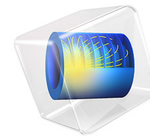
Created in COMSOL Multiphysics 5.3



Comparison of Different Hydrodynamic Bearings

Introduction

This example compares the load bearing abilities of different hydrodynamic bearings. The simulation is performed using the Rotordynamics Module's Hydrodynamic Bearing interface. This interface solves the Reynolds equation to compute the pressure developed in a thin fluid film for different bearing types. The bearings included in this example are of plain, elliptic, split-halves, and multilobe type (2, 3, and 4 lobes).

Model Definition

Eight bearings are compared: One each of plain, elliptic, and split-halves type, and five different multilobe bearings. The latter are one two-lobe bearing and two three-lobe and four-lobe bearings. The two three-lobe bearings differ from each other in their relative orientation with respect to the applied load direction, as do the two four-lobe bearings.

The journals rotate inside the bearing with an angular speed Ω (rad/s). The static position of the journal is obtained such that the net force due to the fluid film in the horizontal direction is zero whereas that in the vertical direction balances the journal weight, W.

The bearing configuration is shown in Figure 1 below.

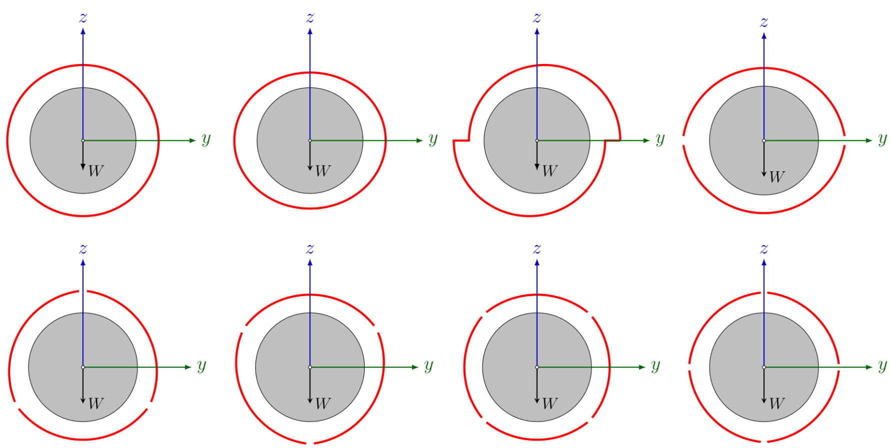


Figure 1: Bearing configuration. Top row: Plain, elliptic, split halves, two-lobe. Bottom row: Three-lobe (LOP), three-lobe (LBP), four-lobe (LOP), four-lobe (LBP).

On the fluid side, the parameters needed for the computation are the dynamic viscosity, the density at cavitation pressure, and the compressibility. The fluid parameters, whose values are summarized in Table 1, are close to those of lubricating oils used in real bearings.

TABLE 1: FLUID PROPERTIES.

PROPERTY	VALUE
Density ρ	1000 kg/m^3
Dynamic viscosityμ	0.072 Pa·s
Compressibility β	10^{-7} Pa^{-1}

BEARING DATA

The maximum and minimum clearance, C_{max} and C_{min}, respectively, of all the bearings are set to the same values in order to make them equivalent.

The initial clearance, h_b, assuming that the journal is located at the center of the bearing, is listed in Table 2.

TABLE 2: INITIAL FILM THICKNESS.

BEARING	INITIAL FILM THICKNESS
Plain	$h_b = C$
Elliptic	$h_b = C_{min} + (C_{max} - C_{min})\cos\theta$
Split halves	$h_b = C + \mathrm{sign}(\sin\theta) d\cos\theta$
Multilobe	$h_b = C + d\cos(\theta - \alpha_m), \alpha_m = \frac{\pi}{N} + \frac{2\pi}{N}\left\lfloor \frac{\theta N}{2\pi} \right\rfloor$

The objective is to obtain various parameters in Table 2 for different bearings by setting maximum and minimum values to C_{max} and C_{min} respectively. Following sections provide these expressions.

Plain Bearing

Because the initial thickness is uniform, the best choice of C for the plain bearing is $C = (C_{min} + C_{min})/2$.

Elliptic Bearing

The maximum and minimum clearance C_{max} and C_{min} are known.

Split-halves Bearing

For split-halves bearings, $C_{min} = C - d,$ $C_{max} = C + d$, from which one finds $C = (C_{max} + C_{min})/2$ and $d = (C_{max} - C_{min})/2$.

Multilobe Bearings

For multilobe bearings, $C_{max} = C + d$ and $C_{min} = C + d\cos(\pi/N)$.

Hence, one obtains $C = (C_{min} - \cos(\pi/N)C_{max})/(1 - \cos(\pi/N))$, and $d = (C_{max} - C_{min})/(1 - \cos(\pi/N))$.

Results and Discussion

Figure 2 below shows the fluid pressure profile on the bearing.

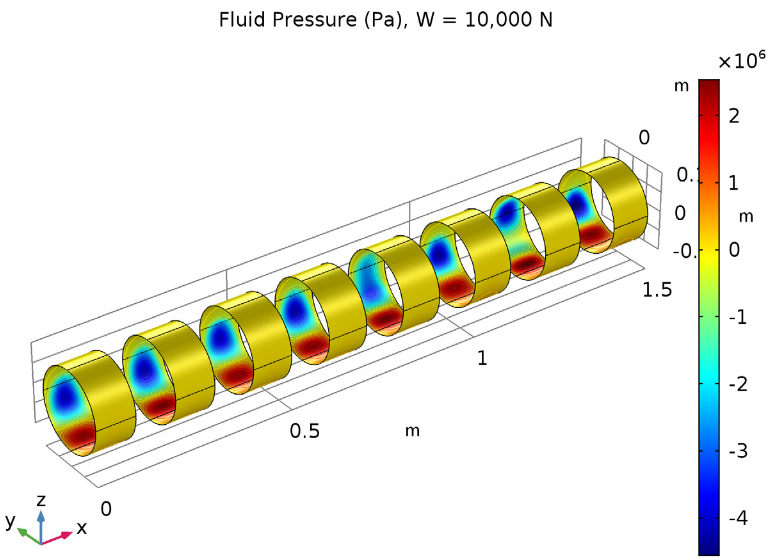


Figure 2: Fluid film pressure profile.

Several results from the simulation provide valuable information about bearing performance. Figure 3 shows a plot of journal eccentricity versus load. The journals that exhibit lower eccentricity are the better ones. From the plot, it seems that the split-halves and 3-lobe LBP (load between pad) bearings have optimum eccentricity in the operating range. For loads higher than 5000 N, the 4-lobe bearing with load on pad (LOP) has the largest eccentricity, while the 4-lobe LBP has the smallest one. The performances of the other bearings lie somewhere in between.

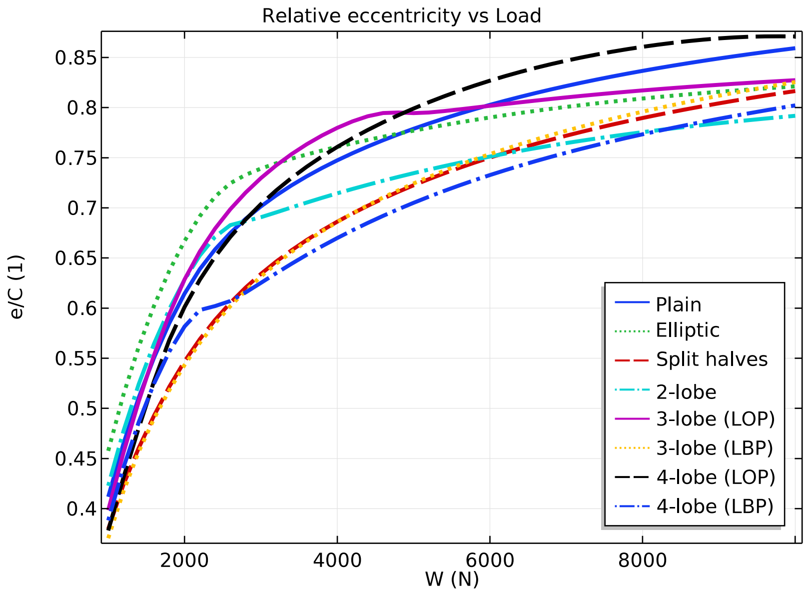


Figure 3: Eccentricity vs. load.

The equilibrium position of the journals is shown in Figure 4 with increasing load W. The y-coordinate of the journal position is plotted on the x-axis, and the z-coordinate is plotted on the y-axis. When the load W is small, all journals tend to move more in the y direction while the movement in the z direction is small. However, as the load increases, they move significantly in the negative z direction and touch the bottom part of the bearing.

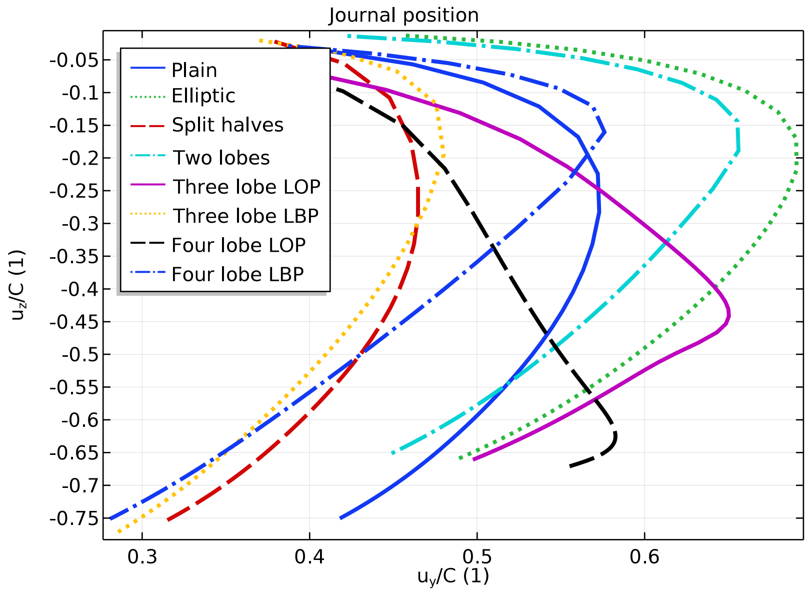


Figure 4: Journal position.

Figure 5 shows the plot of the fluid thickness profile when the journal is concentric with the bearing. The geometric parameters of bearings are set in such a way that the minimum and maximum clearances are the same for all bearings except for the plain bearing, which is kept at the mean position.

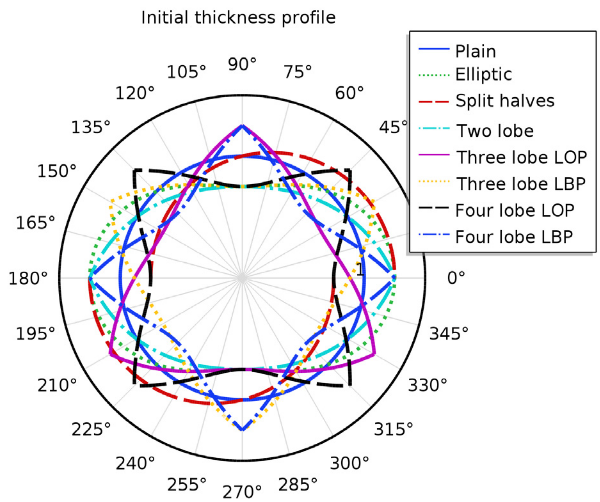


Figure 5: Initial thickness profile.

Figure 6 shows a plot of the steady-state (current) thickness profile of the fluid.

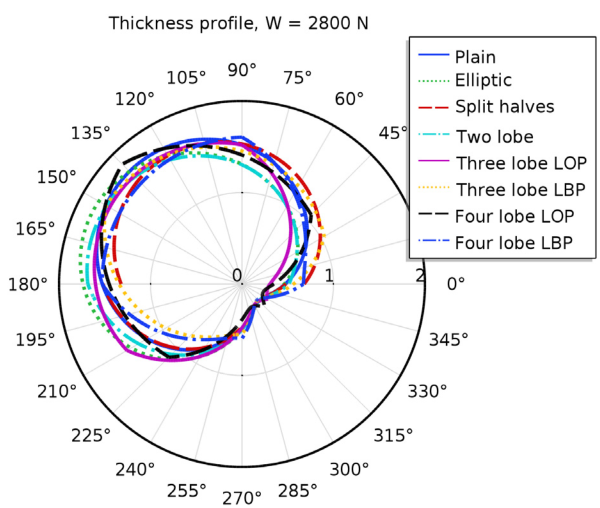


Figure 6: Current thickness profile.

Notes About the COMSOL Implementation

The position of the journals is computed using the **Global Equations** interface in COMSOL Multiphysics. It computes the *y* and *z* positions of the bearing such that load balance is achieved in all directions.

In the computation, use an **Auxiliary sweep** study extension on the load applied by the journal on the bearing to automatically run a loop over the parameter. The Auxiliary sweep functionality is activated in the study step settings.

Application Library path: `Rotordynamics_Module/Tutorials/hydrodynamic_bearings_comparison`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1. In the **Model Wizard** window, click **3D**.
2. In the **Select Physics** tree, select **Structural Mechanics>Rotordynamics>Hydrodynamic Bearing (hdb)**.
3. Click **Add**.
4. Click **Study**.
5. In the **Select Study** tree, select **Preset Studies>Stationary**.
6. Click **Done**.

GLOBAL DEFINITIONS

Parameters

1. On the **Home** toolbar, click **Parameters**.
2. In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
Rj	0.1[m]	0.1 m	Radius of journal
H	0.1[m]	0.1 m	Height of journal
C	0.001[m]	0.001 m	Mean bearing clearance
d	0.1*C	1E-4 m	Pad center offset
Cmax	C+d	0.0011 m	Maximum bearing clearance
Cmin	C-d	9E-4 m	Minimum bearing clearance
Ow	200[rad/s]	200 rad/s	RPS
W	100[N]	100 N	Load on bearing, z component
mu	0.072[Pa*s]	0.072 Pa·s	Dynamic viscosity

GEOMETRY 1

Cylinder 1 (cyl1)

1 On the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `Rj`.

4 In the **Height** text field, type `H`.

5 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

6 Locate the **Object Type** section. From the **Type** list, choose **Surface**.

7 Click **Build Selected**.

Array 1 (arr1)

Replicate 7 more cylinders along x direction by executing the following commands.

1 On the **Geometry** toolbar, click **Transforms** and choose **Array**.

2 Select the object **cyl1** only.

3 In the **Settings** window for **Array**, locate the **Size** section.

4 In the **x size** text field, type `8`.

5 Locate the **Displacement** section. In the **x** text field, type `2*H`.

Form Union (fin)

1 On the **Geometry** toolbar, click **Build All**.

2 Click the **Zoom Extents** button on the **Graphics** toolbar.

DEFINITIONS

Explicit 1

1 On the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Plain bearing` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundary 1 only.

5 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

6 Select the **Group by continuous tangent** check box.

Selecting this checkbox allows automatic selection of multiple surfaces across which tangent is continuous.

Plain bearing 1

1 Right-click **Plain bearing** and choose **Duplicate**.

2 In the **Settings** window for **Explicit**, type `Elliptic bearing` in the **Label** text field.

3 Locate the **Input Entities** section. Click **Clear Selection**.

4 Select Boundary 5 only.

Explicit Selections

1 Repeat above sequence of commands to add more **Explicit** selections using the information given in the following table:

Name	Selection
Split halves bearing	9, 10, 11, 12
Two lobe bearing	13, 14, 15, 16
Three Lobe bearing (LOP)	17, 18, 19, 20
Three lobe bearing (LBP)	21, 22, 23, 24
Four lobe bearing (LOP)	25, 26, 27, 28
Four lobe bearing (LBP)	29, 30, 31, 32

In above table we display the entire selection for each bearing. But to create for example the **Hydrodynamic Journal Bearing (Split halves)** selection, selecting surface 9 is enough. This is so because you duplicate the existing selection to create the new ones and the checkbox **Group by continuous tangent** is already selected within the old.

2 In the **Model Builder** window, collapse the **Definitions** node.

HYDRODYNAMIC BEARING (HDB)

1 In the **Model Builder** window's toolbar, click the **Show** button and select **Advanced Physics Options** in the menu.

2 In the **Model Builder** window, under **Component 1 (comp1)** click **Hydrodynamic Bearing (hdb)**.

3 In the **Settings** window for **Hydrodynamic Bearing**, click to expand the **Cavitation** section.

4 Select the **Cavitation** check box.

You can change the compressibility β inside the bearing node.

Hydrodynamic Journal Bearing 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Hydrodynamic Bearing (hdb)** click **Hydrodynamic Journal Bearing 1**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (Plain)` in the **Label** text field.

3 Locate the **Bearing Properties** section. In the C text field, type `C`.

4 Locate the **Journal Properties** section. In the Ω text field, type `Ow`.

5 Locate the **Fluid Properties** section. From the μ list, choose **User defined**. In the associated text field, type `mu`.

Hydrodynamic Journal Bearing (Plain) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (Plain)** and choose **Duplicate**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (Elliptic)` in the **Label** text field.

3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Elliptic bearing**.

4 Locate the **Bearing Properties** section. From the **Bearing type** list, choose **Elliptic**.

5 In the C_{min} text field, type `Cmin`.

6 In the C_{max} text field, type `Cmax`.

Hydrodynamic Journal Bearing (Elliptic) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (Elliptic)** and choose **Duplicate**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (Split halves)` in the **Label** text field.

3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Split halves bearing**.

4 Locate the **Bearing Properties** section. From the **Bearing type** list, choose **Split halves**.

5 In the C text field, type `C`.

6 From the **Preload factor** list, choose **Compute from offset**.

7 In the d text field, type `d`.

Hydrodynamic Journal Bearing (Split halves) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (Split halves)** and choose **Duplicate**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (2-lobe)` in the **Label** text field.

3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Two lobe bearing**.

4 Locate the **Bearing Properties** section. From the **Bearing type** list, choose **Multilobe**.

5 In the C text field, type `Cmax`.

6 From the **Preload factor** list, choose **Compute from offset**.

7 In the d text field, type `2*d`.

Hydrodynamic Journal Bearing (2-lobe) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (2-lobe)** and choose **Duplicate**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (3-lobe LOP)` in the **Label** text field.

3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Three Lobe bearing (LOP)**.

4 Locate the **Bearing Properties** section. In the C text field, type `2*Cmax-Cmin`.

5 In the d text field, type `4*d`.

6 In the N text field, type `3`.

Hydrodynamic Journal Bearing (3-lobe LOP) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (3-lobe LOP)** and choose **Duplicate**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (3-lobe LBP)` in the **Label** text field.

3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Three lobe bearing (LBP)**.

Hydrodynamic Journal Bearing (3-lobe LBP) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (3-lobe LBP)** and choose **Duplicate**.
2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (4-lobe LOP)` in the **Label** text field.
3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Four lobe bearing (LOP)**.
4 Locate the **Bearing Properties** section. In the C text field, type `(sqrt(2)*Cmax-Cmin)/(sqrt(2)-1)`.
5 In the d text field, type `sqrt(2)*(Cmax-Cmin)/(sqrt(2)-1)`.
6 In the N text field, type `4`.

Hydrodynamic Journal Bearing (4-lobe LOP) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)>Hydrodynamic Journal Bearing (4-lobe LOP)** and choose **Duplicate**.
2 In the **Settings** window for **Hydrodynamic Journal Bearing**, type `Hydrodynamic Journal Bearing (4-lobe LBP)` in the **Label** text field.
3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Four lobe bearing (LBP)**.

Next set the orientation of the bearings using following instructions.

Bearing Orientation 2

1 On the **Physics** toolbar, click **Boundaries** and choose **Bearing Orientation**.
2 In the **Settings** window for **Bearing Orientation**, type `Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LOP)` in the **Label** text field.
3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Three Lobe bearing (LOP)**.
4 Locate the **Bearing Orientation** section. In the ϕ text field, type `-pi/6`.

Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LOP) 1

1 Right-click **Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LOP)** and choose **Duplicate**.
2 In the **Settings** window for **Bearing Orientation**, type `Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LBP)` in the **Label** text field.
3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Three lobe bearing (LBP)**.

4 Locate the **Bearing Orientation** section. In the ϕ text field, type pi/6.

Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LBP) 1

1 Right-click **Component 1 (comp1)>Hydrodynamic Bearing (hdb)> Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LBP)** and choose **Duplicate**.

2 In the **Settings** window for **Bearing Orientation**, type Bearing Orientation Hydrodynamic Journal Bearing (4-lobe LOP) in the **Label** text field.

3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Four lobe bearing (LOP)**.

4 Locate the **Bearing Orientation** section. In the ϕ text field, type pi/4.

Global Equations 1

Add a **Global equation** node.

1 On the **Physics** toolbar, click **Global** and choose **Global Equations**.

2 In the **Settings** window for **Global Equations**, locate the **Units** section.

3 Find the **Dependent variable quantity** subsection. From the list, choose **Displacement field (m)**.

4 Find the **Source term quantity** subsection. From the list, choose **Force load (N)**.

5 Locate the **Global Equations** section. In the table, enter the following settings:

Name	f(u,ut,utt,t) (N)	Initial value (u_0) (m)	Initial value (u_t0) (m/s)	Description
u1y	-hdb.hjb1.Fjy	0	0	Plain bearing journal displacement, y component
u1z	W-hdb.hjb1.Fjz	-0.1*C	0	Plain bearing journal displacement, z component
u2y	-hdb.hjb2.Fjy	0	0	Elliptic bearing journal displacement, y component
u2z	W-hdb.hjb2.Fjz	-0.1*C	0	Elliptic bearing journal displacement, z component
u3y	-hdb.hjb3.Fjy	0	0	Split halves bearing journal displacement, y component

Name	f(u,ut,utt, t) (N)	Initial value (u_0) (m)	Initial value (u_t0) (m/s)	Description
u3z	W-hdb.hjb3.Fjz	-0.1*C	0	Split halves bearing journal displacement, z component
u4y	-hdb.hjb4.Fjy	0	0	Two lobe bearing journal displacement, y component
u4z	W-hdb.hjb4.Fjz	-0.1*C	0	Two lobe bearing journal displacement, z component
u5y	-hdb.hjb5.Fjy	0	0	Three lobe (LOP) bearing journal displacement, y component
u5z	W-hdb.hjb5.Fjz	-0.1*C	0	Three lobe (LOP) bearing journal displacement, z component
u6y	-hdb.hjb6.Fjy	0	0	Three lobe (LBP) bearing journal displacement, y component
u6z	W-hdb.hjb6.Fjz	-0.1*C	0	Three lobe (LBP) bearing journal displacement, z component
u7y	-hdb.hjb7.Fjy	0	0	Four lobe (LOP) bearing journal displacement, y component
u7z	W-hdb.hjb7.Fjz	-0.1*C	0	Four lobe (LOP) bearing journal displacement, z component
u8y	-hdb.hjb8.Fjy	0	0	Four lobe (LBP) bearing journal displacement, y component
u8z	W-hdb.hjb8.Fjz	-0.1*C	0	Four lobe (LBP) bearing journal displacement, z component

Hydrodynamic Journal Bearing (Plain)

1 In the **Model Builder** window, under **Component 1 (comp1)>Hydrodynamic Bearing (hdb)** click **Hydrodynamic Journal Bearing (Plain)**.

2 In the **Settings** window for **Hydrodynamic Journal Bearing**, locate the **Journal Properties** section.

3 Specify the $\mathbf{u}_j$ vector as

0	x
u1y	y
u1z	z

Journal Displacements

Write similar expressions in the **Journal displacement** field of other bearings using the information given in the following table:

Name	Journal displacement
Hydrodynamic Journal Bearing (Elliptic)	(0,u2y,u2z)
Hydrodynamic Journal Bearing (Split halves)	(0,u3y,u3z)
Hydrodynamic Journal Bearing (2-lobe)	(0,u4y,u4z)
Hydrodynamic Journal Bearing (3-lobe LOP)	(0,u5y,u5z)
Hydrodynamic Journal Bearing (3-lobe LBP)	(0,u6y,u6z)
Hydrodynamic Journal Bearing (4-lobe LOP)	(0,u7y,u7z)
Hydrodynamic Journal Bearing (4-lobe LBP)	(0,u8y,u8z)

MESH 1

Mapped 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **More Operations>Mapped**.

2 In the **Settings** window for **Mapped**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **All boundaries**.

Distribution 1

1 Right-click **Component 1 (comp1)>Mesh 1>Mapped 1** and choose **Distribution**.

2 In the **Settings** window for **Distribution**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **All edges**.

4 Locate the **Distribution** section. In the **Number of elements** text field, type 15.

5 In the **Model Builder** window, click **Mesh 1**.

6 In the **Settings** window for **Mesh**, click **Build All**.

STUDY 1

Step 1: Stationary

1 In the **Settings** window for **Stationary**, click to expand the **Study extensions** section.

Use following instructions to add an **Auxiliary sweep** on load *W*.

2 Locate the **Study Extensions** section. Select the **Auxiliary sweep** check box.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
W	range(1000,200,10000)	

5 On the **Home** toolbar, click **Compute**.

RESULTS

Fluid Pressure (hdb)

1 In the **Model Builder** window, under **Results** click **Fluid Pressure (hdb)**.

2 In the **Settings** window for **3D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Fluid Pressure (Pa), W = 10,000 N`.

Contour 1

1 In the **Model Builder** window, expand the **Fluid Pressure (hdb)** node, then click **Contour 1**.

2 In the **Settings** window for **Contour**, locate the **Coloring and Style** section.

3 Clear the **Color legend** check box.

4 Click the **Zoom Extents** button on the **Graphics** toolbar.

Fluid Pressure (hdb)

In the **Model Builder** window, collapse the **Results>Fluid Pressure (hdb)** node.

Use the following instructions to plot eccentricity of the journals against load as shown in Figure 3.

1D Plot Group 2

1 On the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Eccentricity vs. Load` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Relative eccentricity vs Load`.

5 Locate the **Plot Settings** section. Select the **x-axis label** check box.

6 In the associated text field, type `W (N)`.

7 Select the **y-axis label** check box.

8 In the associated text field, type `e/C (1)`.

Global 1

1 Right-click **Eccentricity vs. Load** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	**Unit**	**Description**
sqrt(u1y^2+u1z^2)/C	1	Plain
sqrt(u2y^2+u2z^2)/C	1	Elliptic
sqrt(u3y^2+u3z^2)/C	1	Split halves
sqrt(u4y^2+u4z^2)/C	1	2-lobe
sqrt(u5y^2+u5z^2)/C	1	3-lobe (LOP)
sqrt(u6y^2+u6z^2)/C	1	3-lobe (LBP)
sqrt(u7y^2+u7z^2)/C	1	4-lobe (LOP)
sqrt(u8y^2+u8z^2)/C	1	4-lobe (LBP)

4 Click to expand the **Coloring and style** section. Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Cycle**.

5 In the **Width** text field, type `3`.

Eccentricity vs. Load

1 In the **Model Builder** window, under **Results** click **Eccentricity vs. Load**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Lower right**.

4 On the **Eccentricity vs. Load** toolbar, click **Plot**.

5 Click the **Zoom Extents** button on the **Graphics** toolbar.

6 In the **Model Builder** window, collapse the **Eccentricity vs. Load** node.

Use the following instructions to plot attitude angle against load as shown in Figure 3.

1D Plot Group 3

1 On the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Attitude Angle vs Load` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Attitude angle vs Load`.

5 Locate the **Plot Settings** section. Select the **x-axis label** check box.

6 In the associated text field, type `W (N)`.

7 Select the **y-axis label** check box.

8 In the associated text field, type `\phi (degree)`.

Global 1

1 Right-click **Attitude Angle vs Load** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
atan2(u1z,u1y)	deg	Plain
atan2(u2z,u2y)	deg	Elliptic
atan2(u3z,u3y)	deg	Split halves
atan2(u4z,u4y)	deg	2-lobe
atan2(u5z,u5y)	deg	3-lobe (LOP)
atan2(u6z,u6y)	deg	3-lobe (LBP)
atan2(u7z,u7y)	deg	4-lobe (LOP)
atan2(u8z,u8y)	deg	4-lobe (LBP)

4 Click to expand the **Coloring and style** section. Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Cycle**.

5 In the **Width** text field, type `3`.

Attitude Angle vs Load

1 In the **Model Builder** window, under **Results** click **Attitude Angle vs Load**.

2 On the **Attitude Angle vs Load** toolbar, click **Plot**.

3 Click the **Zoom Extents** button on the **Graphics** toolbar.

4 In the **Model Builder** window, collapse the **Attitude Angle vs Load** node.

Use the following instructions to plot journal position versus load as shown in Figure 4.

1D Plot Group 4

1 On the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type Journal Position in the **Label** text field.
3 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.
4 In the **Title** text area, type Journal position.
5 Locate the **Plot Settings** section. Select the **x-axis label** check box.
6 In the associated text field, type u_y/C (1).
7 Select the **y-axis label** check box.
8 In the associated text field, type u_z/C (1).

Global 1

1 Right-click **Journal Position** and choose **Global**.
2 In the **Settings** window for **Global**, type Plain in the **Label** text field.
3 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
u1z/C	1	

4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
5 In the **Expression** text field, type u1y/C.
6 Click to expand the **Coloring and style** section. Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Cycle**.
7 In the **Width** text field, type 3.
8 Click to expand the **Legends** section. From the **Legends** list, choose **Manual**.
9 In the table, enter the following settings:

Legends
Plain

Plain 1

1 Right-click **Results>Journal Position>Plain** and choose **Duplicate**.
2 In the **Settings** window for **Global**, type Elliptic in the **Label** text field.
3 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
u2z/C	1	

4 Locate the **x-Axis Data** section. In the **Expression** text field, type u2y/C.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
`Elliptic`

Global Display Nodes

Similarly add more **Global** display nodes using the information given in the following table:

Name	y axis Data	x axis Data	Legends
Split halves	`u3z/C`	`u3y/C`	`Split halves`
Two lobe	`u4z/C`	u4y/C	`Two lobe`
Three lobe LOP	`u5z/C`	u5y/C	`Three lobe LOP`
Three lobe LBP	`u6z/C`	`u6y/C`	`Three lobe LBP`
Four lobe LOP	`u7z/C`	u7y/C	`Four lobe LOP`
Four lobe LBP	`u8z/C`	u8y/C	`Four lobe LBP`

Journal Position

1 In the **Model Builder** window, under **Results** click **Journal Position**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Upper left**.

4 On the **Journal Position** toolbar, click **Plot**.

5 Click the **Zoom Extents** button on the **Graphics** toolbar.

6 In the **Model Builder** window, collapse the **Journal Position** node.

Use the following instructions to plot the initial thickness profile of the fluid film as shown in Figure 5.

Polar Plot Group 5

1 On the **Home** toolbar, click **Add Plot Group** and choose **Polar Plot Group**.

2 In the **Settings** window for **Polar Plot Group**, type `Polar: Initial Thickness Profile` in the **Label** text field.

3 Locate the **Data** section. From the **Parameter selection (W)** list, choose **First**.

4 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

5 In the **Title** text area, type `Initial thickness profile`.

6 Locate the **Axis** section. Select the **Manual axis limits** check box.

7 In the **r minimum** text field, type `0.6`.

8 In the **r maximum** text field, type `1.2`.

Line Graph 1

1 Right-click **Polar: Initial Thickness Profile** and choose **Line Graph**.

2 Select Edges 1, 2, 4, and 6 only.

3 In the **Settings** window for **Line Graph**, locate the **r-Axis Data** section.

4 In the **Expression** text field, type `hdb.hB1/C`.

5 Select the **Description** check box.

6 In the associated text field, type `Plain`.

7 Locate the θ **Angle Data** section. From the **Parameter** list, choose **Expression**.

8 In the **Expression** text field, type `hdb.Th+hdb.ang_bearing`.

9 Click to expand the **Coloring and style** section. Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Cycle**.

10 In the **Width** text field, type `3`.

11 Click to expand the **Legends** section. Select the **Show legends** check box.

12 From the **Legends** list, choose **Manual**.

13 In the table, enter the following settings:

Legends
`Plain`

14 In the **Label** text field, type `Plain`.

Plain 1

1 Right-click **Results>Polar: Initial Thickness Profile>Plain** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, type `Elliptic` in the **Label** text field.

3 Locate the **Selection** section. Click **Clear Selection**.

4 Select Edges 13, 14, 16, and 18 only.

5 Locate the **r-Axis Data** section. In the **Description** text field, type `Elliptic`.

6 Locate the **Legends** section. In the table, enter the following settings:

Legends
`Elliptic`

Line graph Nodes

Similarly add more **Line Graph** nodes using the information given in the following table:

Name	**Selection**	**r-Axis Data: Expression**	**Legends**
Split halves	`25, 26, 28, 30`	`Split halves`	`Split halves`
Two lobe	`37, 38, 40, 42`	Two lobe	`Two lobe`
Three lobe LOP	`49, 50, 52, 54`	Three lobe LOP	`Three lobe LOP`
Three lobe LBP	`61, 62, 64, 66`	`Three lobe LBP`	(As is)
Four lobe LOP	`73, 74, 76, 78`	Four lobe LOP	`Four lobe LOP`
Four lobe LBP	`85, 86, 88, 90`	Four lobe LBP	`Four lobe LBP`

Polar: Initial Thickness Profile

1 In the **Model Builder** window, under **Results** click **Polar: Initial Thickness Profile**.

2 On the **Polar: Initial Thickness Profile** toolbar, click **Plot**.

3 In the **Model Builder** window, collapse the **Polar: Initial Thickness Profile** node.

Finally, plot the initial thickness profile of the fluid film as shown in Figure 6 using the following instructions.

Polar: Initial Thickness Profile 1

1 In the **Model Builder** window, right-click **Polar: Initial Thickness Profile** and choose **Duplicate**.

2 In the **Settings** window for **Polar Plot Group**, type `Polar: Current Thickness Profile` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Thickness profile, W = 2800 N`.

Line graph Nodes

1 Edit the existing **Line Graph** nodes under **Polar: Current Thickness Profile** using the information given in the following table:

Name	**r-Axis Data: Expression**	**theta angle data: Expression**
Plain	`hdb.h/C`	`mod(hdb.Th+ hdb.ang_bearing,2*pi)`
Elliptic	`hdb.h/C`	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Split halves	`hdb.h/C`	mod(hdb.Th+hdb.ang_bearing, 2*pi)

Name	r-Axis Data: Expression	theta angle data: Expression
Two lobe	hdb.h/C	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Three lobe LOP	hdb.h/C	mod(hdb.Th+ hdb.ang_bearing,2*pi)
Three lobe LBP	hdb.h/C	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Four lobe LOP	hdb.h/C	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Four lobe LBP	hdb.h/C	mod(hdb.Th+hdb.ang_bearing, 2*pi)

2 In the **Model Builder** window, expand the **Results>Polar: Current Thickness Profile** node, then click **Polar: Current Thickness Profile**.

3 In the **Settings** window for **Polar Plot Group**, locate the **Data** section.

4 From the **Parameter selection (W)** list, choose **Manual**.

5 In the **Parameter indices (1-46)** text field, type `15`.

6 Locate the **Axis** section. In the **r minimum** text field, type `0.0`.

7 In the **r maximum** text field, type `2.0`.

8 On the **Polar: Current Thickness Profile** toolbar, click **Plot**.

9 In the **Model Builder** window, collapse the **Polar: Current Thickness Profile** node.