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LINEARIZED FORCE REPRESENTATIONS FOR TURBOPUMP LIQUID ANNULAR SEALS

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The mechanical integrity and performance of the SSME and ATD turbopumps are a constant concern at NASA. These two factors are in turn significantly influenced by mechanical vibrations. These vibrations arise from imbalance of the rotating shafts, from broadband random excitation and from internal sources of self excitation (instability). Liquid, annular interstage seals are known to influence vibrations within the turbopump. The de-stabilizing and stabilizing forces within the seal are quantified by the cross coupled stiffness and damping coefficients, respectively. Mr. George L. von Pragenau of MSFC initially postulated, and later rigorously proved by simulation, that cross coupled stiffness could be reduced by roughening the stationary part of the seal. Mr. von Pragenau employed a Moody type friction model in his analysis for leakage and dynamic coefficients in these seals. Henry Black first recognized that the inlet tangential velocity (pre-swirl) of the seal can significantly effect its cross-coupled stiffness coefficient. Although von Pragenau did not include this in his simulation his work did have a constant swirl modeled along the length of the seal. Turbomachinery designers have installed axial taper in seals as a means to alter their stiffnesses. An effect of the taper is that the axial velocity component varies along the length of the seal. The varying axial velocity significantly complicates the governing flow equations, requiring numerical integration for their solution.

The summer faculty fellow has developed the analysis and an accompanying Fortran code SEALPAL1 to simulate liquid annular seals with axial taper, Moody friction factors and pre-swirl. The output of the code includes all dynamic coefficients (stiffness, dampings, and inertias), leakage rate, torque and horsepower loss. In addition to the software the faculty fellow has prepared the two following 200 page (plus) theoretical manuals;

Palazzolo, A.B., 1991, "A Theoretical Manual for G. L. von Pragenau's Liquid Seal Simulation Program," May-June

Palazzolo, A.B., 1991, "Dynamic Coefficients for Incompressible, Liquid Annular Seals Including Moody Friction Factor, Taper and Pre-Swirl," June-July

The leakage, torque and horsepower are determined by simultaneously solving the axial momentum, circumferential momentum and continuity equations for a shaft-centered (non-vibrating) configuration. The fluid is simulated with a bulk flow model with shear tractions described by Moody's equations. The dynamic coefficients are obtained by performing a perturbation analysis about the shaft-centered state. This step requires linearization of the momenta and continuity equations. The resulting perturbation pressure is integrated to obtain forces on the shaft that are parallel and perpendicular to the whirl vector. The stiffness, dampings, and inertias are obtained by least square curve fitting these forces to the spring-mass-damper ideal model.

The computer code results were compared with five (5) cases from the literature. The agreement was very good in almost all instances except several predicted cross coupled stiffnesses were significantly lower than those appearing in the literature. This disagreement could reflect a theoretical or programming error by the faculty fellow or in the literature, or could be a result of the difference in friction factor models on other assumptions employed.

The following table shows a comparison between the current code results and those given by Scharrer for a high pressure, high speed seal;

	Scharrer	SEALPAL1
Direct Stiffness	1.4×10^6 lb/in	1.33×10^6 lb/in
Direct Damping	148. lb.s./in	149. lb.s./in
Direct Mass	3.8×10^{-3} lb.s./in^2	3.8×10^{-3} lb.s./in^2
Cross Stiffness	3.8×10^5	3.3×10^5

Figure 1 shows the steady state solution variables (velocities, pressure, whirl ratio) for this test case.

Future work proposed in this area includes expansion of SEALPAL1 to simulate;

- 0 seal housing expansion,
- 0 Hir's friction factors,
- 0 thermal effects,
- 0 arbitrarily shaped clearance profile, and
- 0 compressibility and variable property effects.

REFERENCES

1. Scharrer, J., and Nelson C., "Rotor Dynamic Coefficients for Pertially Tapered Annular Seals, "ASME Paper No. 90-Trib-25.

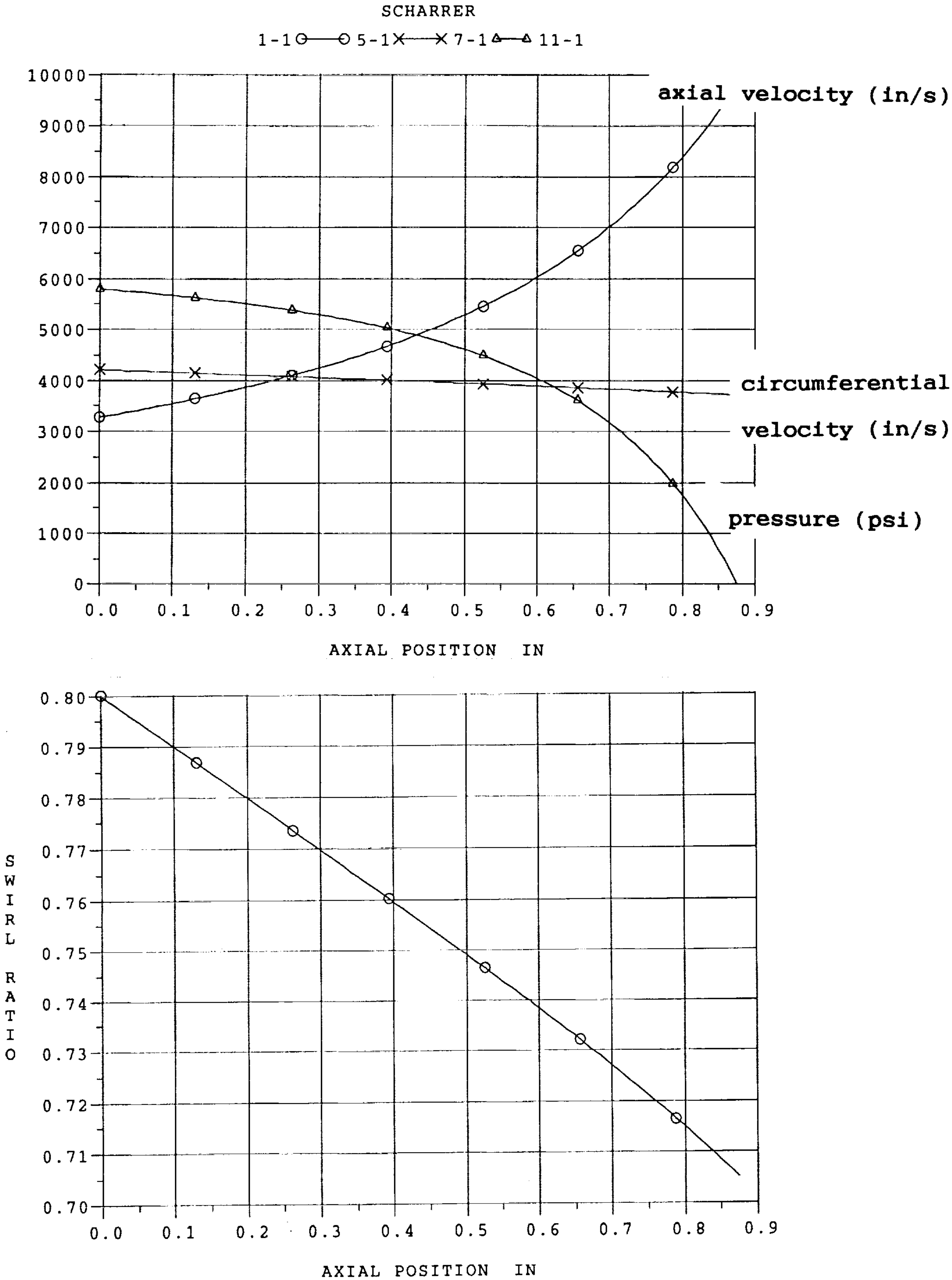

Fig. 1 Steady State Solution Variables