Created in COMSOL Multiphysics 6.0

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 of 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.

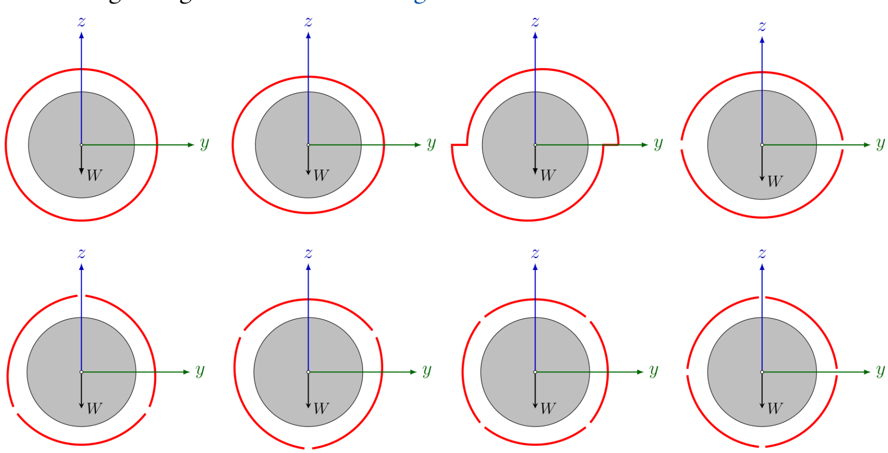

Figure 1: Bearing configuration. Top row: Plain, elliptic, split halves, two-lobe. Bottom row: Three-lobe (LOP), three-lobe (LBP), four-lobe (LOP), four-lobe (LBP).

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 viscosity μ	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	$h_b = C + \text{sign}(\sin\theta) d\cos\theta$
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. The following sections provide these expressions.

Plain Bearing

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

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, it follows that $C = (C_{min} - \cos(\pi/N)C_{max})/(1 - \cos(\pi/N))$, and $d = (C_{max} - C_{min})/(1 - \cos(\pi/N))$.

Results and Discussion

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

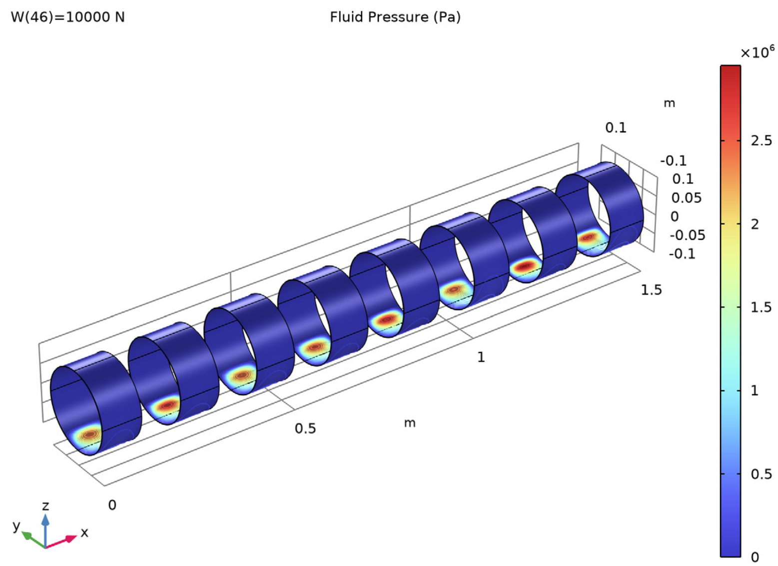

Figure 2: Fluid film pressure profile.

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.

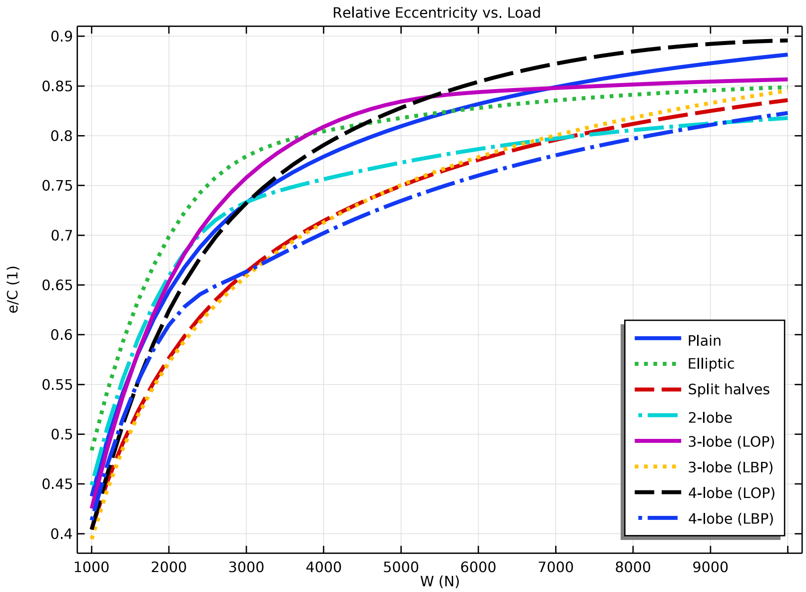

Figure 3: Eccentricity vs. load.

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. In the hydrodynamic bearing, two types of forces act on the journal. One, a radial force due to the pressure distribution in the film and other, a tangential viscous force due to the shear in the film. The journal equilibrium position depends on the relative magnitude of these forces. If the shear force is dominant and is enough to support the weight of the journal, equilibrium position is more toward the horizontal direction. For a large journal weight, shear force alone cannot support the journal and a radial force is also needed. In such a case, journal equilibrium position will move in the negative z direction.

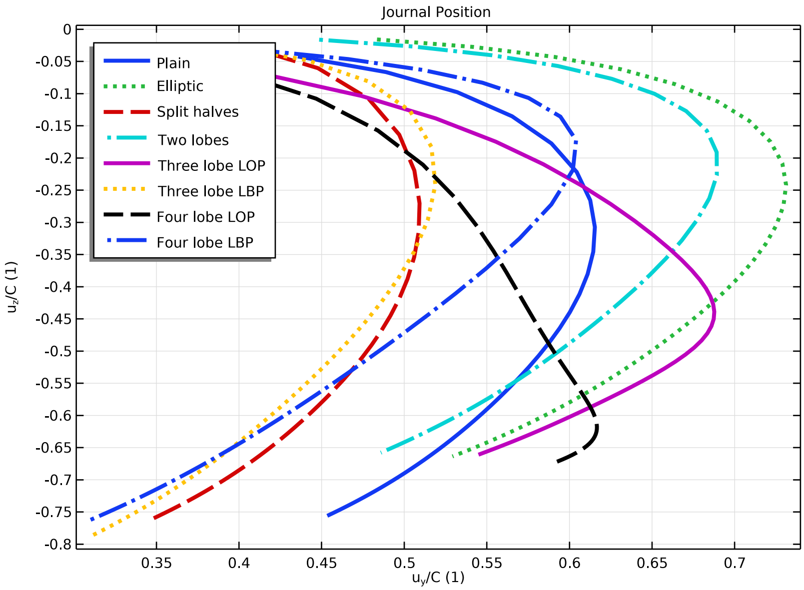

Figure 4: Journal position.

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.

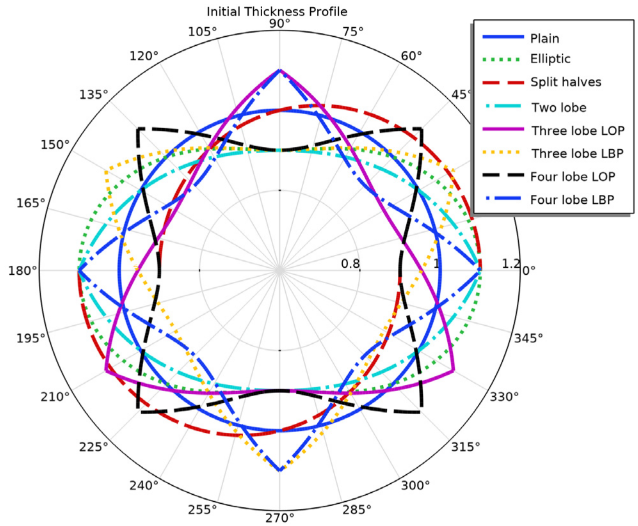

Figure 5: Initial thickness profile.

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

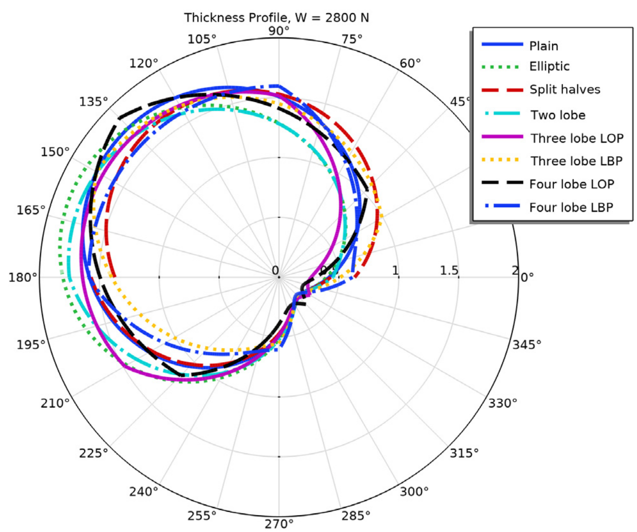

Figure 6: Current thickness profile.

Notes About the COMSOL Implementation

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 **General Studies>Stationary**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

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

Name	Expression	Value	Description
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 In 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 the *x* direction by executing the following commands.

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

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

DEFINITIONS

Plain bearing

1 In 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 Select the **Group by continuous tangent** check box.

Selecting this check box allows automatic selection of multiple surfaces across which the tangent is continuous.

Elliptic bearing

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 Boundaries 5–8 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

The table above displays 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 **Group by continuous tangent** check box is already selected within the old.

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

HYDRODYNAMIC BEARING (HDB)

1 Click the **Show More Options** button in the **Model Builder** toolbar.

2 In the **Show More Options** dialog box, in the tree, select the check box for the node **Physics>Advanced Physics Options**.

3 In the tree, select **Physics>Stabilization**.

4 In the tree, select the check box for the node **Physics>Stabilization**.

5 Click **OK**.

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

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

8 Select the **Cavitation** check box.

You can change the compressibility β inside the bearing node.

9 Click to expand the **Inconsistent Stabilization** section. In the $\delta_{artificial}$ text field, type 20.

The tuning parameter is increased to improve the stabilization in the cavitated film.

Hydrodynamic Journal Bearing (Plain)

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. From the **Specify** list, choose **Load**.

5 Specify the $\mathbf{W}_j$ vector as

0	x
0	y
-W	z

6 Specify the $\mathbf{u}_{J0}$ vector as

0	x
0	y
-0.1*C	z

7 In the Ω text field, type `Ow`.

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

Hydrodynamic Journal Bearing (Elliptic)

1 Right-click **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 (Split halves)

1 Right-click **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 (2-lobe)

1 Right-click **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 (3-lobe LOP)

1 Right-click **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 LBP)

1 Right-click **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 (4-lobe LOP)

1 Right-click **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 LBP)

1 Right-click **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 the following instructions.

Bearing Orientation Hydrodynamic Journal Bearing (3-lobe LOP)

1 In 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 LBP)

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 (4-lobe LOP)

1 Right-click **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`.

MESH 1

Mapped 1

1 In the **Mesh** toolbar, click △ **Boundary** and choose **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 **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, right-click **Mesh 1** and choose **Build All**.

STUDY 1

Step 1: Stationary

1 In the **Model Builder** window, under **Study 1** click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, click to expand the **Study Extensions** section.

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

3 Select the **Auxiliary sweep** check box.

4 Click + **Add**.

5 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
W (Load on bearing, z component)	range(1000,200,10000)	N

6 In the **Home** toolbar, click **Compute**.

RESULTS

Fluid Pressure (hdb)

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

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

3 In the **Title** text area, type `Fluid Pressure (Pa)`.

The dependent variable `pfilm` in the default plot does not represent the physical pressure and can have a negative value in the cavitated zone. Use physics scope variable `hdb.p` instead to show the physical pressure in the bearings.

Surface 1

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

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 In the **Expression** text field, type `hdb.p`.

Contour 1

1 In the **Model Builder** window, click **Contour 1**.

2 In the **Settings** window for **Contour**, locate the **Expression** section.

3 In the **Expression** text field, type `hdb.p`.

4 In the **Fluid Pressure (hdb)** toolbar, click **Plot**.

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

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

Relative Eccentricity vs. Load

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

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

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

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

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

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

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

Global 1

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

2 In the **Settings** window for **Global**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (Plain)>Eccentricity and attitude angle>hdb.hjb1.ec_rel - Relative eccentricity**.

3 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (Elliptic)>Eccentricity and attitude angle>hdb.hjb2.ec_rel - Relative eccentricity**.

4 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (Split halves)>Eccentricity and attitude angle>hdb.hjb3.ec_rel - Relative eccentricity**.

5 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (2-lobe) >Eccentricity and attitude angle>hdb.hjb4.ec_rel - Relative eccentricity**.

6 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (3-lobe LOP)>Eccentricity and attitude angle>hdb.hjb5.ec_rel - Relative eccentricity**.

7 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (3-lobe LBP)>Eccentricity and attitude angle>hdb.hjb6.ec_rel - Relative eccentricity**.

8 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (4-lobe LOP)>Eccentricity and attitude angle>hdb.hjb7.ec_rel - Relative eccentricity**.

9 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing> Hydrodynamic Journal Bearing (4-lobe LBP)>Eccentricity and attitude angle> hdb.hjb8.ec_rel - Relative eccentricity**.

10 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
hdb.hjb1.ec_rel	1	Plain
hdb.hjb2.ec_rel	1	Elliptic
hdb.hjb3.ec_rel	1	Split halves
hdb.hjb4.ec_rel	1	2-lobe
hdb.hjb5.ec_rel	1	3-lobe (LOP)
hdb.hjb6.ec_rel	1	3-lobe (LBP)
hdb.hjb7.ec_rel	1	4-lobe (LOP)
hdb.hjb8.ec_rel	1	4-lobe (LBP)

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

12 In the **Width** text field, type 3.

Relative Eccentricity vs. Load

1 In the **Model Builder** window, click **Relative 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 In the **Relative Eccentricity vs. Load** toolbar, click **Plot**.

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

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

Use the following instructions to plot the attitude angle against the load.

Attitude Angle vs. Load

1 In 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 Locate the **Title** section. From the **Title type** list, choose **Label**.

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

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

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

7 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**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (Plain)>Eccentricity and attitude angle>hdb.hjb1.phia - Attitude angle - rad**.

3 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (Elliptic)>Eccentricity and attitude angle>hdb.hjb2.phia - Attitude angle - rad**.

4 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (Split halves)>Eccentricity and attitude angle>hdb.hjb3.phia - Attitude angle - rad**.

5 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (2-lobe) >Eccentricity and attitude angle>hdb.hjb4.phia - Attitude angle - rad**.

6 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (3-lobe LOP)>Eccentricity and attitude angle>hdb.hjb5.phia - Attitude angle - rad**.

7 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (3-lobe LBP)>Eccentricity and attitude angle>hdb.hjb6.phia - Attitude angle - rad**.

8 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (4-lobe LOP)>Eccentricity and attitude angle>hdb.hjb7.phia - Attitude angle - rad**.

9 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Hydrodynamic Journal Bearing (4-lobe LBP)>Eccentricity and attitude angle>hdb.hjb8.phia - Attitude angle - rad**.

10 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
hdb.hjb1.phia	deg	Plain
hdb.hjb2.phia	deg	Elliptic
hdb.hjb3.phia	deg	Split halves
hdb.hjb4.phia	deg	2-lobe
hdb.hjb5.phia	deg	3-lobe (LOP)
hdb.hjb6.phia	deg	3-lobe (LBP)
hdb.hjb7.phia	deg	4-lobe (LOP)
hdb.hjb8.phia	deg	4-lobe (LBP)

11 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Cycle**.

12 In the **Width** text field, type 3.

Attitude Angle vs. Load

1. In the **Model Builder** window, click **Attitude Angle vs. Load**.
2. In the **Attitude Angle vs. Load** toolbar, click **Plot**.
3. Click the **Zoom Extents** button in the **Graphics** toolbar.
4. In the **Model Builder** window, collapse the **Attitude Angle vs. Load** node.

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

Journal Position

1. In 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. Locate the **Title** section. From the **Title type** list, choose **Label**.
4. Locate the **Plot Settings** section. Select the **x-axis label** check box.
5. In the associated text field, type u_y/C (1).
6. Select the **y-axis label** check box.
7. In the associated text field, type u_z/C (1).

Plain

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
hdb.hjb1.uJz/C	1	

4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

5 In the **Expression** text field, type `hdb.hjb1.uJy/C`.

6 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

Elliptic

1 Right-click **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
hdb.hjb2.uJz/C	1	

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `hdb.hjb2.uJy/C`.

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

Legends
Elliptic

Global Display Nodes

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

Name	y axis Data	x axis Data	Legends
Split halves	hdb.hjb3.uJz/C	hdb.hjb3.uJy/C	Split halves
Two lobe	hdb.hjb4.uJz/C	hdb.hjb4.uJy/C	Two lobe
Three lobe LOP	hdb.hjb5.uJz/C	hdb.hjb5.uJy/C	Three lobe LOP

Name	y axis Data	x axis Data	Legends
Three lobe LBP	hdb.hjb6.uJz/C	hdb.hjb6.uJy/C	Three lobe LBP
Four lobe LOP	hdb.hjb7.uJz/C	hdb.hjb7.uJy/C	Four lobe LOP
Four lobe LBP	hdb.hjb8.uJz/C	hdb.hjb8.uJy/C	Four lobe LBP

Journal Position

1 In the **Model Builder** window, 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 In the **Journal Position** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in 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.

Initial Thickness Profile

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

2 In the **Settings** window for **Polar Plot Group**, type `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 **Label**.

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

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

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

Plain

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

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

3 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **r-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Journal and bearing properties>Film thickness and clearance>hdb.hi_rel - Relative film thickness, initial**.

4 Locate the **r-Axis Data** section. Select the **Description** check box.

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

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

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

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

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

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

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

12 In the table, enter the following settings:

Legends
`Plain`

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

Elliptic

1 Right-click **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`

Initial Thickness Profile

1 In the **Model Builder** window, click **Initial Thickness Profile**.

2 In the **Initial Thickness Profile** toolbar, click **Plot**.

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

Initial Thickness Profile 1

Right-click **Initial Thickness Profile** and choose **Duplicate**.

Initial Thickness Profile

In the **Model Builder** window, collapse the **Results>Initial Thickness Profile** node.

Current Thickness Profile

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

2 In the **Settings** window for **Polar Plot Group**, type `Current Thickness Profile` 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 `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_rel`	`mod(hdb.Th+hdb.ang_bearing,2*pi)`
Elliptic	`hdb.h_rel`	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Split halves	`hdb.h/C`	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Two lobe	`hdb.h_rel`	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Three lobe LOP	`hdb.h_rel`	`mod(hdb.Th+hdb.ang_bearing,2*pi)`
Three lobe LBP	`hdb.h_rel`	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Four lobe LOP	`hdb.h_rel`	mod(hdb.Th+hdb.ang_bearing, 2*pi)
Four lobe LBP	`hdb.h_rel`	mod(hdb.Th+hdb.ang_bearing, 2*pi)

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

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

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

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

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

7 In the **Current Thickness Profile** toolbar, click **Plot**.

8 In the **Model Builder** window, collapse the **Results>Current Thickness Profile** node.