Determining Dynamic Stiffness of a Pressurized Bearing Using 3D CFD Code with Experimental Verification

Problem Statement

- Existing Methods of Pressurized Bearing Dynamic Stiffness Prediction Not Generally Applicable for All Geometries
- 1-D, 2-D Bulk Flow Methods Require Analytical/Geometric Approximations

A Generalized 3D Approach Applicable to All Geometries and Operating Conditions is Highly Desirable

CFX-TASCflow

- General 3-D Navier-Stokes Fluid Flow Solver Developed By AEA Technology Engineering Software
- Applicable to Laminar/Turbulent, Compressible/Incompressible, Steady/Transient Flow
- Flexible Fluid Properties (Constant, Variable)
- Uses Multi-block, Locally Structured Grids with Arbitrary Block Connectivity
- **Unique "Moving Grid" Feature Allows Motion of Walls in Computational Model. Modeling of Positive Displacement Pumps, Hydrostatic Bearings, and Seals Now Possible**

“Moving Grid” Approach

- User Provides Mathematical Model of Time-Dependent Position of Each Node On Moving Boundary Via User-FORTRAN Subroutine

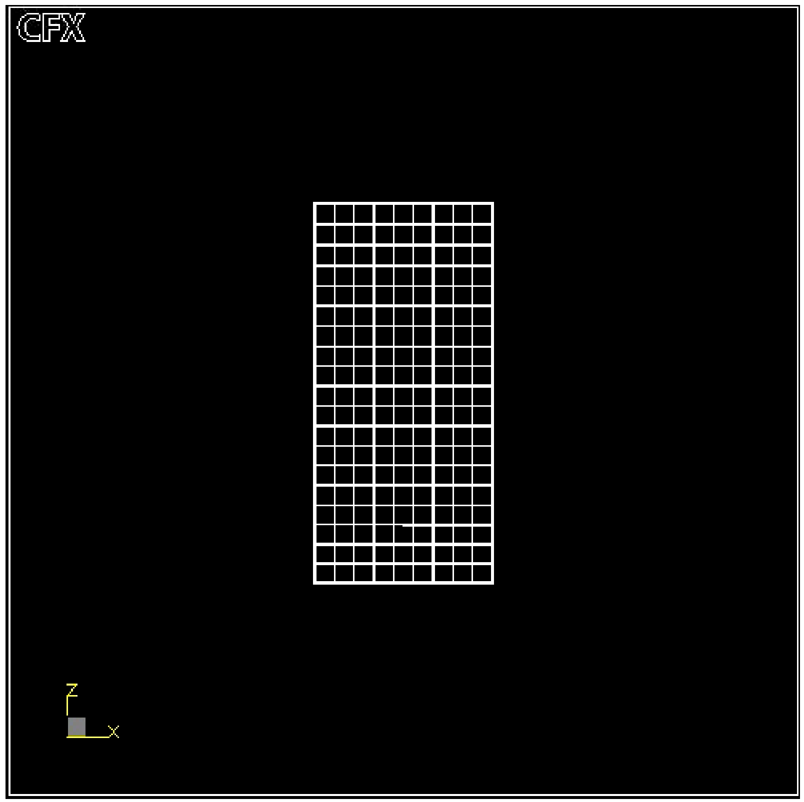
- User Defines Nodes in Model Which Will Not Move (Frozen Nodes)

- All Other Nodes Will Move Based On A Laplacian Diffusion Solution

- The Entire Grid is Smoothly Adjusted In A Shape-Preserving Manner

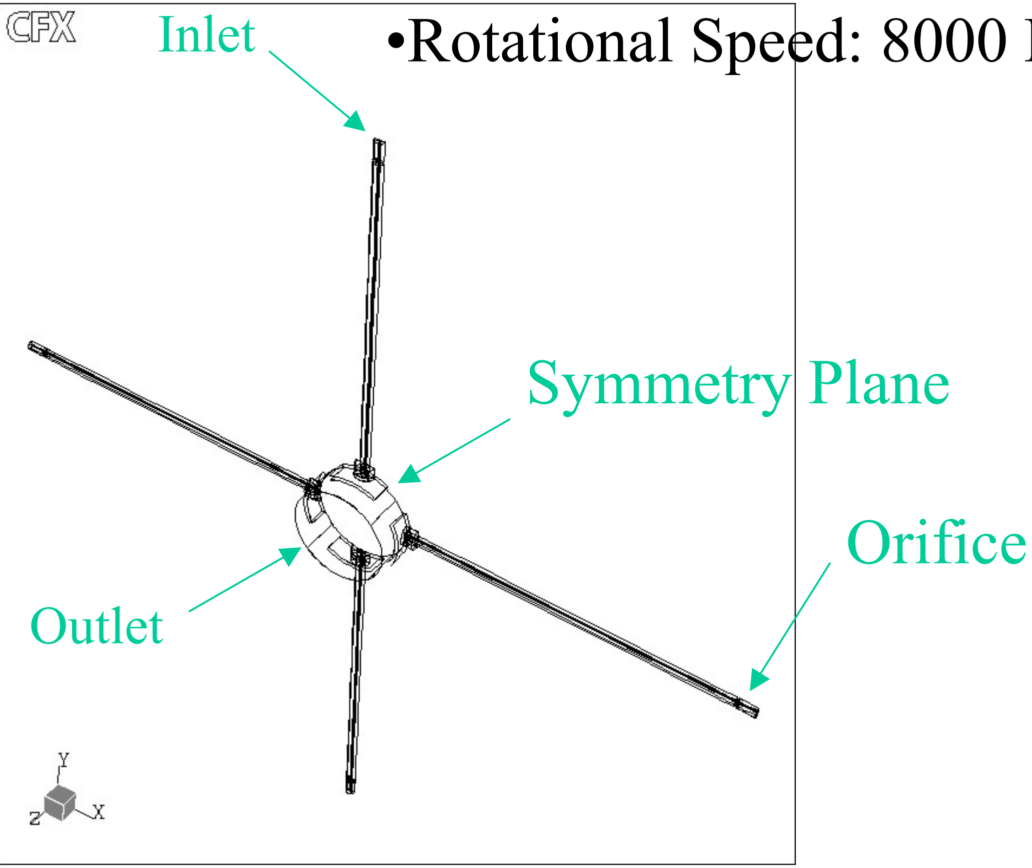
- A Transient Solution is Created Based on The Time-Dependant Position of the Moving Boundary

Moving Grid Example:
"Piston" Grid



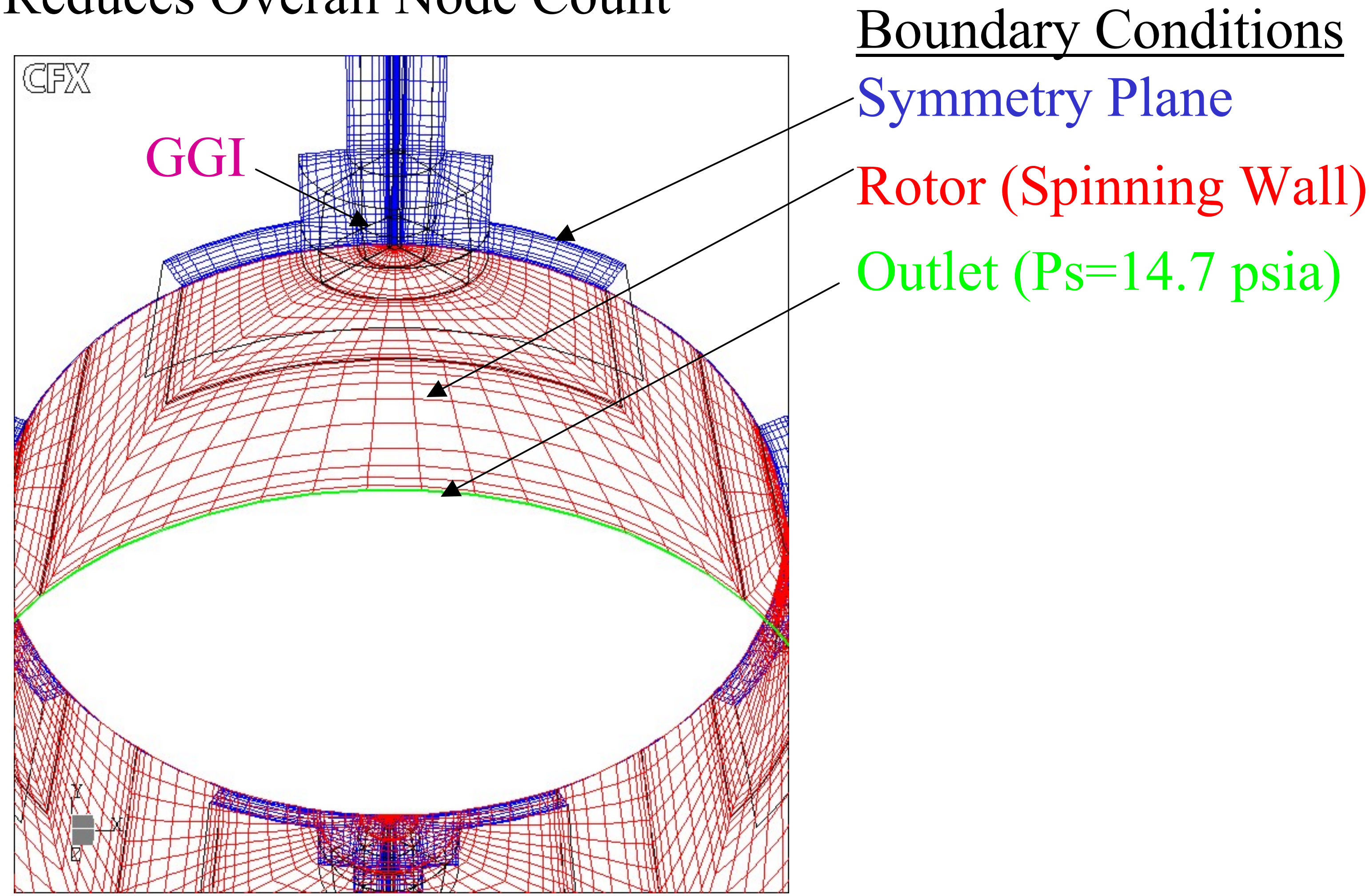
Pressurized Bearing Model

- Four Pocket Fixed-Ring Orifice-Compensated Bearing
- Half Bearing Modeled (No Mis-alignment Assumed)
- Model Size: 177K Nodes
- Fluid: ISO 32 Oil at T=89 deg F
- Rotational Speed: 8000 RPM



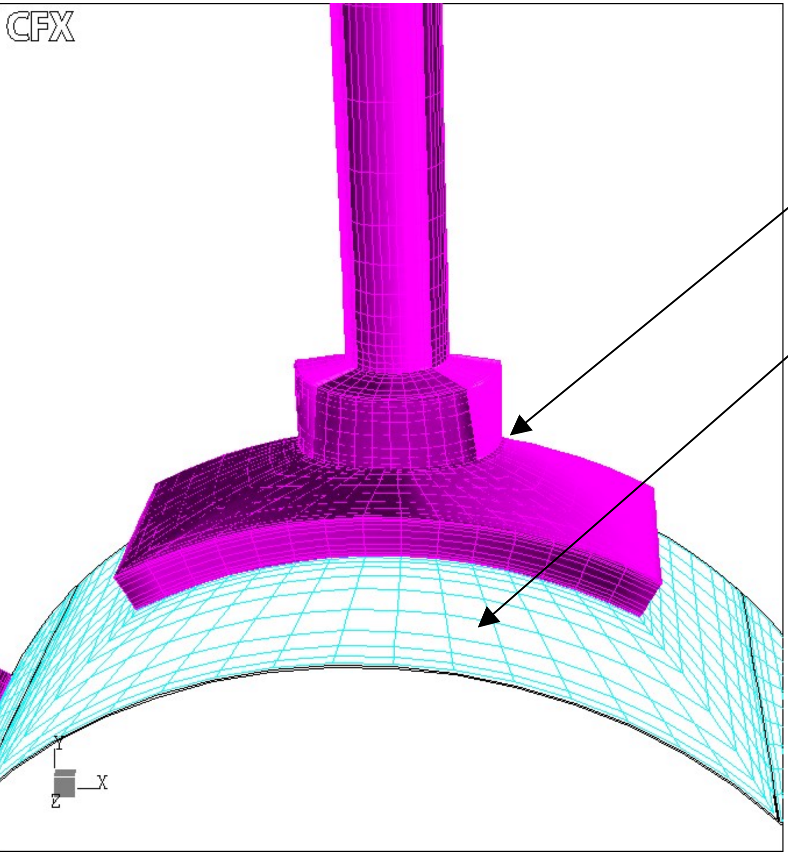
Bearing CFD Model

- Multi-Block Structured Grid
- Generalized Grid Interface (GGI) Allows Arbitrary Block Connections, Reduces Overall Node Count



Bearing CFD Model - “Moving Grid” Feature

- User Specifies Two Nodal Regions:
  - “Moved” Nodes - Nodes which follow a user-prescribed motion as a function of time (e.g. elliptical orbit)
  - “Frozen” Nodes - Nodes which are fixed



“Frozen Nodes” - Feed Tube, Recess

“Moved” Nodes - Rotor Surface

All Other Nodes (Land Region, Region Between Rotor and Recess) Will Move To Accommodate Motion Of The Rotor

“Moving Grid” Boundary Conditions

- Four Perturbation Speeds Analyzed: 1500,3000,4500,6000 RPM

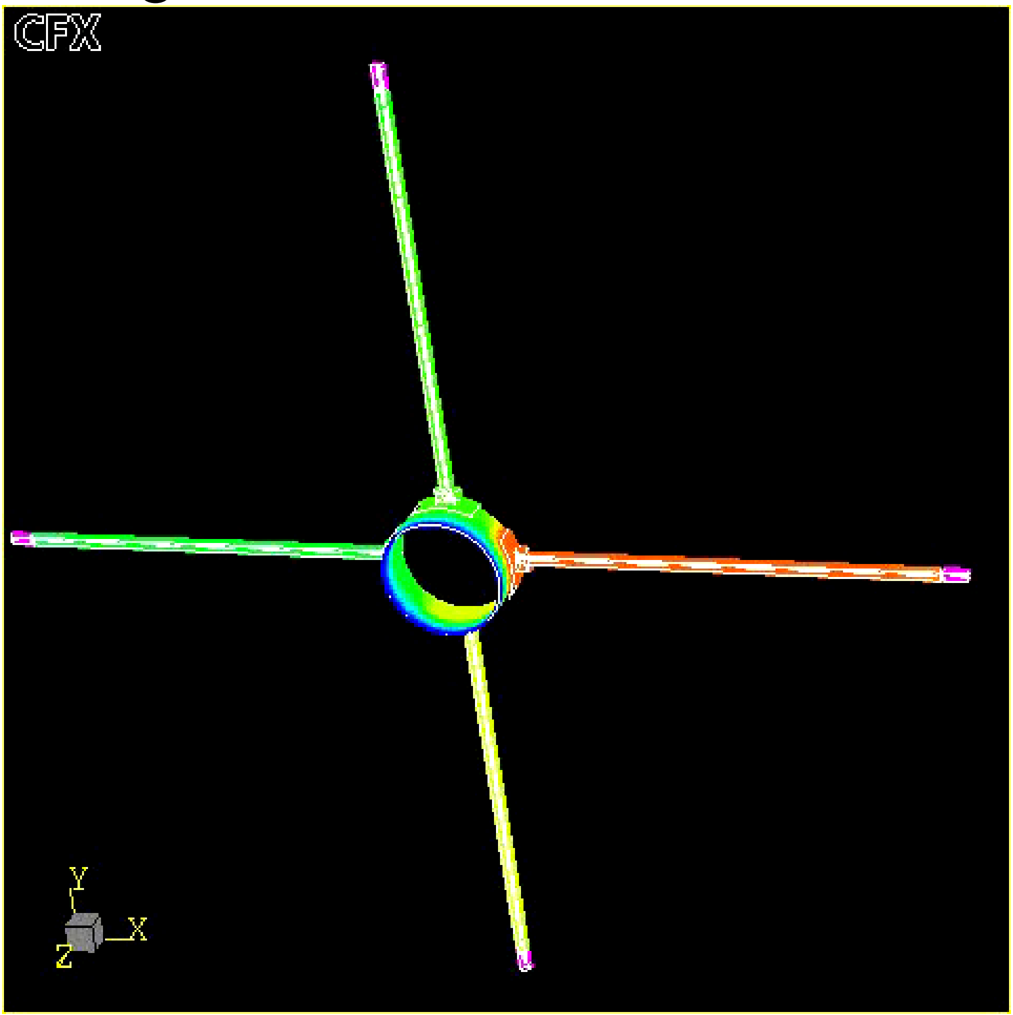
- Circular Orbit of Journal Center Specified:

  XNODE,YNODE: New Position of Nodes on Journal Surface[in]
  RO: Journal Eccentricity [in]
  OMEGA: Perturbation Circular Frequency [sec]
  STIME: Current Solution Time [sec]
  DTIME: Time Step Size [sec]
  OFF: Journal Offset At Time=0

```
XNODE=X(INODE,JNODE,KNODE)+RO*(COS(OMEGA*STIME)-
    &                                COS(OMEGA*(STIME-DTIME)))+OFF
YNODE=Y(INODE,JNODE,KNODE)+RO*(SIN(OMEGA*STIME)-
    &                                SIN(OMEGA*(STIME-DTIME)))
```

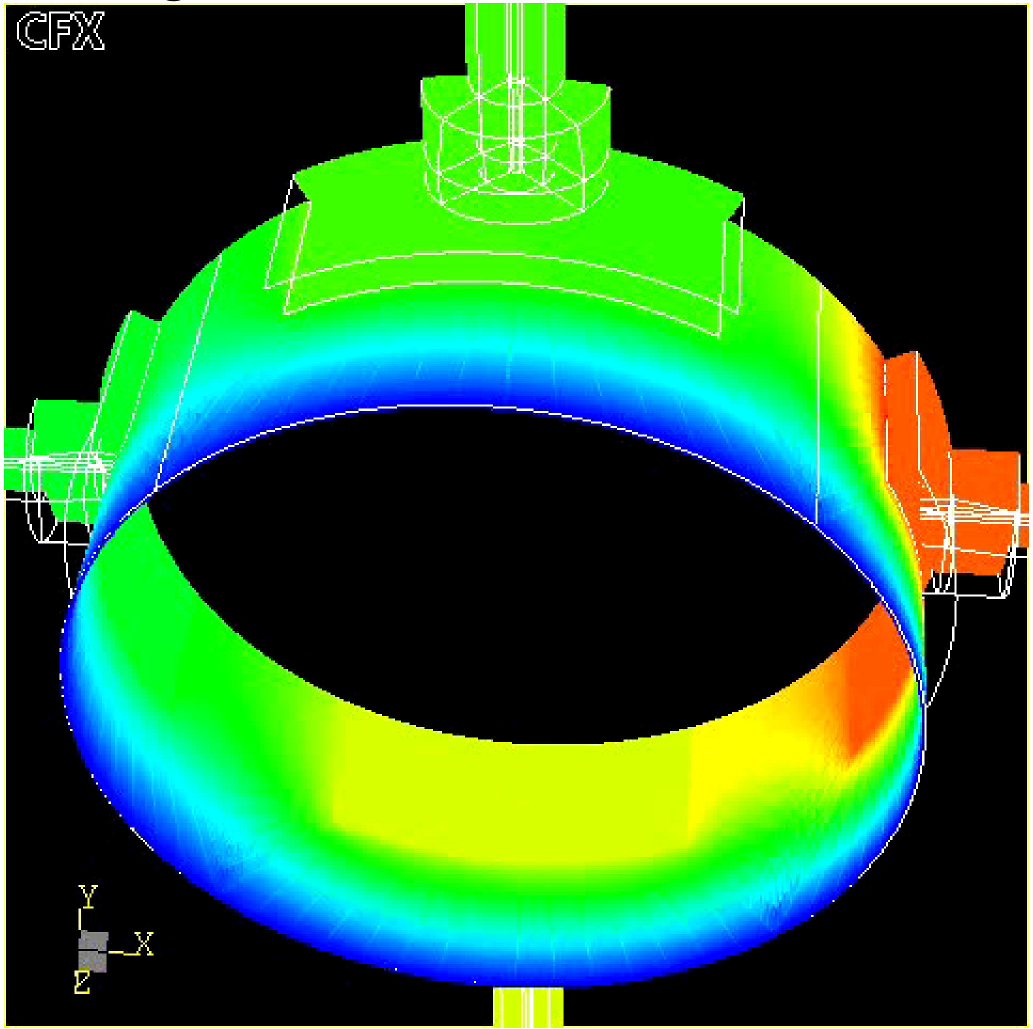
Pressurized Bearing CFD Results

Bearing Static Pressure as a Function of Time



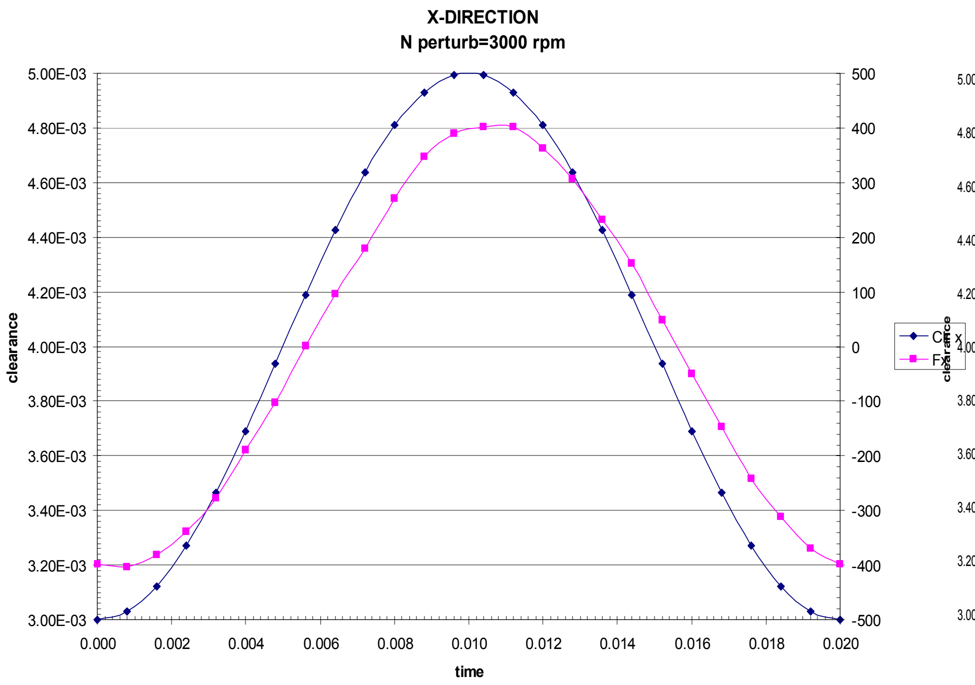
Pressurized Bearing CFD Results

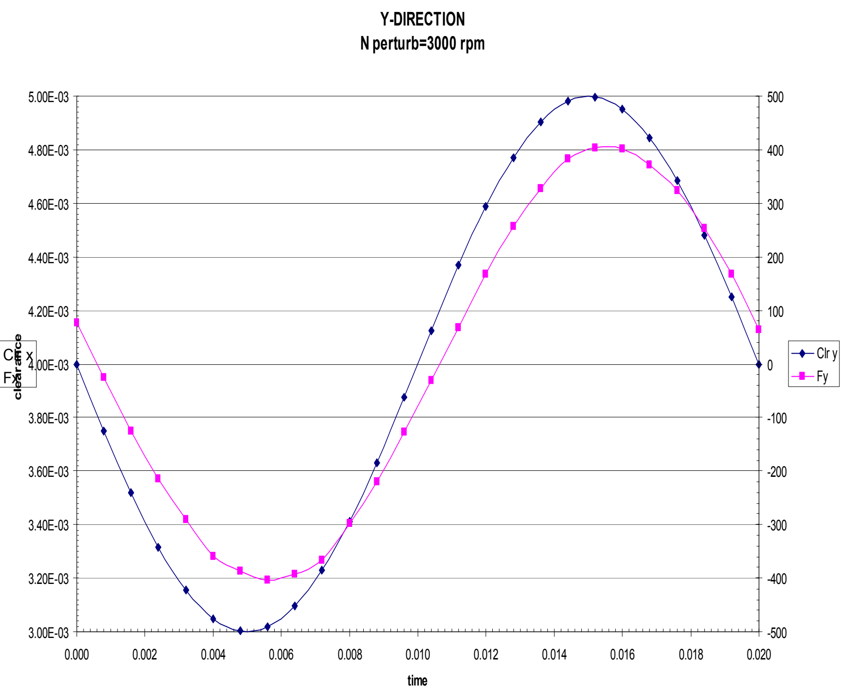
Bearing Static Pressure as a Function of Time



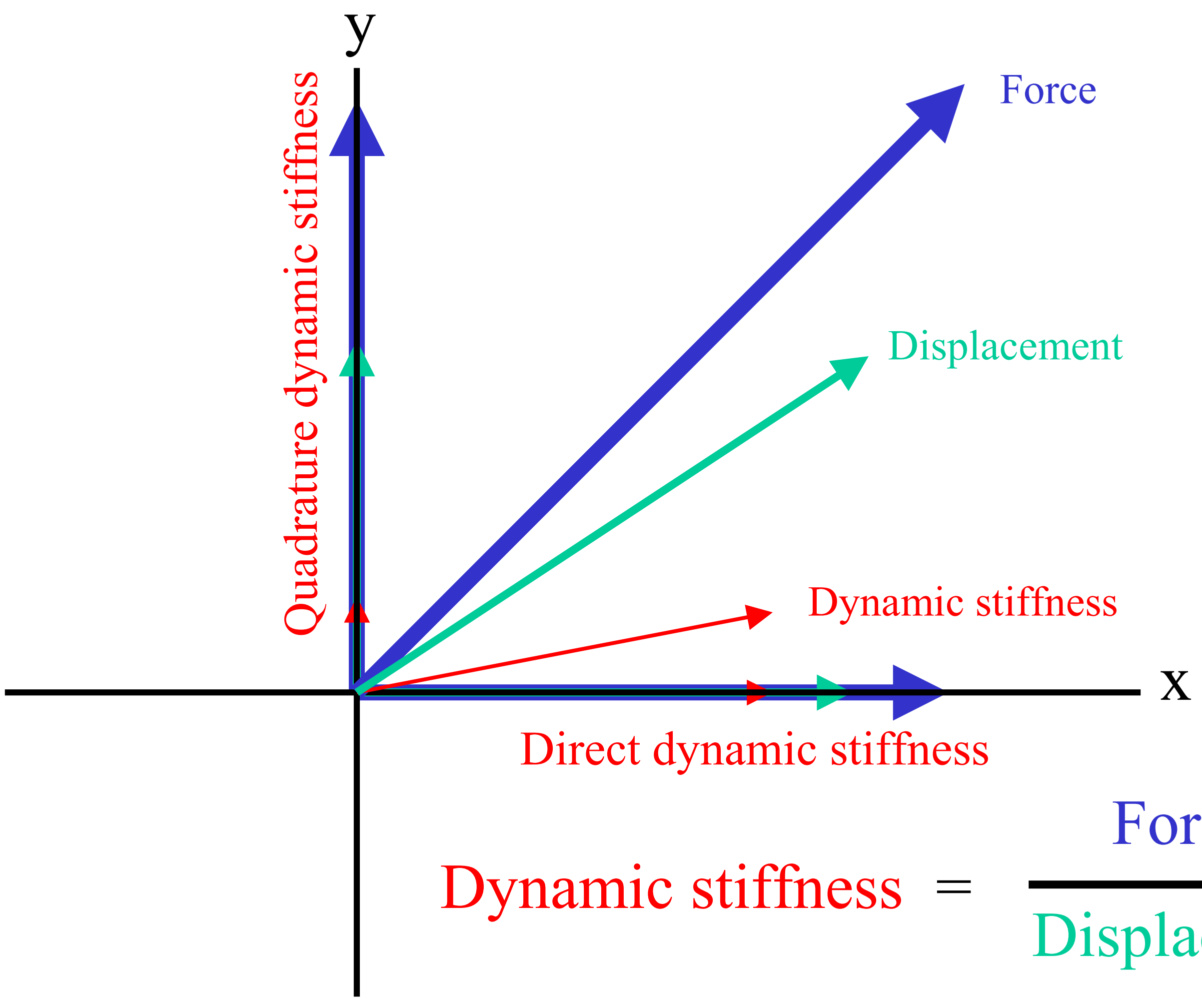
Pressurized Bearing CFD Results

Time-Dependant Journal Forces Used to Calculate Direct and Quadrature Dynamic Stiffness



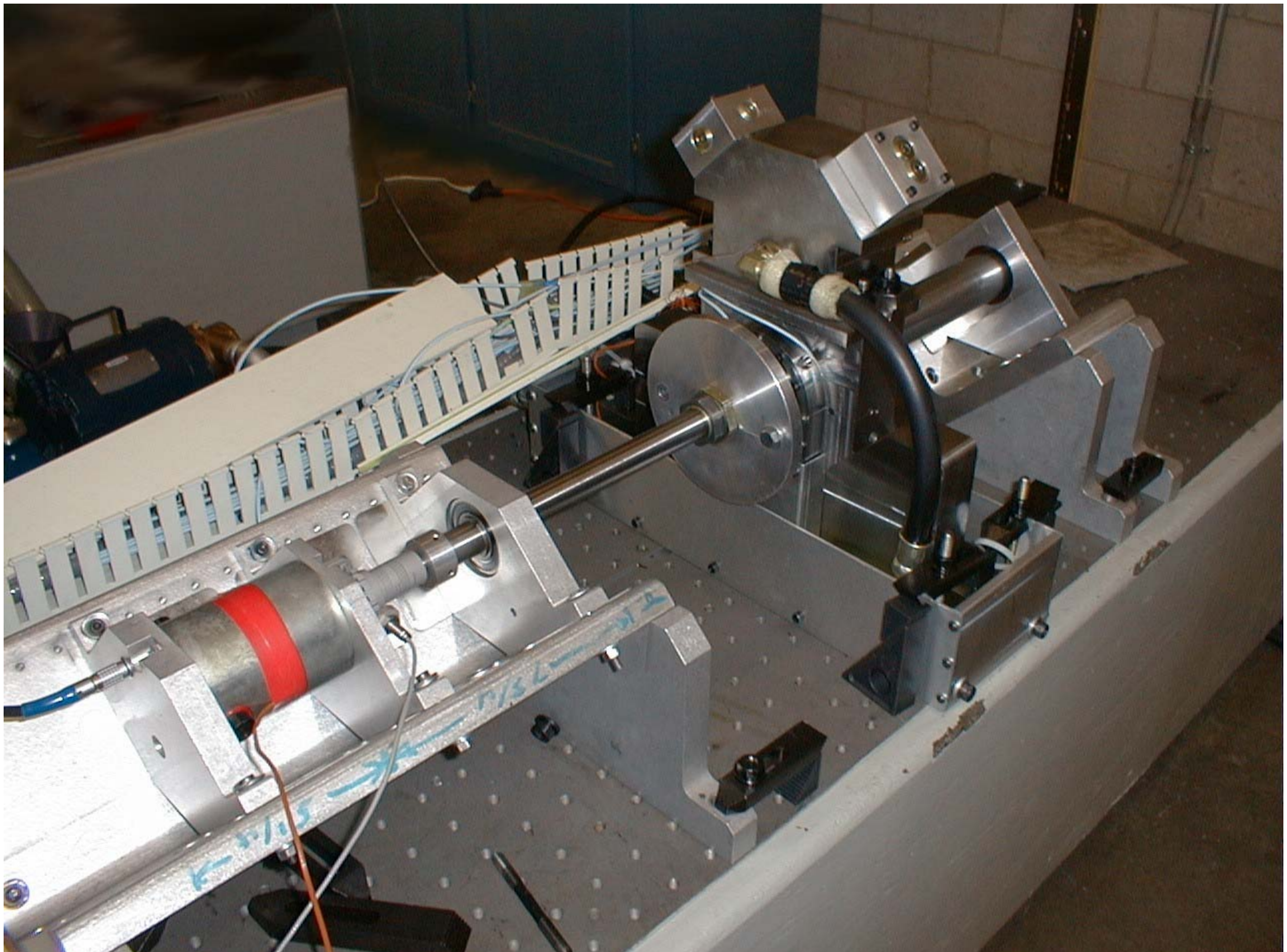


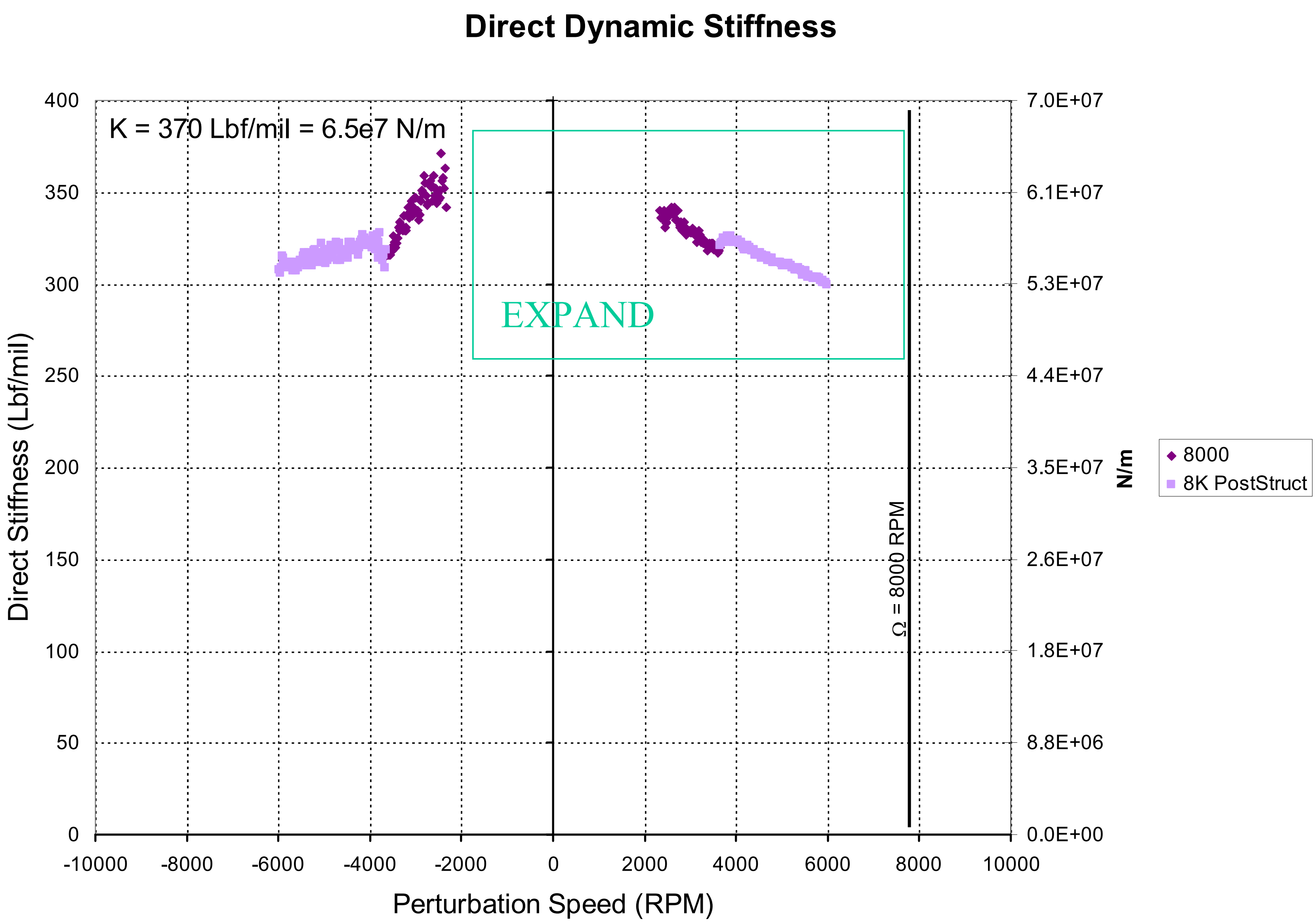
Calculation of Bearing Dynamic Stiffness from CFD Solution



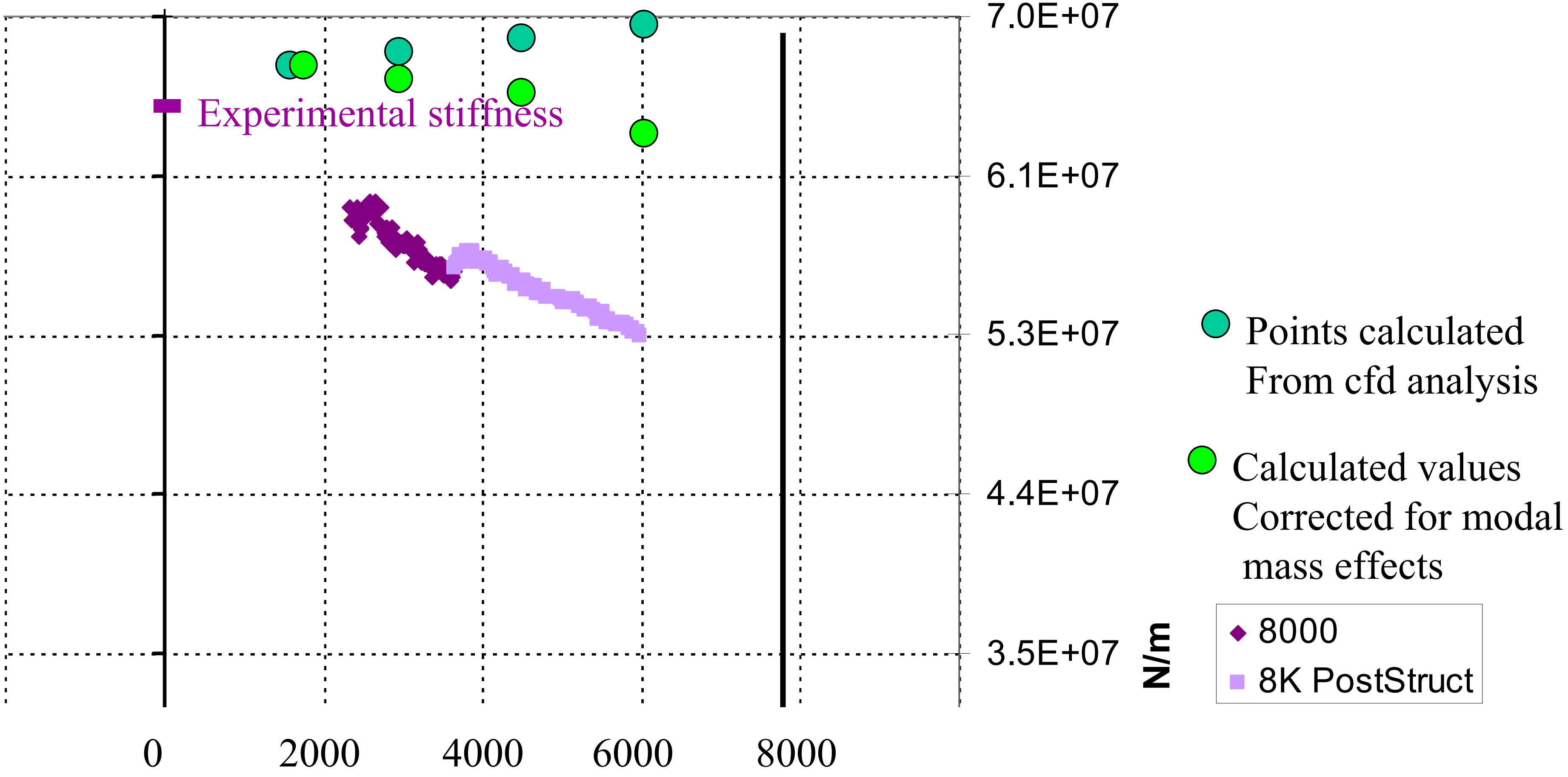
$$\text{Dynamic stiffness} = \frac{\text{Force}}{\text{Displacement}}$$

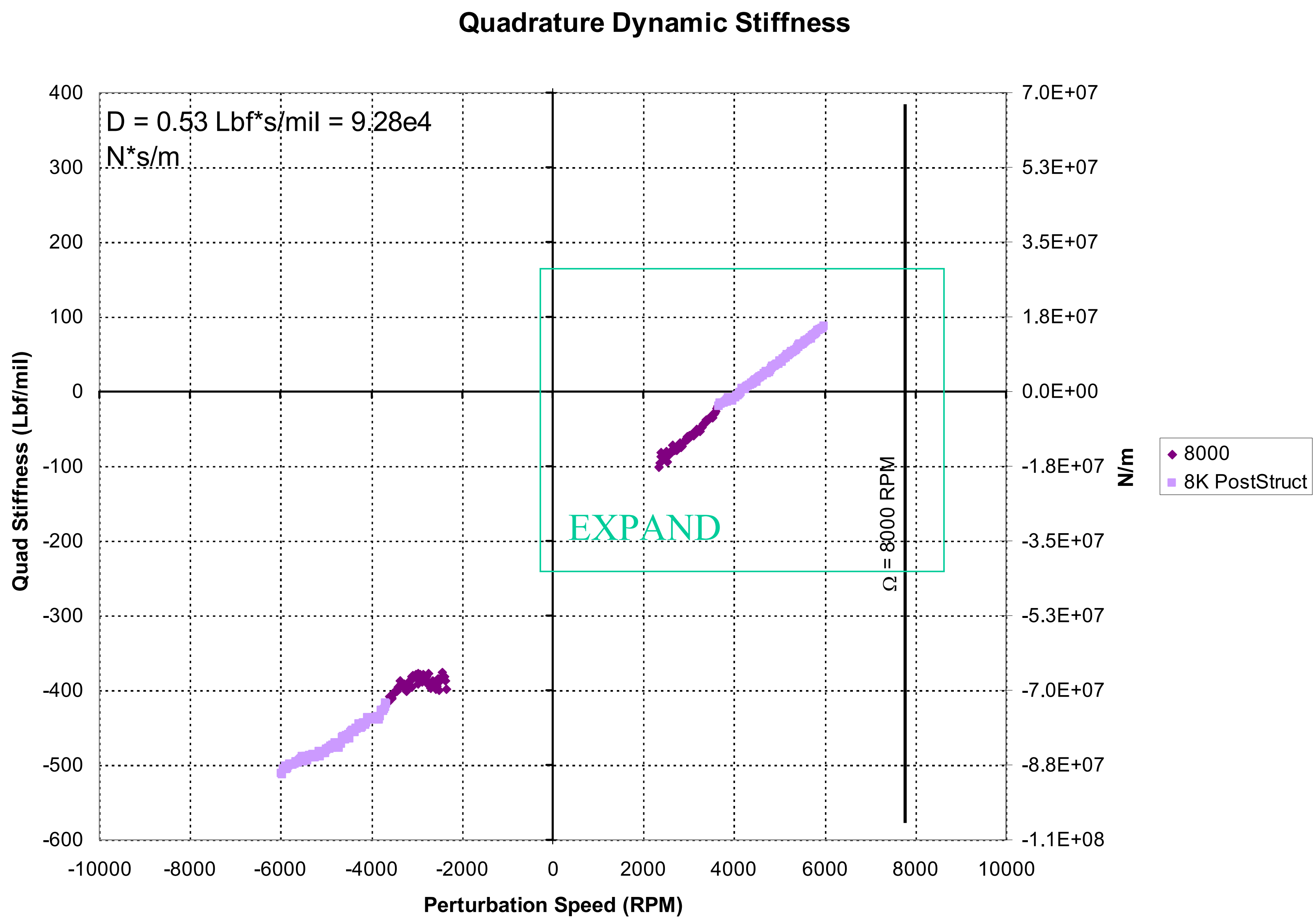
Bearing



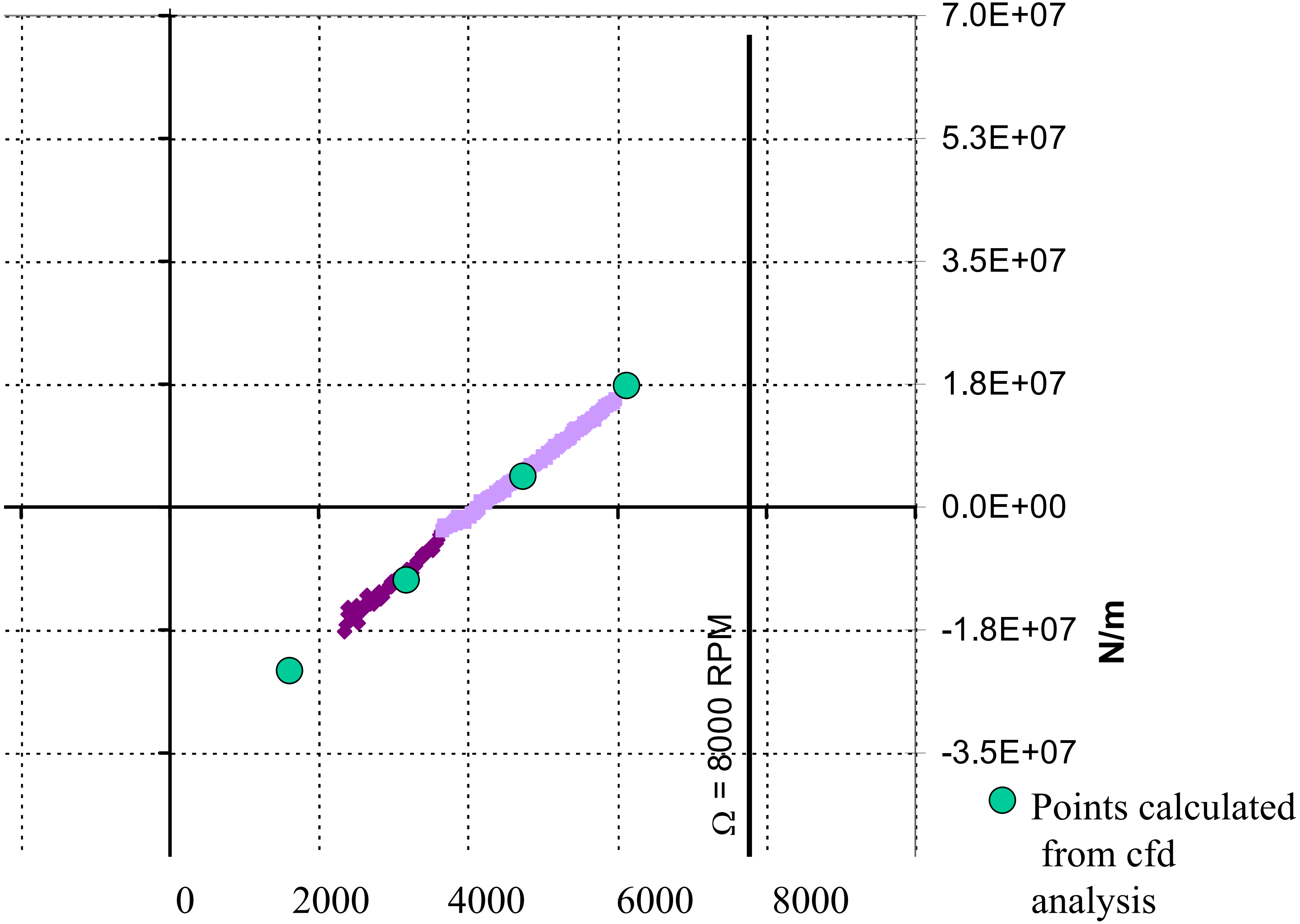

Direct Dynamic Stiffness
K = 370 Lbf/mil = 6.5e7 N/m
EXPAND
Ω = 8000 RPM
Direct Stiffness (Lbf/mil)
N/m
Perturbation Speed (RPM)
0
50
100
150
200
250
300
350
400
0.0E+00
8.8E+06
1.8E+07
2.6E+07
3.5E+07
4.4E+07
5.3E+07
6.1E+07
7.0E+07
-10000
-8000
-6000
-4000
-2000
0
2000
4000
6000
8000
10000
8000
8K PostStruct

Direct Dynamic Stiffness




Quadrature Dynamic Stiffness
D = 0.53 Lbf*s/mil = 9.28e4
N*s/m
Quad Stiffness (Lbf/mil)
400
300
200
100
0
-100
-200
-300
-400
-500
-600
7.0E+07
5.3E+07
3.5E+07
1.8E+07
0.0E+00
-1.8E+07
-3.5E+07
-5.3E+07
-7.0E+07
-8.8E+07
-1.1E+08
N/m
EXPAND
Ω = 8000 RPM
-10000
-8000
-6000
-4000
-2000
0
2000
4000
6000
8000
10000
Perturbation Speed (RPM)
8000
8K PostStruct

Quadrature Dynamic Stiffness



Summary

- A New Method of Simulating Pressurized Bearing Operation using Computational Fluid Dynamics was Presented

- "Moving Boundary" Feature Allows Time-Accurate Modeling of Journal Motion Within Bearing

- Good Comparison of Predicted vs Measured Dynamic Stiffness

- **New Approach is Applicable to Any Bearing/Seal Geometry**