791.543	5000.000	
15	1000.000	2768.676	4370.608	5774.794	6816.161
	7318.873	7205.578	6447.792	5000.000	
16	1000.000	1769.635	2449.447	3065.687	3607.202
	4054.535	4420.668	4726.036	5000.000	
17	1000.000	1116.625	1064.252	1004.189	1069.303
	1395.848	2091.627	3246.740	5000.000	
18	1000.000	1552.840	1319.085	1017.156	860.4861
	1020.331	1612.572	2832.873	5000.000	
19	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
20	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
21	1000.000	4452.467	6621.209	8265.159	9297.000
	9690.847	9284.950	7828.724	5000.000	
22	1000.000	4261.857	6947.088	9121.805	10489.59
	10900.35	10255.35	8366.242	5000.000	
23	1000.000	3690.924	6066.037	8077.863	9434.603
	9895.534	9374.088	7791.543	5000.000	
24	1000.000	2768.676	4370.608	5774.794	6816.161
	7318.873	7205.578	6447.792	5000.000	
25	1000.000	1769.635	2449.447	3065.687	3607.202
	4054.535	4420.668	4726.036	5000.000	
26	1000.000	1116.625	1064.252	1004.189	1069.303
	1395.848	2091.627	3246.740	5000.000	
27	1000.000	1552.840	1319.085	1017.156	860.4861
	1020.331	1612.572	2832.873	5000.000	
28	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
29	1000.000	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	
30	1000.000	4452.547	6621.327	8265.292	9297.129
	9690.957	9285.028	7828.764	5000.000	
31	1000.000	4262.100	6947.448	9122.207	10489.98
	10900.67	10255.58	8366.360	5000.000	
32	1000.000	3691.574	6066.978	8078.895	9435.580
	9896.344	9374.660	7791.837	5000.000	
33	1000.000	2770.448	4373.024	5777.346	6818.513
	7320.792	7206.916	6448.475	5000.000	
34	1000.000	1774.885	2455.728	3071.829	3612.557
	4058.742	4423.532	4727.478	5000.000	
35	1000.000	1134.036	1080.696	1018.118	1080.229
	1403.806	2096.781	3249.263	5000.000	
36	1000.000	1618.000	1360.970	1044.183	877.5730

	1030.958	1618.819	2835.784	5000.000	
37	0.0000000E+00	5000.000	5000.000	5000.000	5000.000
	5000.000	5000.000	5000.000	5000.000	

	x	y	z	
Eccentricity ratio=			0.00000E+00	
Misalignment ratio=	6.02986-309	2.12200-313		
Axial force =			3.40236E+05	lbs
Moment components =	-60.803	-94.904		in-lb

	Location		
Maximum pressure	(6, 31)=	10901.	psi
Minimum film thickness	(1, 7)=	5.00000E-04	inches

Radial flow from inside=	-8.9846	in**3/sec
Radial flow to outside=	2.9171	in**3/sec
Circumferential flow at start =	18.083	in**3/sec
Circumferential flow at end =	9.4546	in**3/sec
Overall flow error =	-3.2731	in**3/sec
Torque about z-axis =	2365.6	in-lb
Power loss =	5.03829E+06	in-lb/sec

Dynamic Coefficients (Force unit / displacement unit)

Disp.	z inches	inches	α radians	β radians	Force unit
Kz	2.63241E+08	0.00000E+00	-1.81383E+05	-4.78331E+05	lbs
Kα	-61750.	0.00000E+00	2.03474E+09	9.84157E+09	in-lb
Kβ	-1.54449E+05	0.00000E+00	-9.84091E+09	2.03583E+09	in-lb
Bz	6.83482E+05	0.00000E+00	-36.118	-74.331	lbs-sec
Bα	-50.429	0.00000E+00	5.82013E+06	1352.0	in-lb-sec
Bβ	-65.936	0.00000E+00	-1129.9	5.82029E+06	in-lb-sec

Pressures & velocities written to file: iface13.888
IFACE13 4 PRELOADED PADS WITH BOTH SURFACES SMOOTH

Input values:

Seal Type: Face seal
Outer Radius = 5.0000 inches
inner Radius = 2.0000 inches
Clearance = 1.00000E-03 inches
Rotor Roughness = 0.00000E+00 inches
Housing Roughness = 0.00000E+00 inches
Rotor Angular Velocity = 30000. r/min.
Housing Angular Velocity = 0.00000E+00 r/min.
Inertia pressure drop coefficient = 0.00000E+00

	Inside	Outside radius	
Pressure at top =	1000.0	5000.0	psi
Pressure at bottom =	0.00000E+00	0.00000E+00	psi

Viscosity = 1.00000E-07 psi-sec
Density = 1.00000E-04 lb-s**2/in**4

Number of radial grid intervals = 8
Number of circumferential grid intervals = 36

K	I1F	I2F	J1F	J2F	DELTA(1,K)	DELTA(2,K)	DELTA(3,K)	DELTA(4,K)	DELTA(5,K)
1	2	9	1	2	0.000000	0.000000	0.000000	0.000000	5000.00
2	1	9	2	10	0.000000	0.000000	0.000000	0.500000	-999.00
3	2	9	37	37	0.000000	0.000000	0.000000	0.000000	5000.00
4	2	9	10	11	0.000000	0.000000	0.000000	0.000000	5000.00
5	1	9	11	19	0.000000	0.000000	0.000000	0.500000	-999.00
6	2	9	19	20	0.000000	0.000000	0.000000	0.000000	5000.00

7	1	9	20	28	0.000000	0.000000	0.000000	0.500000	-999.00
8	2	9	28	29	0.000000	0.000000	0.000000	0.000000	5000.00
9	1	9	29	37	0.000000	0.000000	0.000000	0.500000	-999.00

Pressure scale P0= 5000.0 psi
Dimensionless parameters:
Speed of rotor surface XLj= 9.4248
Speed of housing surface XLb= 0.00000E+00
Inertia pressure drop coefficient XLI= 0.00000E+00
Couette Reynolds numbers RE0= 15708.
Poisseuille Reynolds numbers RE0S= 10000.

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components

Outputs:

Pressure, psi

	1 6	2 7	3 8	4 9	5
1	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
2	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
3	1000.000 8309.604	4040.255 8062.372	5801.870 7036.691	7103.339 5000.000	7952.828
4	1000.000 9080.937	3715.736 8704.177	5861.946 7395.092	7557.474 5000.000	8664.894
5	1000.000 8263.547	3233.080 8001.594	5147.202 6945.710	6728.402 5000.000	7815.798
6	1000.000 6389.277	2527.902 6410.966	3877.718 5961.161	5038.037 5000.000	5914.252
7	1000.000 4069.888	1780.025 4431.480	2460.045 4730.750	3071.960 5000.000	3615.081
8	1000.000 2245.694	1340.609 2813.066	1506.334 3689.861	1655.315 5000.000	1880.083
9	1000.000 2082.504	1859.325 2517.986	1908.722 3412.859	1878.715 5000.000	1910.159
10	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
11	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
12	1000.000 8309.604	4040.255 8062.372	5801.870 7036.691	7103.339 5000.000	7952.828
13	1000.000 9080.937	3715.736 8704.177	5861.946 7395.092	7557.474 5000.000	8664.894
14	1000.000 8263.547	3233.080 8001.594	5147.202 6945.710	6728.402 5000.000	7815.798
15	1000.000 6389.277	2527.902 6410.966	3877.718 5961.161	5038.037 5000.000	5914.252
16	1000.000 4069.888	1780.025 4431.480	2460.045 4730.750	3071.960 5000.000	3615.081
17	1000.000 2245.694	1340.609 2813.066	1506.334 3689.861	1655.315 5000.000	1880.083
18	1000.000 2082.504	1859.325 2517.986	1908.722 3412.859	1878.715 5000.000	1910.159
19	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
20	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
21	1000.000 8309.604	4040.255 8062.372	5801.870 7036.691	7103.339 5000.000	7952.828
22	1000.000 9080.937	3715.736 8704.177	5861.946 7395.092	7557.474 5000.000	8664.894
23	1000.000 8263.547	3233.080 8001.594	5147.202 6945.710	6728.402 5000.000	7815.798

24	1000.000 6389.277	2527.902 6410.966	3877.718 5961.161	5038.037 5000.000	5914.252
25	1000.000 4069.888	1780.025 4431.480	2460.045 4730.750	3071.960 5000.000	3615.081
26	1000.000 2245.694	1340.609 2813.066	1506.334 3689.861	1655.315 5000.000	1880.083
27	1000.000 2082.504	1859.325 2517.986	1908.722 3412.859	1878.715 5000.000	1910.159
28	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
29	1000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000
30	1000.000 8309.715	4040.338 8062.451	5801.990 7036.732	7103.474 5000.000	7952.960
31	1000.000 9081.261	3715.980 8704.407	5862.306 7395.210	7557.872 5000.000	8665.276
32	1000.000 8264.345	3233.731 8002.157	5148.139 6945.998	6729.421 5000.000	7816.758
33	1000.000 6391.125	2529.679 6412.249	3880.117 5961.811	5040.540 5000.000	5916.535
34	1000.000 4073.825	1785.243 4434.127	2466.204 4732.071	3077.884 5000.000	3620.171
35	1000.000 2252.842	1357.492 2817.624	1522.007 3692.073	1668.336 5000.000	1890.111
36	1000.000 2091.485	1920.363 2523.222	1946.539 3415.287	1902.477 5000.000	1924.859
37	0.0000000E+00 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000 5000.000	5000.000

	x	y	z	
Eccentricity ratio=			0.00000E+00	
Misalignment ratio=	6.02986-309	2.12200-313		
Axial force =			3.21634E+05	lbs
Moment components =	-55.465	-79.665		in-lb

	Location		
Maximum pressure	(6, 31)=	9081.3	psi
Minimum film thickness	(1, 7)=	5.00000E-04	inches

Radial flow from inside= -9.4077 in**3/sec
Radial flow to outside= 2.4733 in**3/sec
Circumferential flow at start = 16.493 in**3/sec
Circumferential flow at end = 8.6844 in**3/sec
Overall flow error = -4.0720 in**3/sec
Torque about z-axis = 2006.4 in-lb
Power loss = 4.24683E+06 in-lb/sec

Dynamic Coefficients (Force unit / displacement unit)

Disp.	z inches	inches	α radians	β radians	Force unit
Kz	1.84064E+08	0.00000E+00	-60127.	-2.77713E+05	lbs
Kα	-2398.1	0.00000E+00	1.33734E+09	7.18157E+09	in-lb
Kβ	-15784.	0.00000E+00	-7.18137E+09	1.33801E+09	in-lb
Bz	5.74578E+05	0.00000E+00	-51.174	-112.75	lbs-sec
Bα	-53.804	0.00000E+00	4.86516E+06	867.07	in-lb-sec
Bβ	-92.775	0.00000E+00	-568.21	4.86541E+06	in-lb-sec

Pressures & velocities written to file: iface13.888
IFACE Analysis Completed 06/04/93 12:17:34 1085.62 SEC

```
          Pressure Iter.No.  1, Max.change @ (  6, 31)=    1.54777
          Pressure Iter.No.  2, Max.change @ (  3, 31)=   4.013409E-02
          Pressure Iter.No.  3, Max.change @ (  2, 31)=   3.184082E-04
          Pressure Iter.No.  4, Max.change @ (  2, 31)=   1.801797E-08
          Pressure Iter.No.  5, Max.change @ (  4, 36)=  -6.682516E-12

Calculation of Stiffness and/or Damping Coefficients

Calculating Stiffness Coefficients...Perturbing displacement:z

Calculating Stiffness Coefficients...Perturbing displacement:α

Calculating Stiffness Coefficients...Perturbing displacement:β

Calculating Damping Coefficients...B Perturbing velocity    :z

Calculating Damping Coefficients...B Perturbing velocity    :α

Calculating Damping Coefficients...B Perturbing velocity    :β
 Pressures & velocities written to file:  iface13.888

 Reading namelist input...
IFACE13 4 PRELOADED PADS WITH ROUGH HOUSING
          Pressure Iter.No.  1, Max.change @ (  6, 31)=  -0.416699
          Pressure Iter.No.  2, Max.change @ (  3, 31)=   2.890515E-03
          Pressure Iter.No.  3, Max.change @ (  2, 31)=   8.612634E-07
          Pressure Iter.No.  4, Max.change @ (  2, 13)=   1.223466E-13

Calculation of Stiffness and/or Damping Coefficients

Calculating Stiffness Coefficients...Perturbing displacement:z

Calculating Stiffness Coefficients...Perturbing displacement:α

Calculating Stiffness Coefficients...Perturbing displacement:β

Calculating Damping Coefficients...B Perturbing velocity    :z

Calculating Damping Coefficients...B Perturbing velocity    :α

Calculating Damping Coefficients...B Perturbing velocity    :β
 Pressures & velocities written to file:  iface13.888

 Reading namelist input...
IFACE13 4 PRELOADED PADS WITH ROUGH ROTOR
          Pressure Iter.No.  1, Max.change @ (  5, 31)=   0.355529
          Pressure Iter.No.  2, Max.change @ (  3, 31)=   3.241073E-03
          Pressure Iter.No.  3, Max.change @ (  2, 31)=   1.602405E-06
          Pressure Iter.No.  4, Max.change @ (  2, 22)=   4.609646E-13

Calculation of Stiffness and/or Damping Coefficients

Calculating Stiffness Coefficients...Perturbing displacement:z

Calculating Stiffness Coefficients...Perturbing displacement:α

Calculating Stiffness Coefficients...Perturbing displacement:β

Calculating Damping Coefficients...B Perturbing velocity    :z

Calculating Damping Coefficients...B Perturbing velocity    :α

Calculating Damping Coefficients...B Perturbing velocity    :β
 Pressures & velocities written to file:  iface13.888

 Reading namelist input...
```



```
IFACE13 4 PRELOADED PADS WITH BOTH SURFACES SMOOTH
          Pressure Iter.No.  1, Max.change @ (  5, 31)=  -0.366640
          Pressure Iter.No.  2, Max.change @ (  3, 31)=   2.683634E-03
          Pressure Iter.No.  3, Max.change @ (  2, 31)=   7.287847E-07
          Pressure Iter.No.  4, Max.change @ (  2, 31)=   9.059420E-14

Calculation of Stiffness and/or Damping Coefficients

Calculating Stiffness Coefficients...Perturbing displacement:z

Calculating Stiffness Coefficients...Perturbing displacement:α

Calculating Stiffness Coefficients...Perturbing displacement:β

Calculating Damping Coefficients...B Perturbing velocity    :z

Calculating Damping Coefficients...B Perturbing velocity    :α

Calculating Damping Coefficients...B Perturbing velocity    :β
 Pressures & velocities written to file:  iface13.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

Incompressible FACE seal program (IFACE) 06/01/93 11:09:41 iface17

```
&INPUTS
TITLE= 'IFACE17 8 RAYLEIGH STEPS FED FROM GROOVE FROM ID',
NPADS=8,          PL1=1000.,
CREF=  0.001,     RHO=   1.0E-7,      LENGTH= 3.,        PR1=  0.,
RADIUS= 5.,       XMU=   1.0E-6,      RPMJ=1600,
TS=     0,        TE=    45.,         PCAV=  -1.E9,      IPER=   1,
IFACE=  1,        ISTIFF= 0,          M=     9,          N=      9,
I1F(1)=3, I2F(1)=7, J1F(1)=3, J2F(1)=7, DELTA(1,1)= 0.001, 0.0, -0.000,
I1F(2)=1, I2F(2)=7, J1F(2)=1, J2F(2)=2, DELTA(1,2)= 0.008,
DZT= 1, .01, 1, 3, 3, 1, .01, 1,      ALFA=0.5,
DTH= 2, .01, 3, 3, 1, 1, .01, 2,
&END
```

IFACE17 8 RAYLEIGH STEPS FED FROM GROOVE FROM ID

Input values:

Seal Type: Face seal
Outer Radius = 5.0000 inches
inner Radius = 2.0000 inches
Clearance = 1.00000E-03 inches
Rotor Roughness = 0.00000E+00 inches
Housing Roughness = 0.00000E+00 inches
Rotor Angular Velocity = 1600.0 r/min.
Housing Angular Velocity = 0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient = 1.0000

	Inside	Outside radius
Pressure at top =	1000.0	0.00000E+00 psi

Viscosity = 1.00000E-06 psi-sec
Density = 1.00000E-07 lb-s**2/in**4

Number of radial grid intervals = 8
Number of circumferential grid intervals = 64

K	I1F	I2F	J1F	J2F	DELTA(1,K)	DELTA(2,K)	DELTA(3,K)	DELTA(4,K)	DELTA(5,K)
1	3	7	3	7	0.001000	0.000000	0.000000	0.000000	-999.00
2	1	7	1	2	0.008000	0.000000	0.000000	0.000000	-999.00
3	3	7	11	15	0.001000	0.000000	0.000000	0.000000	-999.00
4	1	7	9	10	0.008000	0.000000	0.000000	0.000000	-999.00
5	3	7	19	23	0.001000	0.000000	0.000000	0.000000	-999.00
6	1	7	17	18	0.008000	0.000000	0.000000	0.000000	-999.00
7	3	7	27	31	0.001000	0.000000	0.000000	0.000000	-999.00
8	1	7	25	26	0.008000	0.000000	0.000000	0.000000	-999.00
9	3	7	35	39	0.001000	0.000000	0.000000	0.000000	-999.00
10	1	7	33	34	0.008000	0.000000	0.000000	0.000000	-999.00
11	3	7	43	47	0.001000	0.000000	0.000000	0.000000	-999.00
12	1	7	41	42	0.008000	0.000000	0.000000	0.000000	-999.00
13	3	7	51	55	0.001000	0.000000	0.000000	0.000000	-999.00
14	1	7	49	50	0.008000	0.000000	0.000000	0.000000	-999.00
15	3	7	59	63	0.001000	0.000000	0.000000	0.000000	-999.00
16	1	7	57	58	0.008000	0.000000	0.000000	0.000000	-999.00

Pressure scale P0= 1000.0 psi
Dimensionless parameters:
Speed of rotor surface XLj= 25.133
Speed of housing surface XLb= 0.00000E+00
Inertia pressure drop coefficient XLI= 1.38889E-08
Couette Reynolds numbers REO= 8.37758E-02
Poisseuille Reynolds numbers REOS= 2.00000E-02

Friction formula based on Moody diagram (Nelson)

Newton-Raphson itertions for velocity components

Outputs:

Pressure, psi	1	2	3	4	5
	6	7	8	9	
1	999.9953	974.9056	974.6752	954.3203	910.5517
	884.1055	879.7245	870.5838	0.0000000E+00	
2	999.9899	981.3794	981.2038	964.1781	926.6688
	906.6267	903.0078	884.5138	0.0000000E+00	
3	1000.0000	979.9151	978.0157	959.6825	918.1287
	890.1925	871.7441	867.1601	0.0000000E+00	
4	1000.0000	973.5612	973.2849	961.6257	868.9062
	687.1980	599.0821	592.8651	0.0000000E+00	
5	1000.000	1012.073	1012.170	1007.832	912.7107
	684.7253	584.5267	578.4042	0.0000000E+00	
6	1000.000	1031.255	1031.588	1034.645	952.5260
	723.2186	603.4108	597.0006	0.0000000E+00	
7	1000.000	1050.149	1051.967	1067.269	1005.466
	790.2644	617.4660	608.5741	0.0000000E+00	
8	1000.000	1050.003	1051.049	1066.487	1004.566
	789.7272	611.1990	606.2943	0.0000000E+00	
9	999.9905	965.4604	965.1443	936.8722	875.1690
	836.5110	829.2222	820.2500	0.0000000E+00	
10	999.9748	971.5460	971.2798	946.0621	889.9481
	856.6258	849.6277	833.8121	0.0000000E+00	
11	1000.0000	970.3259	968.6521	943.1112	884.7526
	846.6811	825.2434	820.3270	0.0000000E+00	
12	1000.0000	949.3250	948.7853	931.2099	818.1520
	615.7804	517.1879	511.8649	0.0000000E+00	
13	1000.0000	976.9500	976.6731	964.6843	844.0003
	597.6347	492.4695	487.3333	0.0000000E+00	
14	1000.0000	994.5072	994.4283	988.0612	878.1100
	631.3612	511.1175	505.7076	0.0000000E+00	
15	1000.000	1013.960	1014.976	1017.612	925.4710
	692.3018	527.7832	520.7748	0.0000000E+00	
16	1000.000	1013.924	1014.467	1017.125	925.0352
	692.3818	523.6200	519.4451	0.0000000E+00	
17	999.9893	963.7843	963.4527	933.7211	867.9991
	825.4617	816.8042	807.8676	0.0000000E+00	
18	999.9709	969.8088	969.5265	942.8133	882.5726
	845.3392	837.2859	822.6849	0.0000000E+00	
19	1000.0000	968.8560	967.3563	940.6041	878.6233
	837.3946	815.7453	810.7987	0.0000000E+00	
20	1000.0000	962.9229	962.4794	946.5710	838.6482
	636.1730	534.2305	528.7911	0.0000000E+00	
21	1000.000	1000.715	1000.634	992.6112	883.1206
	638.7889	530.4304	524.9620	0.0000000E+00	
22	1000.000	1020.367	1020.516	1019.484	923.3456
	680.7456	558.8550	553.0089	0.0000000E+00	
23	1000.000	1040.673	1042.081	1052.319	976.9350
	750.3478	583.8767	576.1640	0.0000000E+00	
24	1000.000	1040.597	1041.429	1051.802	976.4986
	750.4489	579.2448	574.6674	0.0000000E+00	
25	999.9945	973.4129	973.1685	951.4015	902.3611
	869.2087	862.1906	852.9031	0.0000000E+00	
26	999.9873	979.7440	979.5528	961.0003	917.8799
	890.8450	885.1141	870.5281	0.0000000E+00	
27	1000.0000	979.1748	977.9721	959.1695	914.0956
	882.4215	863.7350	858.7720	0.0000000E+00	
28	1000.000	1020.972	1021.049	1015.475	943.9812
	766.8114	668.7354	662.0502	0.0000000E+00	
29	1000.000	1093.647	1094.438	1102.516	1049.086
	838.4991	730.9076	723.5534	0.0000000E+00	
30	1000.000	1119.946	1121.091	1140.582	1109.164

	907.1260	786.7301	778.7290	0.0000000E+00	
31	1000.000	1141.540	1144.838	1183.592	1182.556
	1005.794	835.5428	823.9060	0.0000000E+00	
32	1000.000	1141.225	1143.337	1182.643	1181.521
	1005.163	827.2625	820.8248	0.0000000E+00	
33	999.9987	986.8096	986.6870	976.1200	951.3765
	933.0690	929.2167	919.8398	0.0000000E+00	
34	999.9988	993.6631	993.6004	986.6207	968.6052
	957.6227	955.5013	940.4125	0.0000000E+00	
35	1000.0000	993.7574	993.1389	985.2771	964.2258
	945.8270	931.7495	927.3968	0.0000000E+00	
36	1000.000	1125.100	1126.193	1135.934	1132.627
	1023.313	946.4871	937.4126	0.0000000E+00	
37	1000.000	1267.838	1270.403	1303.913	1366.702
	1263.935	1176.383	1165.112	0.0000000E+00	
38	1000.000	1307.304	1310.489	1363.136	1467.504
	1396.031	1299.469	1287.009	0.0000000E+00	
39	1000.000	1331.291	1338.715	1424.481	1580.178
	1563.090	1423.138	1402.289	0.0000000E+00	
40	1000.000	1330.452	1335.223	1422.497	1577.546
	1560.344	1405.587	1395.021	0.0000000E+00	
41	999.9996	992.4779	992.4065	986.6029	972.6675
	961.6808	959.6568	951.4132	0.0000000E+00	
42	1000.0000	999.7648	999.7590	997.9013	991.4730
	988.9058	988.7890	971.3831	0.0000000E+00	
43	1000.000	1000.415	1000.291	996.4426	983.5825
	964.4956	952.3856	950.9975	0.0000000E+00	
44	1000.000	1210.228	1212.262	1231.330	1282.759
	1245.869	1200.507	1189.614	0.0000000E+00	
45	1000.000	1413.071	1417.299	1468.688	1634.469
	1654.222	1599.356	1584.684	0.0000000E+00	
46	1000.000	1462.534	1467.609	1544.613	1769.956
	1844.820	1782.034	1765.545	0.0000000E+00	
47	1000.000	1486.919	1498.363	1619.445	1914.471
	2074.036	1981.830	1950.597	0.0000000E+00	
48	1000.000	1485.573	1492.740	1616.270	1909.746
	2068.014	1951.969	1937.460	0.0000000E+00	
49	999.9993	989.7271	989.6305	981.5607	963.6474
	951.6778	949.8507	942.0436	0.0000000E+00	
50	999.9998	997.0578	997.0273	992.9739	982.7923
	979.5883	979.6972	955.1907	0.0000000E+00	
51	1000.0000	996.7488	995.5628	987.8570	966.2524
	935.1161	920.2189	920.9499	0.0000000E+00	
52	1000.000	1158.664	1160.269	1173.186	1194.427
	1132.641	1088.842	1078.200	0.0000000E+00	
53	1000.000	1321.182	1324.547	1365.100	1473.436
	1434.718	1373.551	1360.026	0.0000000E+00	
54	1000.000	1361.645	1365.678	1428.656	1584.407
	1579.180	1496.971	1482.038	0.0000000E+00	
55	1000.000	1382.275	1391.606	1492.620	1704.630
	1758.980	1621.415	1592.917	0.0000000E+00	
56	1000.000	1381.174	1386.900	1489.716	1700.190
	1753.076	1593.199	1580.709	0.0000000E+00	
57	999.9982	983.7297	983.5790	970.5704	942.7932
	926.1068	923.6657	914.8294	0.0000000E+00	
58	999.9977	990.7083	990.6190	981.3479	960.7555
	951.9927	951.0928	928.0889	0.0000000E+00	
59	1000.0000	989.2681	987.1767	974.8225	945.8083
	919.8108	904.7232	902.0027	0.0000000E+00	
60	1000.000	1042.460	1042.894	1042.186	994.8334
	861.2231	794.5347	786.3036	0.0000000E+00	
61	1000.000	1124.276	1125.551	1140.018	1119.461
	952.4138	865.6450	856.6624	0.0000000E+00	
62	1000.000	1150.626	1152.279	1180.109	1183.714
	1021.543	908.9391	899.3941	0.0000000E+00	
63	1000.000	1169.578	1174.021	1224.316	1259.974

	1122.051	942.7712	927.2277	0.0000000E+00	
64	1000.000	1169.092	1171.783	1222.727	1257.765
	1119.622	929.1461	921.6823	0.0000000E+00	
65	999.9953	974.9056	974.6752	954.3203	910.5517
	884.1055	879.7245	870.5838	0.0000000E+00	

	x	y	z	
Eccentricity ratio=			0.00000E+00	
Misalignment ratio=	0.50000	1.27323-313		
Axial force =			62348.	lbs
Moment components =	-28082.	4622.5		in-lb

	Location		
Maximum pressure	(6, 47)=	2074.0	psi
Minimum film thickness	(9, 49)=	5.00000E-04	inches

Radial flow from inside=	8.2138	in**3/sec
Radial flow to outside=	8.2138	in**3/sec
Overall flow error =	7.55544E-13	in**3/sec
Torque about z-axis =	180.27	in-lb
Power loss =	19176.	in-lb/sec

Pressures & velocities written to file: iface17.888
IFACE Analysis Completed 06/01/93 11:11:24 102.75 SEC

```
        Pressure Iter.No.  1, Max.change @ (  8, 47)=    1.82578
        Pressure Iter.No.  2, Max.change @ (  1, 42)=  -4.164297E-04
        Pressure Iter.No.  3, Max.change @ (  1, 19)=  -1.256962E-08
        Pressure Iter.No.  4, Max.change @ (  4, 15)=   3.796963E-14
 Pressures & velocities written to file:  iface17.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

```
Incompressible FACE seal program (IFACE) 06/01/93  17:38:29   iface15a

&INPUTS
TITLE= 'IFACE15A 4-POCKET FACE SEAL DORIF,K,B'
CREF=   0.003,      RHO=   1.0E-4,      EX=    0.0,      Fxg= -999.,
RADIUS= 4.,         XMU=   6.0E-8,      ALFA=  0.0,      Mxg= -999.,
LENGTH= 3.,         RPMJ= 30000.,       BETA=  0.0,      Myg= -999.,
TS=      0,         RPMB=  0.0,         PCAV=  -1.E9,
TE=     90.,        XKE=   1.0,         PL1=  100.,      PR1= 200.,
IFACE=  1,          ISTIFF= 2,          NPADS=4,
M=     10,          N=     16,
ISYM=   0,          IPER=   1,
MAXDIT= 4,          IREADP= 0,
DZT=  .05, .05, .05, .150,  0.30000,  0.15, .05, .05, .05,
DTH=  4, 3, 2, 1, 3, 5, 15, 24, 15, 5, 3, 1, 2, 3, 4,
NPOCK=  1,          PSUP= 1000.,        CD= 0.6,
M1=   3,     N1=   5,                   DORIF=0.,
M2=   8,     N2=  12,                   PPOCK= 500.,
&END

IFACE15A 4-POCKET FACE SEAL DORIF,K,B

Input values:

Seal Type: Face seal
Outer Radius =   4.0000      inches
inner Radius =   1.0000      inches
Clearance =  3.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =   30000.     r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient =  1.0000

                          Inside      Outside radius
Pressure at top     =   100.00      200.00      psi
Viscosity =  6.00000E-08 psi-sec
Density =  1.00000E-04 lb-s**2/in**4

Number of radial grid intervals =            9
Number of circumferential grid intervals =  60

Data for   4 pressurized pockets:
Supply pressure =   1000.0      psi
Discharge Coeff. = 0.60000

Pocket        radial            Circumferential     Pressure
Number     Start   End              Start   End     (psi            )
 1                3     8           5     12          500.00
 2                3     8          20     27          500.00
 3                3     8          35     42          500.00
 4                3     8          50     57          500.00

Pressure scale P0=  1000.0      psi
Dimensionless parameters:
   Speed of rotor surface            XLj=  2.0106
   Speed of housing surface          XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 0.48828
   Couette Reynolds numbers          REO=  62832.
   Poisseuille Reynolds numbers      REOS= 1.87500E+05

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components
Orifice diameter calculated:
DORIF=        0.114973732836587
```


Outputs:

Pressure, psi	1	2	3	4	5
	6	7	8	9	10
1	100.0000	242.0466	354.2858	426.2152	474.6655
	452.1002	363.0012	313.6085	258.0987	200.0000
2	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
3	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
4	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
5	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
6	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
7	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
8	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
9	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
10	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
11	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
12	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
13	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
14	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
15	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
16	100.0000	242.0466	354.2858	426.2152	474.6655
	452.1002	363.0012	313.6085	258.0987	200.0000
17	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
18	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
19	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
20	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
21	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
22	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
23	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
24	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
25	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
26	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
27	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
28	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
29	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
30	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000

31	100.0000	242.0466	354.2858	426.2152	474.6655
	452.1002	363.0012	313.6085	258.0987	200.0000
32	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
33	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
34	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
35	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
36	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
37	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
38	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
39	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
40	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
41	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
42	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
43	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
44	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
45	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
46	100.0000	242.0466	354.2858	426.2152	474.6655
	452.1002	363.0012	313.6085	258.0987	200.0000
47	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
48	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
49	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
50	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
51	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
52	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
53	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
54	100.0000	263.1334	407.5174	500.0000	500.0000
	500.0000	500.0000	473.1500	335.7596	200.0000
55	100.0000	261.0131	405.8971	500.0000	500.0000
	500.0000	500.0000	473.0680	335.6008	200.0000
56	100.0000	257.9577	403.5717	500.0000	500.0000
	500.0000	500.0000	471.0010	332.8701	200.0000
57	100.0000	254.9467	401.2141	478.7527	498.6920
	498.4591	489.5642	452.9429	319.9746	200.0000
58	100.0000	252.9380	391.5989	468.3925	494.3776
	490.2167	461.4411	411.3120	305.9039	200.0000
59	100.0000	249.0466	376.1834	451.3343	486.8310
	475.6056	417.8386	362.0989	283.6683	200.0000
60	100.0000	244.4592	361.2121	434.2724	478.7171
	459.8829	379.1920	326.9278	265.2895	200.0000
61	100.0000	242.0466	354.2858	426.2152	474.6655
	452.1002	363.0012	313.6085	258.0987	200.0000

	x	y	z
Eccentricity ratio=			0.00000E+00
Misalignment ratio=	0.00000E+00	0.00000E+00	

Axial force = 21129. lbs
Moment components = 2.21320E-11 3.14818E-11 in-lb

	Location		
Maximum pressure	(4, 6)=	500.00	psi
Minimum film thickness	(1, 1)=	3.00000E-03	inches

Pressurized Pockets: Orifice diameter = 0.11497 inches

Pocket Number	Pressure (psi)	Flow (in**3/sec)
1	500.01	19.698
2	499.99	19.699
3	499.99	19.699
4	500.01	19.698
Total=		78.795

Radial flow from inside= -33.282 in**3/sec
Radial flow to outside= 45.513 in**3/sec
Overall flow error = 9.80556E-08 in**3/sec
Torque about z-axis = 181.09 in-lb
Power loss = 4.35816E+05 in-lb/sec

Dynamic Coefficients (Force unit / displacement unit)

Disp.	z inches	inches	α radians	β radians	Force unit
Kz	7.25155E+06	0.00000E+00	2728.8	-2686.4	lbs
Kα	-51.190	0.00000E+00	3.09909E+07	3.87133E+07	in-lb
Kβ	-57.237	0.00000E+00	-3.87133E+07	3.09846E+07	in-lb
Bz	5915.6	0.00000E+00	3.6079	-0.48020	lbs-sec
Bα	1.1996	0.00000E+00	25139.	2.1306	in-lb-sec
Bβ	0.79754	0.00000E+00	0.55953	25137.	in-lb-sec

Pressures & velocities written to file: iface15a.888
IFACE Analysis Completed 06/01/93 18:13:44 2114.97 SEC

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06/01/1993  18:13        Filename: IFACE15A.ITR                          Page   1

          Pressure Iter.No.  1, Max.change @ (  4,  4)=    1.34117
          Pressure Iter.No.  2, Max.change @ (  4,  4)=  -0.993535
          Pressure Iter.No.  3, Max.change @ (  3, 43)=   7.234833E-02
          Pressure Iter.No.  4, Max.change @ (  3, 12)=  -9.292253E-02
          Pressure Iter.No.  5, Max.change @ (  3, 20)=  -3.499636E-02
          Pressure Iter.No.  6, Max.change @ (  3, 35)=  -6.298852E-03
          Pressure Iter.No.  7, Max.change @ (  3, 50)=  -2.470918E-04
          Pressure Iter.No.  8, Max.change @ (  3, 12)=  -3.813863E-07
          Pressure Iter.No.  9, Max.change @ (  4, 42)=   4.957479E-12

Calculation of Stiffness and/or Damping Coefficients

Calculating Stiffness Coefficients...Perturbing displacement:z
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.50000         0.50000         0.50000         0.50000
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     -1.90539E-04    -1.90539E-04    -1.90539E-04    -1.90539E-04
       Max.Error for PPOCK  2eqn.=    1.90539E-04
       Max.Error for PPOCK  3eqn.=    3.45196E-08 previous=    1.90539E-04

Calculating Stiffness Coefficients...Perturbing displacement:α
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.49995         0.49995         0.49995         0.49995
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      1.20087E-06     2.05869E-04     3.79671E-04     1.75042E-04
       Max.Error for PPOCK  3eqn.=    3.79671E-04
       Max.Error for PPOCK  2eqn.=    2.15654E-08 previous=    3.79671E-04

Calculating Stiffness Coefficients...Perturbing displacement:β
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.49995         0.50000         0.50005         0.50000
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      1.73844E-04    -2.04672E-04    -1.73882E-04     2.04675E-04
       Max.Error for PPOCK  4eqn.=    2.04675E-04
       Max.Error for PPOCK  2eqn.=    3.50105E-08 previous=    2.04675E-04

Calculating Damping Coefficients...B Perturbing velocity    :z
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.50000         0.49995         0.50000         0.50005
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
     -1.00864E-04     7.29550E-05    -1.31705E-04    -3.05577E-04
       Max.Error for PPOCK  4eqn.=    3.05577E-04
       Max.Error for PPOCK  4eqn.=    5.61652E-08 previous=    3.05577E-04

Calculating Damping Coefficients...B Perturbing velocity    :α
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.49997         0.49997         0.49997         0.49997
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      6.48688E-05     6.48835E-05     1.67637E-04     1.67609E-04
       Max.Error for PPOCK  3eqn.=    1.67637E-04
       Max.Error for PPOCK  3eqn.=    1.57338E-08 previous=    1.67637E-04
```

```
06/01/1993  18:13        Filename: IFACE15A.ITR                          Page   2

Calculating Damping Coefficients...B Perturbing velocity    :β
       ----Current position----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      0.49999         0.49999         0.50001         0.50001
Calculations at current position...
       ----Equation errors-----
         PPOCK  1        PPOCK  2        PPOCK  3        PPOCK  4
      1.02793E-04     1.09399E-08    -1.02774E-04     1.36316E-08
       Max.Error for PPOCK  1eqn.=    1.02793E-04
       Max.Error for PPOCK  3eqn.=    1.33353E-08 previous=    1.02793E-04
 Pressures & velocities written to file:  iface15a.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
```

```
Incompressible FACE seal program (IFACE) 06/01/93  18:13:45   iface15b

&INPUTS
TITLE= 'IFACE15B 4-POCKET FACE SEAL PRESCRIBED EX and MOMENTS'
CREF=   0.003,     RHO=   1.0E-4,                          EX=0.,
RADIUS= 4.,        XMU=   6.0E-8,                          Mxg= 3087.6,
LENGTH= 3.,        RPMJ= 30000.,                           Myg= -3894.8,
TS=      0,        RPMB=  0.0,          PCAV=  -1.E9,
TE=     90.,       XKE=   1.0,          PL1=  100.,        PR1= 200.,
IFACE=  1,         ISTIFF= 0,           NPADS=4,
M=     10,         N=     16,           READP='IFACE15A.888',
ISYM=   0,         IPER=   1,
MAXDIT= 4,         IREADP= 1,
DZT=  .05, .05, .05, .150,   0.30000,   0.15, .05, .05, .05,
DTH=  4, 3, 2, 1, 3, 5, 15, 24, 15, 5, 3, 1, 2, 3, 4,
NPOCK=  1,         PSUP= 1000.,         CD= 0.6,
M1=   3,     N1=   5,                   DORIF=0.115,
M2=   8,     N2=  12,                   PPOCK=500.,
&END

IFACE15B 4-POCKET FACE SEAL PRESCRIBED EX and MOMENTS

Input values:

Seal Type: Face seal
Outer Radius =   4.0000      inches
inner Radius =   1.0000      inches
Clearance =  3.00000E-03 inches
Rotor Roughness =  0.00000E+00 inches
Housing Roughness =  0.00000E+00 inches
Rotor Angular Velocity =   30000.      r/min.
Housing Angular Velocity =  0.00000E+00 r/min.
Periodic conditions at circumferential ends
Inertia pressure drop coefficient =  1.0000

                          Inside      Outside radius
Pressure at top     =    100.00       200.00      psi
Viscosity =  6.00000E-08 psi-sec
Density =  1.00000E-04 lb-s**2/in**4

Number of radial grid intervals =            9
Number of circumferential grid intervals =  60

Data for   4 pressurized pockets:
Orifice diameter =  0.11500      inches
Supply pressure =   1000.0      psi
Discharge Coeff. = 0.60000

Pocket        radial            Circumferential     Pressure
Number     Start   End             Start   End      (psi            )
 1                3     8          5     12           500.00
 2                3     8         20     27           500.00
 3                3     8         35     42           500.00
 4                3     8         50     57           500.00

Pressure scale P0=  1000.0      psi
Dimensionless parameters:
   Speed of rotor surface            XLj=  2.0106
   Speed of housing surface          XLb= 0.00000E+00
   Inertia pressure drop coefficient XLI= 0.48828
   Couette Reynolds numbers          REO=  62832.
   Poisseuille Reynolds numbers      REOS= 1.87500E+05

 Friction formula based on Moody diagram (Nelson)
 Newton-Raphson itertions for velocity components
Pressures & velocities read from file: IFACE15A.888
```


Outputs:

Pressure, psi	1 6	2 7	3 8	4 9	5 10
1	100.0000	219.7070	315.0549	374.8441	408.1441
	369.1627	290.3551	256.9046	225.2341	200.0000
2	100.0000	218.7811	315.0466	373.5127	401.8137
	369.1972	300.2942	265.6917	230.1295	200.0000
3	100.0000	221.0553	324.5891	383.3386	404.8707
	384.7045	335.9348	297.6121	246.7754	200.0000
4	100.0000	223.5605	336.1424	395.2052	410.2483
	401.8476	377.5699	342.4206	266.9884	200.0000
5	100.0000	224.9468	343.7227	402.7892	413.8281
	412.2150	404.6780	379.6569	279.6354	200.0000
6	100.0000	226.6353	344.5920	414.7679	414.7679
	414.7679	414.7679	395.7082	291.1561	200.0000
7	100.0000	228.2614	345.0790	414.7679	414.7679
	414.7679	414.7679	396.1186	293.1673	200.0000
8	100.0000	229.3691	345.0564	414.7679	414.7679
	414.7679	414.7679	395.0130	293.3267	200.0000
9	100.0000	229.9048	345.0708	414.7679	414.7679
	414.7679	414.7679	394.6668	294.0830	200.0000
10	100.0000	230.0013	344.8683	414.7679	414.7679
	414.7679	414.7679	393.8076	294.3541	200.0000
11	100.0000	229.8468	345.9137	414.7679	414.7679
	414.7679	414.7679	391.8837	292.6200	200.0000
12	100.0000	229.4866	347.8740	406.7288	414.7679
	414.4371	407.4265	379.1163	283.8799	200.0000
13	100.0000	228.6098	341.6465	401.1231	415.2818
	411.1524	387.9042	350.1127	274.2978	200.0000
14	100.0000	227.1109	332.5600	392.8864	417.1992
	406.3755	359.0337	316.9308	259.6090	200.0000
15	100.0000	226.2026	326.0625	387.5531	422.7554
	404.8657	336.9936	295.9895	248.8230	200.0000
16	100.0000	228.4518	328.7115	392.7806	435.9314
	414.7398	336.2022	294.2863	247.8657	200.0000
17	100.0000	234.9274	343.3584	411.8923	456.1989
	438.8897	363.5402	315.2934	259.0272	200.0000
18	100.0000	242.0645	362.7997	435.9500	475.9652
	466.3513	408.9455	353.9067	279.0078	200.0000
19	100.0000	247.4026	380.4329	457.0860	491.1082
	488.6729	456.8138	402.8859	301.1839	200.0000
20	100.0000	250.0618	390.8790	469.3142	499.1865
	500.7729	487.3164	442.3794	314.7804	200.0000
21	100.0000	254.9499	396.7656	505.2328	505.2328
	505.2328	505.2328	463.1269	328.7058	200.0000
22	100.0000	260.2472	402.3961	505.2328	505.2328
	505.2328	505.2328	467.2089	332.8694	200.0000
23	100.0000	264.6411	406.8542	505.2328	505.2328
	505.2328	505.2328	469.5711	335.1773	200.0000
24	100.0000	265.6929	408.0414	505.2328	505.2328
	505.2328	505.2328	471.1584	337.2208	200.0000
25	100.0000	266.6830	410.4358	505.2328	505.2328
	505.2328	505.2328	473.7057	339.4437	200.0000
26	100.0000	267.1952	414.2777	505.2328	505.2328
	505.2328	505.2328	474.5249	339.1447	200.0000
27	100.0000	267.2304	419.0143	496.3159	505.2328
	505.2328	500.5700	463.5934	330.7335	200.0000
28	100.0000	266.3053	411.7452	489.9000	508.5940
	507.9914	482.7956	430.4544	319.9634	200.0000
29	100.0000	264.6632	401.0614	480.4572	515.3359
	513.0507	456.2109	394.1243	303.7821	200.0000
30	100.0000	263.5723	393.2137	474.2282	526.1569
	521.4754	436.3451	372.5405	292.3528	200.0000

31	100.0000	265.8912	395.7873	479.8194	543.1236
	537.0859	437.1916	371.4228	291.5515	200.0000
32	100.0000	272.9566	412.3917	501.2276	563.9659
	559.5085	465.4824	393.7740	303.5941	200.0000
33	100.0000	280.8470	434.9987	528.6693	582.2086
	580.7452	512.2340	436.2326	325.9818	200.0000
34	100.0000	286.7589	455.8160	553.0987	595.4038
	596.2585	561.6918	493.1867	352.0007	200.0000
35	100.0000	289.6932	468.2586	567.3510	602.2169
	604.0244	592.9725	541.3251	368.4359	200.0000
36	100.0000	294.8873	473.7900	605.3299	605.3299
	605.3299	605.3299	563.0098	384.0839	200.0000
37	100.0000	300.4294	479.7238	605.3299	605.3299
	605.3299	605.3299	568.7749	389.3098	200.0000
38	100.0000	304.5190	484.4188	605.3299	605.3299
	605.3299	605.3299	571.9355	391.2968	200.0000
39	100.0000	303.7877	484.4667	605.3299	605.3299
	605.3299	605.3299	573.1885	391.1708	200.0000
40	100.0000	298.4548	480.8812	605.3299	605.3299
	605.3299	605.3299	575.1226	390.9072	200.0000
41	100.0000	291.3186	473.6234	605.3299	605.3299
	605.3299	605.3299	573.7134	387.1254	200.0000
42	100.0000	284.6785	464.9619	564.1539	599.6974
	602.0709	593.1828	550.6611	369.3094	200.0000
43	100.0000	281.1750	450.8581	547.7541	589.2106
	587.9110	555.3095	492.5665	349.2551	200.0000
44	100.0000	274.1442	427.0924	519.4039	569.4825
	561.2351	494.0987	422.5184	316.8772	200.0000
45	100.0000	264.7516	400.9619	487.1349	543.5832
	527.3613	434.1457	368.3066	287.9589	200.0000
46	100.0000	256.2555	381.3598	461.4985	516.8320
	496.0250	396.3733	338.1910	271.4249	200.0000
47	100.0000	253.3600	377.9068	454.4366	499.3140
	481.3727	395.4837	339.1441	271.9287	200.0000
48	100.0000	254.6334	386.7375	461.4616	491.8903
	481.0339	423.0185	367.5694	286.8577	200.0000
49	100.0000	256.6740	399.0428	472.3400	489.3314
	485.3058	459.4316	414.9300	308.0546	200.0000
50	100.0000	257.8672	407.4756	479.7355	488.6549
	488.4893	483.6854	457.7076	322.1079	200.0000
51	100.0000	258.6649	406.0075	488.6549	488.6549
	488.6549	488.6549	471.3526	332.8812	200.0000
52	100.0000	259.2075	404.9236	488.6549	488.6549
	488.6549	488.6549	471.6430	333.7141	200.0000
53	100.0000	259.0258	403.7805	488.6549	488.6549
	488.6549	488.6549	469.9074	331.2631	200.0000
54	100.0000	258.1219	402.7195	488.6549	488.6549
	488.6549	488.6549	468.6242	329.1098	200.0000
55	100.0000	253.3129	397.4332	488.6549	488.6549
	488.6549	488.6549	466.5303	327.3432	200.0000
56	100.0000	247.1705	389.3488	488.6549	488.6549
	488.6549	488.6549	462.0402	322.8667	200.0000
57	100.0000	241.5615	380.4397	454.6091	480.7650
	481.2713	471.0319	436.8932	305.7532	200.0000
58	100.0000	238.6578	368.8306	441.1239	469.8751
	462.7447	432.8279	386.7101	288.5198	200.0000
59	100.0000	232.9512	349.5425	418.1234	450.4184
	430.3398	373.3363	325.3139	260.7379	200.0000
60	100.0000	225.6429	329.0213	392.8444	427.3321
	394.1930	318.6796	278.6617	236.6578	200.0000
61	100.0000	219.7070	315.0549	374.8441	408.1441
	369.1627	290.3551	256.9046	225.2341	200.0000

	x	y	z
Eccentricity ratio=			0.00000E+00
Misalignment ratio=	0.20000	-2.08372E-06	

Axial force = 21261. lbs
Moment components = -3087.6 3894.8 in-lb

Location
Maximum pressure (4, 36)= 605.33 psi
Minimum film thickness (10, 46)= 2.40000E-03 inches

Pressurized Pockets: Orifice diameter = 0.11500 inches

Pocket Number	Pressure (psi)	Flow (in**3/sec)
1	414.77	21.321
2	505.23	19.604
3	605.33	17.509
4	488.65	19.930
Total=		78.365

Radial flow from inside= -33.199 in**3/sec
Radial flow to outside= 45.166 in**3/sec
Overall flow error = 2.46803E-11 in**3/sec
Torque about z-axis = 182.40 in-lb
Power loss = 4.38383E+05 in-lb/sec

Pressures & velocities written to file: iface15b.888
IFACE Analysis Completed 06/01/93 18:36:33 1367.97 SEC

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Pressures & velocities read from file: IFACE15A.888

      ----Current position----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
     1.27323-313   1.27323-313    0.50001        0.49999        0.49999
        PPOCK  4
     0.50001
Calculations at current position...
         Pressure Iter.No.  1, Max.change @ (  4, 51)=   1.292102E-05
         Pressure Iter.No.  2, Max.change @ (  4, 20)=  -1.433228E-10
      ----Equation errors-----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
     4.82437E-02   -6.08700E-02   4.05313E-04    5.08020E-04    5.08009E-04
        PPOCK  4
     4.05305E-04
      Max.Error for BETA    eqn.=    6.08700E-02

Calculation of Position and/or Pocket Pressures...

 Position Iter.No.  1
         Calculate Partial Derivitives of Errors...
         Perturbing ALFA
         Perturbing BETA
         Perturbing PPOCK  1
         Perturbing PPOCK  2
         Perturbing PPOCK  3
         Perturbing PPOCK  4
      ----New position----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
     0.20051      -9.49204E-04    0.40477        0.50834        0.59546
        PPOCK  4
     0.49192
Calculations at new position...
         Pressure Iter.No.  1, Max.change @ (  6, 33)=   9.837587E-02
         Pressure Iter.No.  2, Max.change @ (  4, 12)=  -4.586620E-03
         Pressure Iter.No.  3, Max.change @ (  4, 12)=  -2.579573E-05
         Pressure Iter.No.  4, Max.change @ (  8, 12)=  -2.005130E-09
      ----Equation errors-----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
    -8.23955E-05    4.85749E-05   5.07880E-02   -1.74870E-02    3.24878E-02
        PPOCK  4
    -1.77295E-02
      Max.Error for PPOCK  1eqn.=    5.07880E-02 previous=    6.08700E-02

 Position Iter.No.  2
         Calculate Partial Derivitives of Errors...
         Perturbing ALFA
         Perturbing BETA
         Perturbing PPOCK  1
         Perturbing PPOCK  2
         Perturbing PPOCK  3
         Perturbing PPOCK  4
      ----New position----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
     0.20001      -9.24917E-06    0.41487        0.50527        0.60544
        PPOCK  4
     0.48869
Calculations at new position...
         Pressure Iter.No.  1, Max.change @ (  4,  6)=   1.010043E-02
         Pressure Iter.No.  2, Max.change @ (  4, 12)=  -7.173061E-05
         Pressure Iter.No.  3, Max.change @ (  4, 12)=  -8.026025E-09
      ----Equation errors-----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
    -9.36468E-07    6.53457E-07   -5.29195E-04   -8.77772E-05   -3.06296E-04
        PPOCK  4
    -9.87072E-05
```

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      Max.Error for PPOCK  1eqn.=    5.29195E-04 previous=    5.07880E-02

 Position Iter.No.  3
         Calculate Partial Derivitives of Errors...
         Perturbing ALFA
         Perturbing BETA
         Perturbing PPOCK  1
         Perturbing PPOCK  2
         Perturbing PPOCK  3
         Perturbing PPOCK  4
      ----New position----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
     0.20000      -2.08372E-06    0.41477        0.50523        0.60533
        PPOCK  4
     0.48865
Calculations at new position...
         Pressure Iter.No.  1, Max.change @ (  4, 36)=  -1.089727E-04
         Pressure Iter.No.  2, Max.change @ (  8, 11)=  -3.553698E-09
      ----Equation errors-----
        ALFA          BETA          PPOCK  1       PPOCK  2       PPOCK  3
     6.65121E-11    3.44095E-10   -1.34554E-07   -3.07103E-08   -4.76743E-08
        PPOCK  4
    -1.11487E-08
      Max.Error for PPOCK  1eqn.=    1.34554E-07 previous=    5.29195E-04
 Pressures & velocities written to file:  iface15b.888

 Reading namelist input...

***** IFACE Analysis Code Complete *****
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13. ABSTRACT ***(Maximum 200 words)***

The computer code IFACE was developed to evaluate the performance of face and cylindrical seals operating with incompressible fluids. Features such as steps, tapers, pockets, and preloaded arcs can be modeled. IFACE can handle laminar and turbulent flows and cavitation. The pressure and velocity distributions within the seal clearance are first evaluated from the governing equations. From these, design quantities such as seal leakage flow, power loss and resulting forces, and moments are calculated. Minimum film thicknesses and maximum pressures as well as critical rotor-dynamics coefficients such as stiffness, damping, and critical mass are evaluated. This users' manual documents the theory, numerical methods, inputs and outputs description, sample problems, code verification, and operating environments.

14. SUBJECT TERMS
Face seals; Seals; Cylindrical seals; Leakage; Incompressible fluids; Users' manual

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