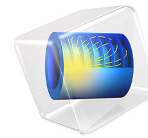

Turbocharger Supported on Floating Ring Bearings

Introduction

A turbocharger is usually supported by hydrodynamic journal bearings, most often floating ring bearings. These bearings are the extension of the plain journal bearings in which a ring is inserted between the journal and bushing surfaces. Therefore, such a bearing can be considered as two plain journal bearings working in series. However, the two films are not completely disconnected; rather they are connected through the oil channels in the ring.

A time-dependent analysis is performed to analyze the dynamics of a turbocharger supported on a pair of floating ring bearings. The results include the stress in the rotor, pressure in the bearing, ring speed and torque, and flow through the channels in the ring.

Model Definition

The model consists of a turbocharger rotor supported by two floating ring bearings, one near the compressor and another near the turbine, making both the compressor and the turbine overhung on the shaft. The schematic of the rotor is shown in Figure 1.

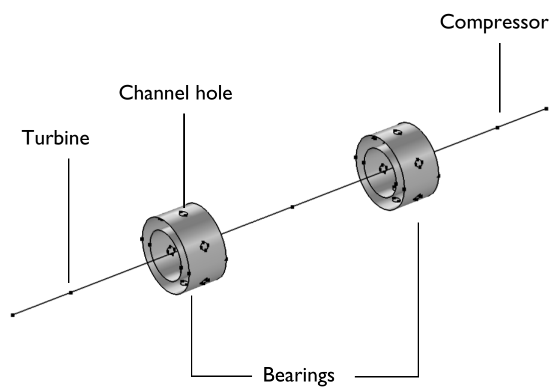

Figure 1: Rotor sketch.

The rotor of the turbocharger is modeled using the Beam Rotor interface and the bearings are modeled using the Floating Ring Bearing feature. The connection between the inner and the outer film is established using an Inner-Outer Film Connection subfeature of the Floating Ring Bearing. The coupling between the rotor and the bearing is handled using a multiphysics coupling feature. The Disk feature is used to model the inertia of the turbine and the compressor. The properties of the rotor are given in Table 1.

TABLE 1: ROTOR PROPERTIES.

PARAMETER	VALUE
Young's modulus of the rotor, E	205 GPa
Poisson's ratio of the rotor, ν	0.3
Density of the rotor, ρ	7800 kg/m^3
Length of the rotor, L	0.15 m
Location of the turbine	0.1 L
Location of the bearing near turbine	0.3 L
Location of the bearing near compressor	0.7 L
Location of the compressor	0.9 L
Mass of the turbine, m_t	1.4 kg
Transverse moment of inertia of the turbine, I_{dt}	6.3 x 10^{-4} kg·m^2
Polar moment of inertia of the turbine, I_{pt}	1.26 x 10^{-4} kg·m^2
Mass of the compressor, m_c	1.0 kg
Transverse moment of inertia of the compressor, I_{dc}	4.5 x 10^{-4} kg·m^2
Polar moment of inertia of the compressor, I_{pc}	9 x10^{-4} kg·m^2

Bearing properties are given in Table 2.

TABLE 2: BEARING PROPERTIES.

PARAMETER	VALUE
Mass of the ring, m_r	0.02 kg
Outer radius of the ring, R_o	9 mm
Inner radius of the ring, R_i	6 mm
Outer bearing clearance, C_o	0.08 mm
Inner bearing clearance, C_i	0.02 mm
Viscosity of the lubricant, μ	0.06 Pa·s
Length of the bearing, L_b	0.01 m

The rotor is rotating at 8,000 rpm and is initially concentric with the bearing. A gravity load acts on the rotor. A time-dependent analysis is performed to analyze the response of the turbocharger system.

Results and Discussion

The pressure in the bearings and the stress in the rotor is shown in Figure 2. The maximum stress occurs in the central region of the rotor. The pressure is maximal in the bottom of the bearing because the rotor moves downward from the bearing center due to the gravitational force. The clearances between the journal and the ring and that between the ring and the bushing decrease due to this motion.

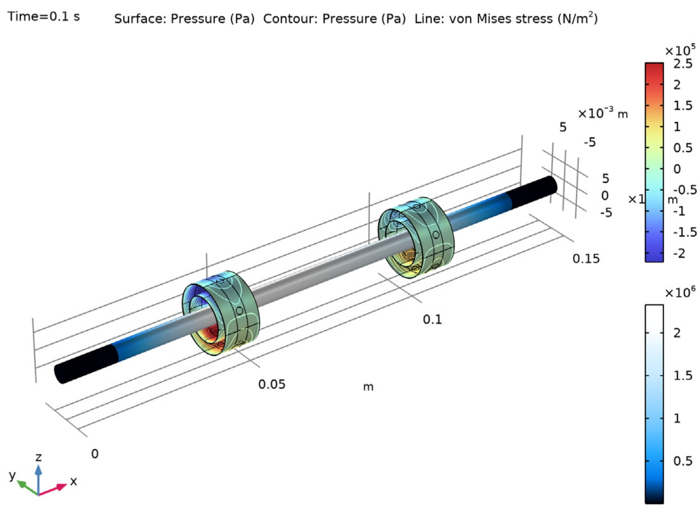

Figure 2: Pressure and stress in the turbocharger at 0.1 s.

The variation of the axial rotational speed of the ring is shown in Figure 3. Initially the ring and bushing are stationary but the journal is moving at the prescribed angular velocity. Thus, there is a relative slip motion in the inner film alone in the beginning. The outer film has no slip motion. The slip in the inner film produces a viscous torque on the ring but there is no torque from the outer film at this stage. The torque on the ring is shown in Figure 4. Due to the net torque on the ring, it starts rotating axially. The ring rotation decreases the relative slip in the inner film while increasing the same in the outer film. As a result, the torque from the inner film reduces and at the same time torque from the outer film increases. Also, the torque from the outer film opposes the torque from the inner film. Consequently, the net angular acceleration of the ring decreases as the ring picks up speed. Eventually, the ring will attain a speed at which the torque from both the inner and outer films are equal and opposite and at this stage the net angular acceleration of the ring becomes zero. Therefore, ring continues to rotate at this speed after this.

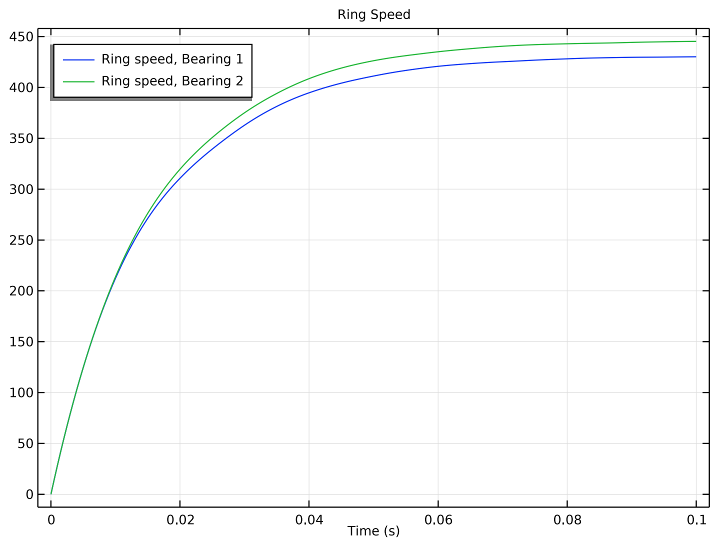

Figure 3: Ring speed.

The orbit of rotor in the ring, shown in Figure 5, shows that after going through the initial transient phase, the rotor performs a small amplitude whirl in the ring about an equilibrium point.

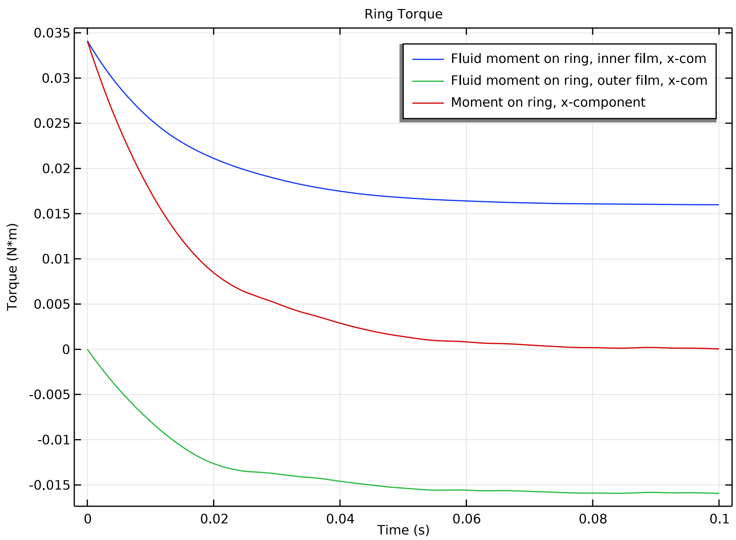

Figure 4: Torque on the ring.

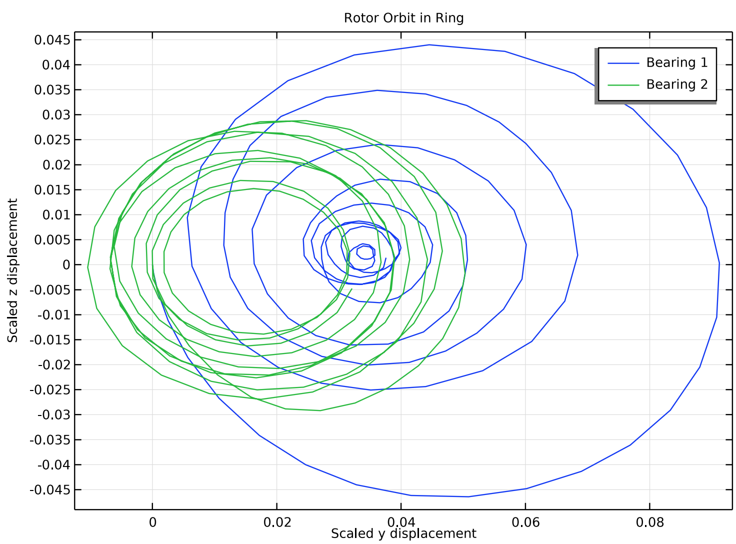

Figure 5: Rotor orbit in the ring.

As shown in Figure 6, the ring orbit characteristics are also similar to the rotor. However, the amplitude of the ring whirl in steady state is very small compared to the rotor.

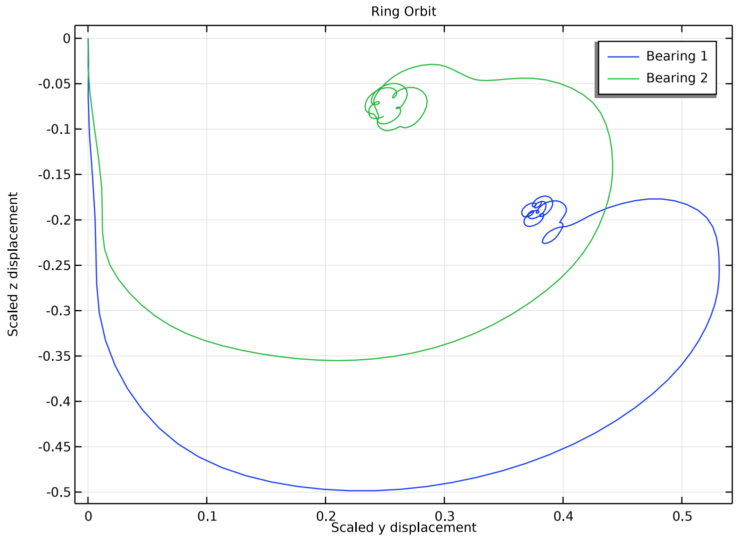

Figure 6: Ring orbit.

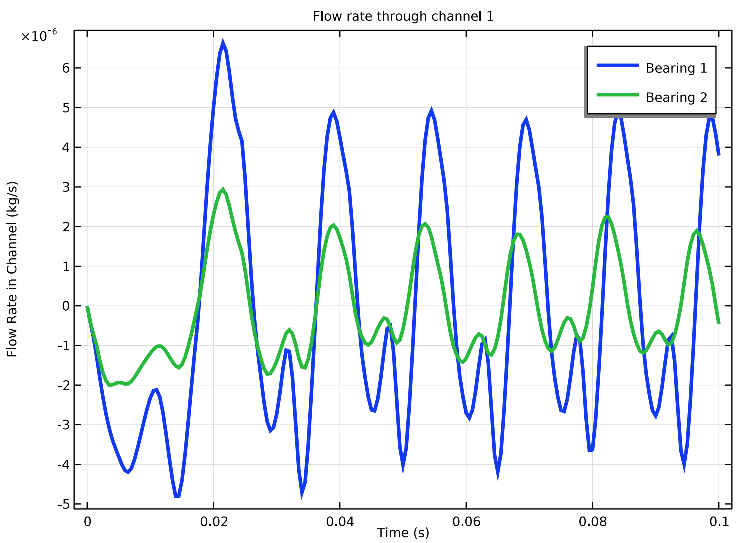

Figure 7: Mass-flow rate through channels.

The mass-flow rate in the first channel of both bearings is shown in Figure 7. The transient response exhibits nonperiodic behavior in the flow rate, but as it reaches steady state the flow-rate variation becomes periodic. Also, note that the flow rate changes from positive to negative values during a cycle, showing that the flow goes both from the inner film to the outer film and vice versa.

Application Library path: `Rotordynamics_Module/Automotive_and_Aerospace/turbocharger_transient_analysis`

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>Beam Rotor with Hydrodynamic Bearing**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Time Dependent**.

6 Click **Done**.

Import the parameters for the turbocharger.

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 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `turbocharger_transient_analysis_rotor_parameters.txt`.

Parameters 2

1. In the **Home** toolbar, click **Parameters** and choose **Add>Parameters**.
2. In the **Settings** window for **Parameters**, locate the **Parameters** section.
3. Click **Load from File**.
4. Browse to the model's Application Libraries folder and double-click the file `turbocharger_transient_analysis_bearing_parameters.txt`.

GEOMETRY 1

Polygon 1 (pol1)

1. In the **Geometry** toolbar, click **More Primitives** and choose **Polygon**.
2. In the **Settings** window for **Polygon**, locate the **Coordinates** section.
3. From the **Data source** list, choose **Vectors**.
4. In the **x** text field, type `x1 x2 x3 L/2`.
5. In the **y** text field, type `0`.
6. In the **z** text field, type `0`.
7. Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.
8. In the **New Cumulative Selection** dialog box, type `Rotor` in the **Name** text field.
9. Click **OK**.

Cylinder 1 (cyl1)

1. In the **Geometry** toolbar, click **Cylinder**.
2. In the **Settings** window for **Cylinder**, locate the **Object Type** section.
3. From the **Type** list, choose **Surface**.
4. Locate the **Size and Shape** section. In the **Radius** text field, type `R_o`.
5. In the **Height** text field, type `Lb`.
6. Locate the **Position** section. In the **x** text field, type `x3-Lb/2`.
7. Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.
8. Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.
9. In the **New Cumulative Selection** dialog box, type `Bearing Surface` in the **Name** text field.
10. Click **OK**.

11 Right-click **Cylinder 1 (cyl1)** and choose **Duplicate**.

Cylinder 2 (cyl2)

1 In the **Model Builder** window, click **Cylinder 2 (cyl2)**.

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

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

Cylinder 1 (cyl1)

1 In the **Model Builder** window, click **Cylinder 1 (cyl1)**.

2 In the **Settings** window for **Cylinder**, click to expand the **Layers** section.

3 Right-click **Cylinder 1 (cyl1)** and choose **Duplicate**.

Cylinder 3 (cyl3)

1 In the **Model Builder** window, click **Cylinder 3 (cyl3)**.

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

3 In the **Height** text field, type `0.3*Lb`.

4 Locate the **Position** section. In the **x** text field, type `x3-0.15*Lb`.

5 Right-click **Cylinder 3 (cyl3)** and choose **Duplicate**.

Cylinder 4 (cyl4)

1 In the **Model Builder** window, click **Cylinder 4 (cyl4)**.

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

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

Cylinder 5 (cyl5)

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 `0.1*R_o`.

4 In the **Height** text field, type `2.5*(R_o-R_i)`.

5 Locate the **Position** section. In the **x** text field, type `x3`.

6 In the **z** text field, type `0.5*R_i`.

7 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. From the **Contribute to** list, choose **Bearing Surface**.

Rotate 1 (rot1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Rotate**.

2 Select the object **cyl5** only.

3 In the **Settings** window for **Rotate**, locate the **Rotation** section.

4 In the **Angle** text field, type `range(0,60,300)`.

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

6 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

7 In the **New Cumulative Selection** dialog box, type `Auxiliary cylinders` in the **Name** text field.

8 Click **OK**.

Union 1 (uni1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 In the **Settings** window for **Union**, locate the **Union** section.

3 From the **Input objects** list, choose **Bearing Surface**.

4 Select the **Keep input objects** check box.

Delete Entities 1 (del1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Delete Entities**.

2 In the **Settings** window for **Delete Entities**, locate the **Entities or Objects to Delete** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Auxiliary cylinders**.

Mirror 1 (mir1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Mirror**.

2 Click in the **Graphics** window and then press Ctrl+A to select all objects.

3 In the **Settings** window for **Mirror**, locate the **Point on Plane of Reflection** section.

4 In the **x** text field, type `L/2`.

5 Locate the **Normal Vector to Plane of Reflection** section. In the **x** text field, type `1`.

6 In the **z** text field, type `0`.

7 Click **Build All Objects**.

8 Click the **Go to Default View** button in the **Graphics** toolbar.

9 Locate the **Input** section. Click to select the **Activate Selection** toggle button for **Input objects**.

10 Select the **Keep input objects** check box.

11 Click **Build All Objects**.

12 Click the **Go to Default View** button in the **Graphics** toolbar.

Create some selections for the later use.

DEFINITIONS

Inner film, bearing 1

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

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

3 From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundary 4 only.

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

6 In the **Label** text field, type `Inner film, bearing 1`.

Outer film, bearing 1

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

2 In the **Settings** window for **Explicit**, type `Outer film, bearing 1` in the **Label** text field.

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

4 Select Boundary 2 only.

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

Inner film, bearing 1

In the **Model Builder** window, right-click **Inner film, bearing 1** and choose **Duplicate**.

Inner film, bearing 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Inner film, bearing 1.1**.

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

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

4 Select Boundaries 43, 44, 46, 47, 51, 52, 54, 55, 59, 60, 63–66, 69, 70, 75, 76, 78, and 79 only.

Outer film, bearing 1

In the **Model Builder** window, right-click **Outer film, bearing 1** and choose **Duplicate**.

Outer film, bearing 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Outer film, bearing 1.1**.

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

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

4 Select Boundaries 41, 42, 45, 48–50, 53, 56–58, 61, 62, 67, 68, 71–74, 77, and 80 only.

Bearing 1

1 In the **Definitions** toolbar, click **Union**.

2 In the **Settings** window for **Union**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. Under **Selections to add**, click **Add**.

5 In the **Add** dialog box, in the **Selections to add** list, choose **Inner film, bearing 1** and **Outer film, bearing 1**.

6 Click **OK**.

7 In the **Settings** window for **Union**, type `Bearing 1` in the **Label** text field.

8 Right-click **Bearing 1** and choose **Duplicate**.

Bearing 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Bearing 1.1**.

2 In the **Settings** window for **Union**, type `Bearing 2` in the **Label** text field.

3 Locate the **Input Entities** section. In the **Selections to add** list, select **Inner film, bearing 1**.

4 Under **Selections to add**, click **Delete**.

5 Under **Selections to add**, click **Delete**.

6 Under **Selections to add**, click **Add**.

7 In the **Add** dialog box, in the **Selections to add** list, choose **Inner film, bearing 2** and **Outer film, bearing 2**.

8 Click **OK**.

Inner film

1 In the **Definitions** toolbar, click **Union**.

2 In the **Settings** window for **Union**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. Under **Selections to add**, click **Add**.

5 In the **Add** dialog box, in the **Selections to add** list, choose **Inner film, bearing 1** and **Inner film, bearing 2**.

6 Click **OK**.

7 In the **Settings** window for **Union**, type `Inner film` in the **Label** text field.

8 Right-click **Inner film** and choose **Duplicate**.

Outer film

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Inner film 1**.

2 In the **Settings** window for **Union**, type `Outer film` in the **Label** text field.

3 Locate the **Input Entities** section. In the **Selections to add** list, select **Inner film, bearing 1**.

4 Under **Selections to add**, click **Delete**.

5 Under **Selections to add**, click **Delete**.

6 Under **Selections to add**, click **Add**.

7 In the **Add** dialog box, in the **Selections to add** list, choose **Outer film, bearing 1** and **Outer film, bearing 2**.

8 Click **OK**.

Channel, inner film, bearing 1

1 In the **Definitions** toolbar, click **Cylinder**.

2 Click the **Go to Default View** button in the **Graphics** toolbar.

3 In the **Settings** window for **Cylinder**, locate the **Geometric Entity Level** section.

4 From the **Level** list, choose **Boundary**.

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

6 Locate the **Size and Shape** section. In the **Outer radius** text field, type `0.5*(R_i+R_o)`.

7 In the **Inner radius** text field, type `0.5*R_i`.

8 In the **Top distance** text field, type `0.11*R_o`.

9 In the **Bottom distance** text field, type `-0.11*R_o`.

10 Locate the **Position** section. In the **x** text field, type `x3`.

11 Locate the **Output Entities** section. From the **Include entity if** list, choose **Entity inside cylinder**.

12 In the **Label** text field, type `Channel, inner film, bearing 1`.

13 Right-click **Channel, inner film, bearing 1** and choose **Duplicate**.

Channel, outer film, bearing 1

1 In the **Model Builder** window, click **Channel, inner film, bearing 1.1**.

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

3 In the **Outer radius** text field, type `1.1*R_o`.

4 In the **Inner radius** text field, type `0.5*(R_i+R_o)`.

5 In the **Label** text field, type `Channel, outer film, bearing 1`.

Channel, inner film, bearing 1, Channel, outer film, bearing 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections**, Ctrl-click to select **Channel, inner film, bearing 1** and **Channel, outer film, bearing 1**.

2 Right-click and choose **Duplicate**.

Channel, inner film, bearing 2

1 In the **Model Builder** window, click **Channel, inner film, bearing 1.1**.

2 In the **Settings** window for **Cylinder**, locate the **Position** section.

3 In the **x** text field, type `x4`.

4 In the **Label** text field, type `Channel, inner film, bearing 2`.

Channel, outer film, bearing 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Channel, outer film, bearing 1.1**.

2 In the **Settings** window for **Cylinder**, type `Channel, outer film, bearing 2` in the **Label** text field.

3 Locate the **Position** section. In the **x** text field, type `x4`.

MATERIALS

Material 1 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Edge**.

4 From the **Selection** list, choose **Rotor**.

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

Property	Variable	Value	Unit	Property group
Young's modulus	E	`Er`	Pa	Young's modulus and Poisson's ratio
Poisson's ratio	nu	`nur`	1	Young's modulus and Poisson's ratio
Density	rho	`rhor`	kg/m³	Basic

BEAM ROTOR (ROTBM)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Beam Rotor (rotbm)**.

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

3 From the **Selection** list, choose **Rotor**.

4 Locate the **Rotor Speed** section. In the text field, type `Ow`.

5 Locate the **Results** section. Clear the **Include undeformed geometry in stress/whirl plot** check box.

Rotor Cross Section 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Rotor Cross Section 1**.

2 In the **Settings** window for **Rotor Cross Section**, locate the **Cross-Section Definition** section.

3 In the d_o text field, type `2*R_i`.

Disk: Turbine

1 In the **Physics** toolbar, click **Points** and choose **Disk**.

2 In the **Settings** window for **Disk**, type `Disk: Turbine` in the **Label** text field.

3 Locate the **Disk Properties** section. From the **Center of mass** list, choose **Offset from selected points**.

4 In the z_r text field, type `1e-4*R_i`.

5 In the m text field, type `m_t`.

6 In the I_p text field, type `Ip_t`.

7 In the I_d text field, type `Id_t`.

8 Select Point 2 only.

9 Right-click **Disk: Turbine** and choose **Duplicate**.

Disk: Compressor

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Disk: Turbine 1**.

2 In the **Settings** window for **Disk**, type `Disk: Compressor` in the **Label** text field.

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

4 Select Point 166 only.

5 Locate the **Disk Properties** section. In the m text field, type `m_c`.

6 In the I_p text field, type `Ip_c`.

7 In the I_d text field, type `Id_c`.

Gravity 1

In the **Physics** toolbar, click **Edges** and choose **Gravity**.

HYDRODYNAMIC BEARING (HDB)

Add two **Floating Ring Bearing** features for both the bearings.

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

Floating Ring Bearing 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Floating Ring Bearing**.

2 In the **Settings** window for **Floating Ring Bearing**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Bearing 1**.

4 Locate the **Bearing Properties** section. In the m_{ring} text field, type `m_r`.

5 From the list, choose **Diagonal**.

6 In the I_{ring} table, enter the following settings:

`Ip_r`	`0`	`0`
`0`	`Id_r`	`0`
`0`	`0`	`Id_r`

7 From the $\mathbf{X}_c$ list, choose **From geometry**.

8 Locate the **Fluid Properties** section. From the μ list, choose **User defined**. In the associated text field, type `mu0`.

9 From the ρ list, choose **User defined**.

DEFINITIONS

Bearing 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Bearing 1**.

2 In the **Settings** window for **Union**, locate the **Input Entities** section.

3 In the **Selections to add** list, select **Outer film, bearing 1**.

HYDRODYNAMIC BEARING (HDB)

Inner Film Properties 1

1 In the **Model Builder** window, expand the **Floating Ring Bearing 1** node, then click **Inner Film Properties 1**.

2. In the **Settings** window for **Inner Film Properties**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Inner film, bearing 1**.
4. Locate the **Clearance** section. In the C text field, type `C_i`.

Outer Film Properties 1

1. In the **Model Builder** window, click **Outer Film Properties 1**.
2. In the **Settings** window for **Outer Film Properties**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Outer film, bearing 1**.
4. Locate the **Clearance** section. In the C text field, type `C_o`.

Floating Ring Bearing 1

In the **Model Builder** window, click **Floating Ring Bearing 1**.

Inner–Outer Film Connection 1

1. In the **Physics** toolbar, click **Attributes** and choose **Inner–Outer Film Connection**.
2. In the **Settings** window for **Inner–Outer Film Connection**, locate the **Channel, Inner Film** section.
3. From the **Selection** list, choose **Channel, inner film, bearing 1**.
4. Locate the **Channel, Outer Film** section. From the **Selection** list, choose **Channel, outer film, bearing 1**.

Floating Ring Bearing 1

Right-click **Floating Ring Bearing 1** and choose **Duplicate**.

Floating Ring Bearing 2

1. In the **Model Builder** window, click **Floating Ring Bearing 2**.
2. In the **Settings** window for **Floating Ring Bearing**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Bearing 2**.

Inner Film Properties 1

1. In the **Model Builder** window, expand the **Floating Ring Bearing 2** node, then click **Inner Film Properties 1**.
2. In the **Settings** window for **Inner Film Properties**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Inner film, bearing 2**.

Outer Film Properties 1

1. In the **Model Builder** window, click **Outer Film Properties 1**.
2. In the **Settings** window for **Outer Film Properties**, locate the **Boundary Selection** section.

3. From the **Selection** list, choose **Outer film, bearing 2**.

Inner–Outer Film Connection 1

1. In the **Model Builder** window, click **Inner–Outer Film Connection 1**.
2. In the **Settings** window for **Inner–Outer Film Connection**, locate the **Channel, Inner Film** section.
3. From the **Selection** list, choose **Channel, inner film, bearing 2**.
4. Locate the **Channel, Outer Film** section. From the **Selection** list, choose **Channel, outer film, bearing 2**.

Create the selection for the outer edges on the bearing to use it in the mesh.

Border 1

1. In the **Model Builder** window, under **Component 1 (comp1)>Hydrodynamic Bearing (hdb)** click **Border 1**.
2. In the **Settings** window for **Border**, locate the **Edge Selection** section.
3. Click **Create Selection**.
4. In the **Create Selection** dialog box, type `Bearing Outer Edges` in the **Selection name** text field.
5. Click **OK**.

MULTIPHYSICS

Beam Rotor–Bearing Coupling 1 (brbc1)

1. In the **Model Builder** window, under **Component 1 (comp1)>Multiphysics** click **Beam Rotor–Bearing Coupling 1 (brbc1)**.
2. In the **Settings** window for **Beam Rotor–Bearing Coupling**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Inner film, bearing 1**.

   Duplicate the multiphysics coupling feature for coupling with the second bearing.
4. Right-click **Component 1 (comp1)>Multiphysics>Beam Rotor–Bearing Coupling 1 (brbc1)** and choose **Duplicate**.

Beam Rotor–Bearing Coupling 2 (brbc2)

1. In the **Model Builder** window, click **Beam Rotor–Bearing Coupling 2 (brbc2)**.
2. In the **Settings** window for **Beam Rotor–Bearing Coupling**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Inner film, bearing 2**.

MESH 1

Edge 1

1 In the **Mesh** toolbar, click **More Generators** and choose **Edge**.

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

3 From the **Selection** list, choose **Rotor**.

Distribution 1

1 Right-click **Edge 1** and choose **Distribution**.

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

3 Click **Clear Selection**.

4 Select Edges 1 and 230 only.

5 Locate the **Distribution** section. In the **Number of elements** text field, type 10.

Distribution 2

1 In the **Model Builder** window, right-click **Edge 1** and choose **Distribution**.

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

3 Click **Clear Selection**.

4 Select Edges 2, 75, 116, and 189 only.

5 Locate the **Distribution** section. In the **Number of elements** text field, type 20.

Mapped 1

1 In the **Mesh** toolbar, click **More Generators** and choose **Mapped**.

2 Select Boundaries 1–8, 33–48, and 73–80 only.

Distribution 1

1 Right-click **Mapped 1** and choose **Distribution**.

2 Select Edges 3, 4, 6, 7, 9, 11, 13, 15, 108–118, 120, 121, 123, 125, 127, 129, and 222–229 only.

3 In the **Settings** window for **Distribution**, locate the **Distribution** section.

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

Distribution 2

1 In the **Model Builder** window, right-click **Mapped 1** and choose **Distribution**.

2 Click the **Go to Default View** button in the **Graphics** toolbar.

3 Select Edges 14, 16, 103, 105, 131, 132, 220, and 221 only.

4 In the **Settings** window for **Distribution**, locate the **Distribution** section.

5 In the **Number of elements** text field, type 2.

Size

1 In the **Model Builder** window, under **Component 1 (comp1)>Mesh 1** click **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 From the **Predefined** list, choose **Finer**.

4 Click **Build All**.

Free Triangular 1

1 In the **Mesh** toolbar, click **More Generators** and choose **Free Triangular**.

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

3 From the **Geometric entity level** list, choose **Remaining**.

4 Click **Build All**.

STUDY 1

Step 1: Time Dependent

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

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 In the **Output times** text field, type `range(0,5e-4,0.1)`.

Solution 1 (sol1)

1 In the **Study** toolbar, click **Show Default Solver**.

2 In the **Model Builder** window, expand the **Solution 1 (sol1)** node, then click **Time-Dependent Solver 1**.

3 In the **Settings** window for **Time-Dependent Solver**, click to expand the **Time Stepping** section.

4 From the **Method** list, choose **BDF**.

5 From the **Steps taken by solver** list, choose **Intermediate**.

6 From the **Maximum BDF order** list, choose **2**.

7 In the **Model Builder** window, expand the **Study 1>Solver Configurations>Solution 1 (sol1)>Dependent Variables 1** node, then click **Displacement field (comp1.u)**.

8 In the **Settings** window for **Field**, locate the **Scaling** section.

9 In the **Scale** text field, type `1e-5`.

10 In the **Study** toolbar, click **Compute**.

Stress in the rotor and pressure in the bearing are the default plots. Copy the **Line** node from the stress plot and paste it in the pressure plot to show the rotor and the bearing together. This plot is shown in Figure 2.

RESULTS

Line 1

1. In the **Model Builder** window, expand the **Results>Stress (rotbm)** node.
2. Right-click **Line 1** and choose **Copy**.

Fluid Pressure (hdb)

In the **Model Builder** window, under **Results** right-click **Fluid Pressure (hdb)** and choose **Paste Line**.

Line 1

1. In the **Model Builder** window, click **Line 1**.
2. In the **Settings** window for **Line**, locate the **Coloring and Style** section.
3. Click **Change Color Table**.
4. In the **Color Table** dialog box, select **Aurora>JupiterAuroraBorealis** in the tree.
5. Click **OK**.
6. In the **Settings** window for **Line**, locate the **Coloring and Style** section.
7. Select the **Radius scale factor** check box. In the associated text field, type `0.4`.

Deformation

1. In the **Model Builder** window, expand the **Line 1** node, then click **Deformation**.
2. In the **Settings** window for **Deformation**, locate the **Scale** section.
3. Select the **Scale factor** check box. In the associated text field, type `50`.

Surface 1

Pressure distribution in the films is obtained in the ring frame. Add the deformation node to convert the distribution in the stationary frame.

Deformation 1

1. In the **Model Builder** window, right-click **Surface 1** and choose **Deformation**.
2. In the **Settings** window for **Deformation**, locate the **Expression** section.
3. In the **X-component** text field, type `hdb.uRax`.
4. In the **Y-component** text field, type `hdb.uRay`.
5. In the **Z-component** text field, type `hdb.uRaz`.

6 Locate the **Scale** section. Select the **Scale factor** check box.

7 Right-click **Deformation 1** and choose **Copy**.

Contour 1

In the **Model Builder** window, under **Results>Fluid Pressure (hdb)** right-click **Contour 1** and choose **Paste Deformation**.

Fluid Pressure (hdb)

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

2 In the **Settings** window for **3D Plot Group**, locate the **Color Legend** section.

3 From the **Position** list, choose **Right double**.

4 Click the **Go to Default View** button in the **Graphics** toolbar.

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

The speed of the ring initially increases due to the viscous forces on the inner and outer film and reaches steady state when the torque on the ring from both films is balanced. Follow the instructions below to generate the ring speed plot shown in Figure 3.

1D Plot Group 3

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

Global 1

1 Right-click **1D Plot Group 3** 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
`hdb.frb1.Omegar`	`rad/s`	`Ring speed, Bearing 1`
`hdb.frb2.Omegar`	`rad/s`	`Ring speed, Bearing 2`

4 In the **1D Plot Group 3** toolbar, click **Plot**.

Ring Speed

1 In the **Model Builder** window, under **Results** click **1D Plot Group 3**.

2 In the **Settings** window for **1D Plot Group**, type `Ring Speed` in the **Label** text field.

3 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

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

5 Click the **Go to Default View** button in the **Graphics** toolbar.

6 In the **Ring Speed** toolbar, click **Plot**.

It is also interesting to analyze the torque on the ring from both the films. Follow the instructions below to plot the ring torque shown in Figure 4.

Ring Torque

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

2 In the **Settings** window for **1D Plot Group**, type `Ring Torque` in the **Label** text field.

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

4 Locate the **Plot Settings** section.

5 Select the **y-axis label** check box. In the associated text field, type `Torque (N*m)`.

Global 1

1 Right-click **Ring Torque** 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>Fluid loads>Fluid moment on ring, inner film - N·m>hdb.frb2.Mr_inx - Fluid moment on ring, inner film, x-component**.

3 Click **Add Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Fluid loads>Fluid moment on ring, outer film - N·m>hdb.frb2.Mr_outx - Fluid moment on ring, outer film, x-component**.

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

Expression	Unit	Description
`hdb.frb2.Mrx`	`N*m`	`Moment on ring, x-component`

5 Click the **Go to Default View** button in the **Graphics** toolbar.

6 In the **Ring Torque** toolbar, click **Plot**.

7 Click **Plot**.

Use the following instructions to plot the orbit of the rotor within the ring as shown in Figure 5.

Rotor Orbit in Ring

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

2 In the **Settings** window for **1D Plot Group**, type `Rotor Orbit in Ring` in the **Label** text field.

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

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** check box. In the associated text field, type `Scaled y displacement`.

6 Select the **y-axis label** check box. In the associated text field, type `Scaled z displacement`.

Global 1

1 Right-click **Rotor Orbit in Ring** 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>Floating Ring Bearing 1>Displacement and velocity>Journal displacement relative to ring (scaled)>hdb.frb1.uJRz_rel - Journal displacement relative to ring (scaled), z-component**.

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

4 Click **Replace Expression** in the upper-right corner of the **x-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Floating Ring Bearing 1>Displacement and velocity>Journal displacement relative to ring (scaled)>hdb.frb1.uJRy_rel - Journal displacement relative to ring (scaled), y-component**.

5 Click to expand the **Legends** section. From the **Legends** list, choose **Manual**.

6 In the table, enter the following settings:

Legends
`Bearing 1`

7 Right-click **Global 1** and choose **Duplicate**.

Global 2

1 In the **Model Builder** window, click **Global 2**.

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>Floating Ring Bearing 2>Displacement and velocity>Journal displacement relative to ring (scaled)>hdb.frb2.uJRz_rel - Journal displacement relative to ring (scaled), z-component**.

3 Click **Replace Expression** in the upper-right corner of the **x-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Floating Ring Bearing 2>Displacement and velocity>Journal displacement relative to ring (scaled)>hdb.frb2.uJRy_rel - Journal displacement relative to ring (scaled), y-component**.

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

Legends
`Bearing 2`

5 Click the **Go to Default View** button in the **Graphics** toolbar.

6 In the **Rotor Orbit in Ring** toolbar, click **Plot**.

Use the following instructions to plot the orbit of the ring as shown in Figure 6.

Ring Orbit

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

2 In the **Settings** window for **1D Plot Group**, type `Ring Orbit` in the **Label** text field.

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

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** check box. In the associated text field, type `Scaled y displacement`.

6 Select the **y-axis label** check box. In the associated text field, type `Scaled z displacement`.

Global 1

1 Right-click **Ring Orbit** 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>Floating Ring Bearing 1>Displacement and velocity>Ring displacement relative to bearing (scaled)>hdb.frb1.uRBz_rel - Ring displacement relative to bearing (scaled), z-component**.

3 Click **Replace Expression** in the upper-right corner of the **x-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Floating Ring Bearing 1>Displacement and velocity>Ring displacement relative to bearing (scaled)>hdb.frb1.uRBy_rel - Ring displacement relative to bearing (scaled), y-component**.

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

5 Locate the **Legends** section. From the **Legends** list, choose **Manual**.

6 In the table, enter the following settings:

Legends
`Bearing 1`

7 Right-click **Global 1** and choose **Duplicate**.

Global 2

1 In the **Model Builder** window, click **Global 2**.

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>Floating Ring Bearing 2>Displacement and velocity> Ring displacement relative to bearing (scaled)>hdb.frb2.uRBz_rel - Ring displacement relative to bearing (scaled), z-component**.

3 Click **Replace Expression** in the upper-right corner of the **x-Axis Data** section. From the menu, choose **Component 1 (comp1)>Hydrodynamic Bearing>Floating Ring Bearing 2> Displacement and velocity>Ring displacement relative to bearing (scaled)> hdb.frb2.uRBy_rel - Ring displacement relative to bearing (scaled), y-component**.

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

Legends
`Bearing 2`

5 Click the Go to Default View button in the **Graphics** toolbar.

6 In the **Ring Orbit** toolbar, click **Plot**.

It is also interesting to analyze the flow through the channels in the ring. Use the following instructions to plot the flow rate from the first channel of both the rings as shown in Figure 7.

Flow rate in Channel

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

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

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

4 In the **Title** text area, type `Flow rate through channel 1`.

5 In the **Label** text field, type `Flow rate in Channel`.

6 Locate the **Plot Settings** section.

7 Select the **y-axis label** check box. In the associated text field, type `Flow Rate in Channel (kg/s)`.

Global 1

1 Right-click **Flow rate in Channel** 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
`hdb.frb1.Qi1`	`kg/s`	`Bearing 1`
`hdb.frb2.Qi1`	`kg/s`	`Bearing 2`

4 Click to expand the **Coloring and Style** section. From the **Width** list, choose **3**.

5 Click the **Go to Default View** button in the **Graphics** toolbar.

6 In the **Flow rate in Channel** toolbar, click **Plot**.

Finally generate the animation of the stress and pressure in the turbocharger.

Animation 1

1 In the **Results** toolbar, click **Animation** and choose **Player**.

2 In the **Settings** window for **Animation**, locate the **Scene** section.

3 From the **Subject** list, choose **Fluid Pressure (hdb)**.

4 Locate the **Frames** section. In the **Number of frames** text field, type `100`.

5 Click the **Play** button in the **Graphics** toolbar.

Fluid Pressure (hdb)

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

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

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