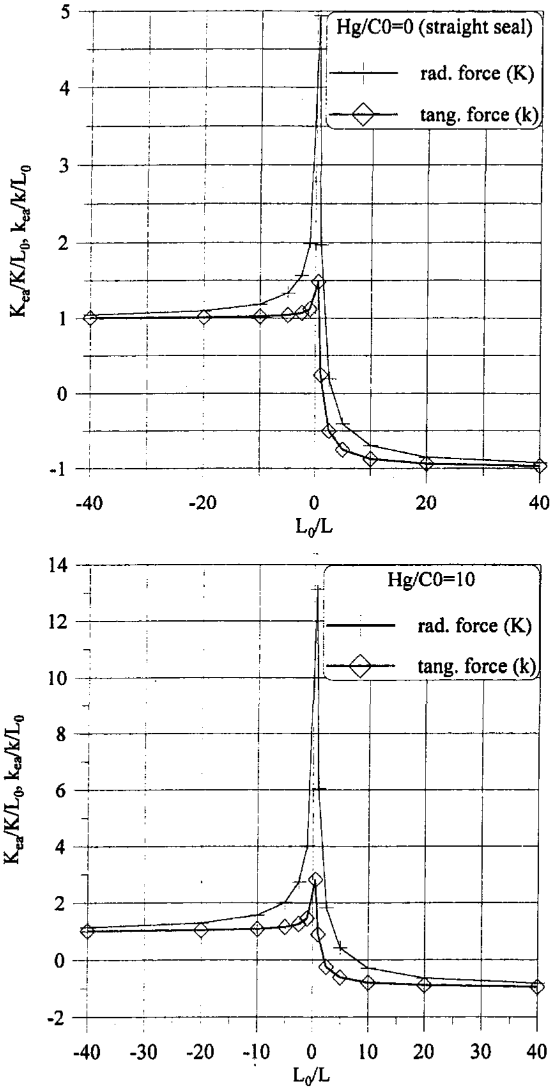


**Fig. C1 Relative importance of misalignment versus eccentricity forces ($\Omega = 0$)**

(large $L/D$) this influence is reduced. From this standpoint, one should expect that, compared to measured results, bulk flow methods give better estimations for long seals than for very short ones.

The grooved seal example is a widely accepted test case and was previously used for validating rotordynamic coefficients arising from cylindrical whirl (Arghir and Frêne, 1996). The given axial Reynolds number is based on the leakage flow. It is indeed recognized and it was acknowledged in our introduction that the ratio $L/D$ governs the importance of $M_r$ and $M_t$ but the resulting forces obey other influences. Calculations showed that for zero whirl ($\Omega = 0$), forces arising from misalignment can be more important than forces due to eccentricity and their relative importance is governed especially by the position of the tilting point, $L_0$. The results in Fig. C1 were obtained for the stator grooved seal presented in the paper and they clearly show the influence of $L_0$.

The mass coefficients in the radial force and moment first increase with increasing groove depth and then start to decrease when the groove depth approaches $H_g/C_0 = 10$. Due to the large groove depth it is difficult to explain this trend by the usual superposition of three effects (Lomakin, hydrodynamic and distributed inertia). The same trend was obtained in the calculations for a nine groove seal ($L/D = 2$) and more intensive investigations would be needed before formulating an explanation.

The tangential force is strongly influenced by the circumferential flow. It was never demonstrated, but it is likely that the tangential moment will also be influenced in the same way. With increasing the (stator) groove depth, the circumferential flow will be reduced due to the enhanced stator friction. This leads to a reduction of the whirl frequency ratio (Fig. 5(*b*)) which is a favorable effect, increasing the threshold from a stable to an unstable tangential force. In fact that is the effect of all artificial roughened stator surfaces. The trends of the tangential moment underlined in the comment are correct but we considered that the values in Fig 5(*d*) are too small for being characteristic. We limit ourselves to observe that the absolute values of the tangential moment are globally decreased with increasing the groove depth.

An extensive sensitivity analysis could be performed but will lengthen the paper. Nevertheless, the effect of the pressure recovery coefficient was analyzed and is presented in response to another comment. One should also point out that the inlet velocity profile has a certain influence but which is less important than reported by Baskharone and Hensel (1991).

### Additional Reference

Arghir, M., Frêne, J., 1996, "Rotordynamic Coefficients of Circumferentially Grooved Liquid Seals Using the Averaged Navier-Stokes Equations," accepted for publication in the ASME JOURNAL OF TRIBOLOGY.

### Answer to Comments of Dr. M. Athavale

The authors would like to thank Dr. Athavale for his comments and insightful questions.

The calculations presented in the paper were performed with an exit loss coefficient of 1. Calculations for $\xi_{ex} = 0.85$ and 0.7 are presented in Fig. C2. Compared to the results obtained for short, cylindrically whirling straight seals (Childs, 1993), the influence of $\xi_{ex}$ on the stiffness coefficients is less important. The explanation is that the pressure recovery effect is a small percentage of the total pressure drop when the seal is long and a large percentage when the seal is short. So it is likely that the

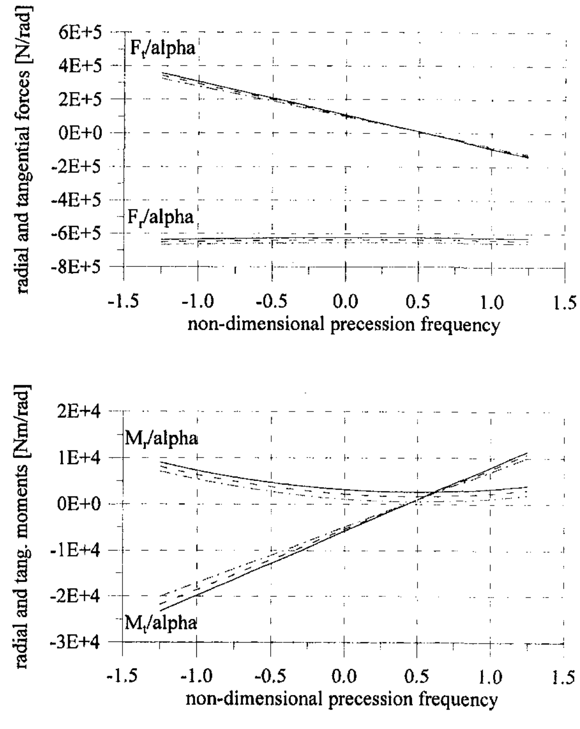


**Fig. C2 Influence of the pressure recovery effect ——— $\xi_{ex} = 1$ ----- $\xi_{ex} = 0.85$ ------ $\xi_{ex} = 0.7$**

pressure recovery effect acts in the same qualitative way on conically and cylindrically whirling seals, but its importance is governed by the $L/D$ ratio.

In answer to the second question, one should underline that the position of the first computational cell near the wall is an important step of the present computational method, whether it deals with cylindrical or conical whirl. In order to obtain accurate results, the first grid point must lie on the logarithmic layer. The effect of varying the non dimensional wall distance $y^+$ was analyzed in another paper (Arghir and Frêne, 1996, Table 3) and it was shown that the requirement is more stringent for the rotor wall. So, the position $y^+$ of the first grid point is verified at the end of the zeroth order calculations. This step is very important for Reynolds number just beyond the transition (4000–5000) when it is easy to get the first computational cell in the laminar sublayer, but with increasing Reynolds number, of the order $10^4-10^5$, it is more easy to control the position of the first grid point on the logarithmic layer.

Finally, the case of a grooved rotor could be treated with a very similar analytic coordinate transformation but the resulting approach would be limited to smooth stator analysis. A better solution is the replacement of the analytic coordinate transformation with a numerical one. In conjunction with all the simplifying assumptions which render the perturbation method quasi-2D (mainly the axisymmetric computational grid), this approach has the ability to treat labyrinth seals of general form without an increase of the computational effort.

## Answer to Comments of Dr. T. Staubli

The authors would like to thank Dr. Staubli for his comments. As it was answered in the previous comment, the extension of the method for treating general labyrinth seals was carried out in a different work by replacing the analytic coordinate transformation by a numerical one.

Concerning the inlet and the exit boundary conditions, if the flow conditions in upstream and downstream plenums can be modeled by using only the first Fourier component in the circumferential direction, then the present use of Bernoulli's equation seems to be a good solution for pressure and axial velocity. Nevertheless, in certain situations, the flow in plenums may influence the radial and the circumferential velocity in a different way from it is now accounted for. On the other hand, when the perturbed flow in plenums cannot be modeled by using only the first Fourier component it is likely that the flow in the seal will be more or less affected, depending on $C_0/r_R$ and $L/D$ ratios. In this case, a quasi 2D approach is of little use and a full 3D method (perturbed or not), gridding also the circumferential direction, should be employed.