N94-24415

**1993**

**NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM**

**MARSHALL SPACE FLIGHT CENTER**
**THE UNIVERSITY OF ALABAMA IN HUNTSVILLE**

# FOIL BEARINGS


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| Prepared By: | David A. Elrod, Ph. D. |
| Academic Rank: | Assistant Professor |
| Institution and Department: | The University of Alabama in Huntsville<br>Mechanical and Aerospace Engineering Department |
| MSFC Colleague: | Henry P. Stinson |
| NASA/MSFC: | |
| Laboratory: | Propulsion |
| Division: | Component Development |
| Branch: | Turbomachinery |

## INTRODUCTION

The rolling element bearings (REB's) which support many turbomachinery rotors offer high load capacity, low power requirements, and durability. Two disadvantages of REB's are:

- rolling or sliding contact within the bearing has life-limiting consequences; and
- REB's provide essentially no damping.

The REB's in the Space Shuttle Main Engine (SSME) turbopumps must sustain high static and dynamic loads, at high speeds, with a cryogenic fluid as lubricant and coolant. The pump end ball bearings limit the life of the SSME high pressure oxygen turbopump (HPOTP). Compliant foil bearing (CFB) manufacturers have proposed replacing turbopump REB's with CFB's. CFB's work well in aircraft air cycle machines, auxiliary power units, and refrigeration compressors. In a CFB, the rotor only contacts the foil support structure during start up and shut down. CFB damping is higher than REB damping. However, the load capacity of the CFB is low, compared to a REB. Furthermore, little stiffness and damping data exist for the CFB. A rotordynamic analysis for turbomachinery critical speeds and stability requires the input of bearing stiffness and damping coefficients.

The two basic types of CFB are the tension-dominated bearing (Figure 1) and the bending-dominated bearing (Figure 2). Many investigators have analyzed and measured characteristics of tension-dominated foil bearings, which are applied principally in magnetic tape recording. The bending-dominated CFB is used more in rotating machinery.

This report describes the first phase of a structural analysis of a bending-dominated, multileaf CFB. A brief discussion of CFB literature is followed by a description and results of the present analysis.

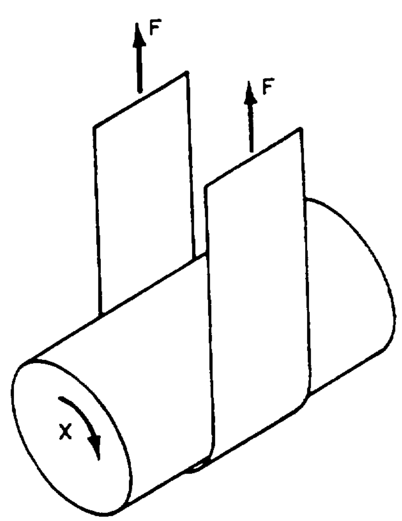


Figure 1. Tension-dominated foil bearing

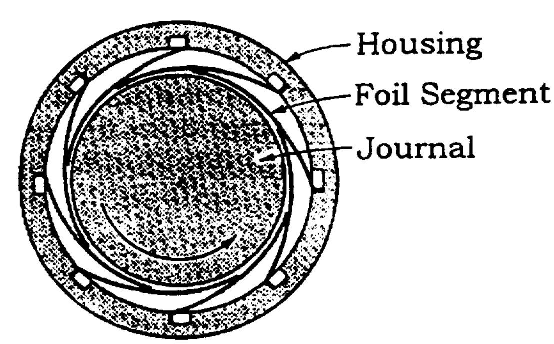


Figure 2. Bending-dominated foil bearing

## ANALYSIS

Most of the analyses of bending-dominated CFB's have the following common characteristics:

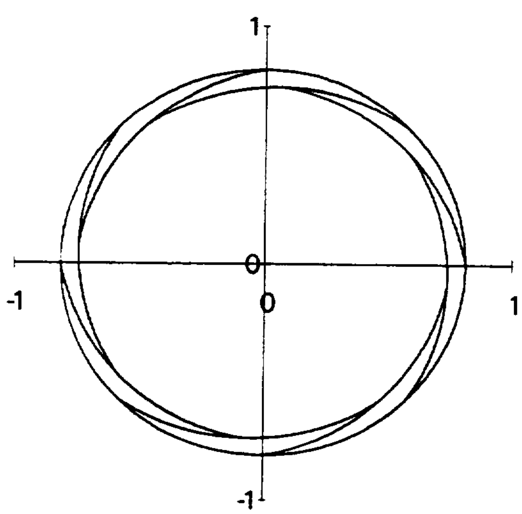
- fluid inertia effects are considered negligible;
- the fluid film is compressible (as in most applications); and
- the equations for the compliant walls and fluid film are coupled in an iterative solution.

In addition, some investigators declare that the foil leaves in a multileaf CFB are more important than the fluid film in determining:

- bearing stiffness and damping;
- load capacity as a function of eccentricity;
- preload between the leaves and journal; and
- startup torque.

In a rocket engine turbopump application, the fluid film is incompressible, and inertia effects may be appreciable. However, the present model is an analysis of the multileaf structure only.

In a manner similar to the analyses of Oh and Rohde (1) and Trippett, Oh, and Rohde (2), the present model first solves for the assembly of overlapping leaves in the bearing housing. The solution is iterative, and is a function of the bearing housing radius $r_b$, the radius of curvature of the pre-formed leaves $r_l$, and the number of leaves $n_l$. Figure 3 shows the result for an input of $r_b = 0.8125\text{inch}$, $r_l = 0.915\text{inch}$, and $n_l = 8$. For a valid solution, the distance from the center of the bearing housing to the end of a leaf must equal the distance from the center to a point on the leaf $2\pi/n_l$ radians away.




| | |
|---|---|
| Input data: | |
| Leaf radius | 0.9150 inch |
| Housing radius | 0.8125 inch |
| Leaf length | 1.102 inches |
| Number of leaves | 8 |

Figure 3. Compliant foil bearing assembly, no rotor

After the foil leaves are assembled in the housing, rotor installation requires deformation of the leaves. The forces deforming the leaves are the rotor forces and leaf reaction forces. The constraints for rotor installation are:

- the minimum distance from the bearing housing center to the leaf is equal to the rotor radius;
- the distance from the housing center to a point on the overlapping part of one leaf must be less than the distance to the "overlapped" part of the next leaf; and
- the leaves can only push (not pull) on one another at contact points.

The application of Castigliano's theorem provides compliance functions which relate the deflection of each point on a leaf to rotor forces and leaf forces. The foil leaves are curved beams with one end fixed. The additional input data required for calculating the effect of rotor installation are the rotor radius $r_r$, the second moment of the area of the leaf cross section $I$, and Young's modulus for the leaf material $E$. The analysis calculates the rotor force required to satisfy the above list of constraints. Figure 4 is a plot of the housing center to leaf distance before and after installation of a 0.7885 inch rotor into the foil bearing of Figure 3. The leaves in the analysis are one inch wide, 0.006 inch thick, with a Young's modulus of 30 Mpsi. The arrows on the "after" leaf represent the locations of the forces required to install the leaf. Figure 5 shows the geometry of the bearing with the rotor installed.

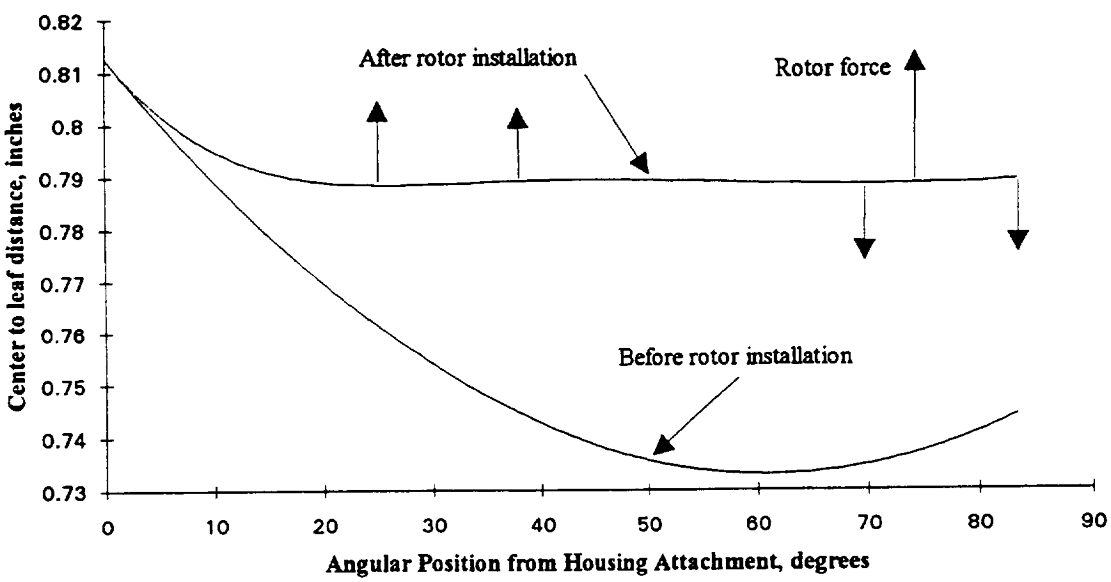
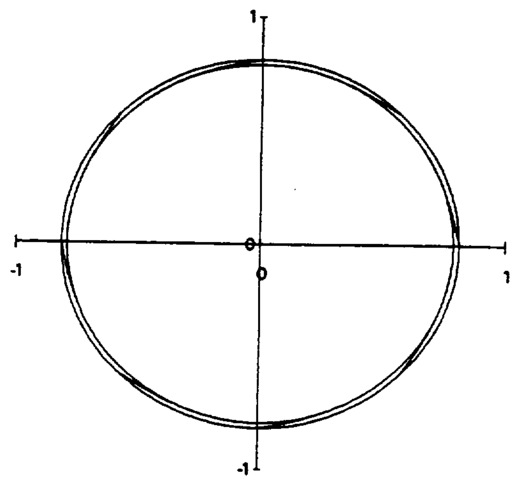



Figure 4. Compliant foil bearing - leaf distance from housing center

## CONCLUSIONS

This report describes an analysis of the geometry of a multileaf, compliant foil bearing. The analysis solves for the assembly of preformed leaves in a bearing housing, and the installation of a rotor in the assembly. The analysis will be modified to include interleaf friction forces, leaf backup support options, and an analysis of the deflection of the rotor due to an applied load. Predictions will be compared to MSFC test data. Future developments will include the interaction of the bearing fluid film.




Input data:

| | |
|---|---|
| Leaf radius | 0.9150 inch |
| Housing radius | 0.8125 inch |
| Leaf length | 1.102 inches |
| Number of leaves | 8 |
| Rotor radius | 0.7885 inch |
| I (area moment) | 1.8E-8 $in^4$ |
| E (Young's mod) | 30E6 psi |

Rotor force
0.72 lbf at 74 degrees
Leaf forces
0.39 lbf at 38 and 83 degrees
0.45 lbf at 25 and 70 degrees

Figure 5. Compliant foil bearing, rotor installed

REFERENCES


(1) Oh, K. P., and Rohde, S. M., "A Theoretical Investigation of the Multileaf Journal Bearing," *ASME Journal of Applied Mechanics*, Vol. 98, No. 2, June 1976, pp. 237-242

(2) Trippett, R. J., Oh, K. P., and Rohde, S. M., "Theoretical and Experimental Load-Deflection Studies of a Multileaf Journal Bearing," *Topics in Fluid Film Bearing and Rotor Bearing System Design and Optimization*, 1978, pp. 130-156