



Evaporator

Introduction

This model shows how to compute the film thickness deposited on a wafer from an evaporative source.

Model Definition

Gold is evaporated from a thermal source at a temperature of 2000 K onto a substrate held on a fixed surface. The deposited film thickness on the substrate and the chamber walls is computed. The model geometry is shown in [Figure 1](#).

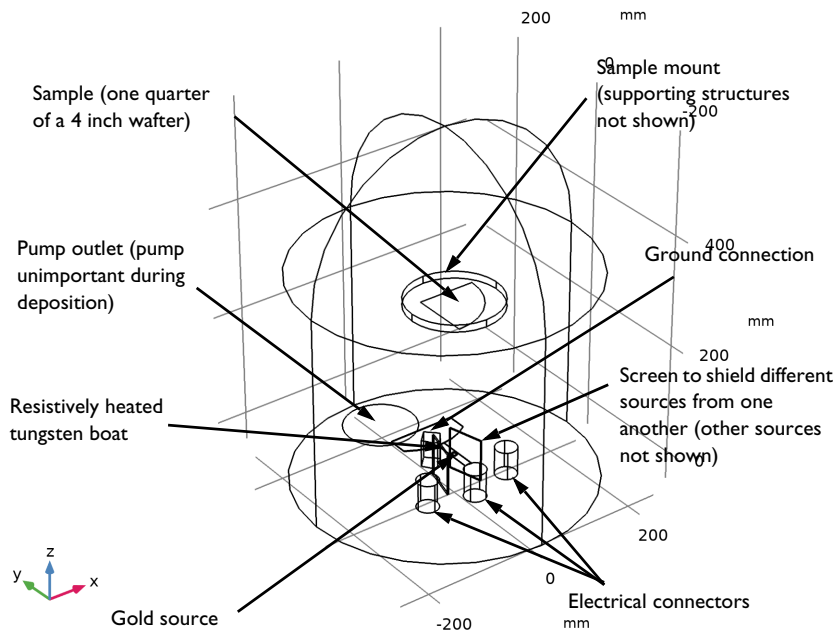


Figure 1: Model geometry. Various components of the evaporator are labeled.

Results and Discussion

[Figure 2](#) shows the flux of gold molecules on the surfaces of the model. This constant flux determines the thickness of gold deposited (shown in [Figure 3](#)). Only the flux is required

to compute the deposition rate, but in this instance, since most of the computational time is used to compute the view factors, solving the time-dependent problem adds little additional time to the solution process. Using a time-dependent model also allows for more advanced extensions of the model, for example, re-evaporation of gold from hot surfaces close to the evaporative source could be included.

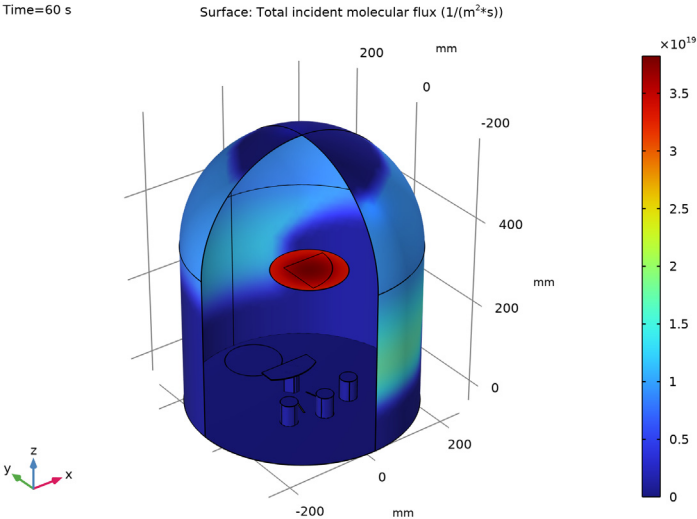


Figure 2: Molecular flux on the surfaces of the system, during deposition.

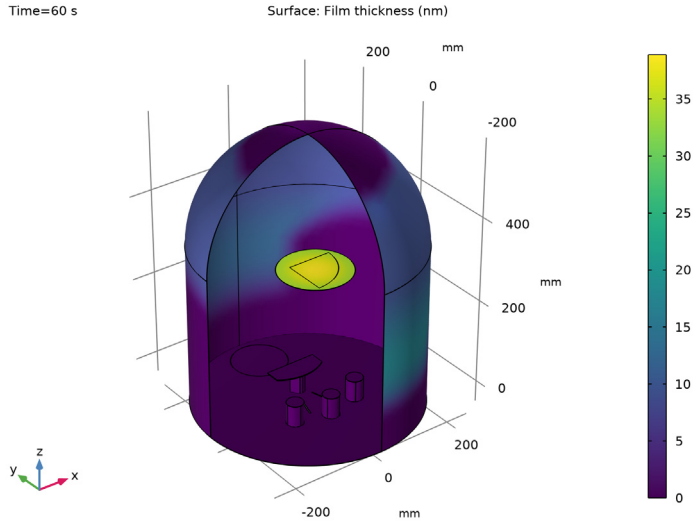


Figure 3: Film thickness on the surfaces of the system, after 60 s of deposition.

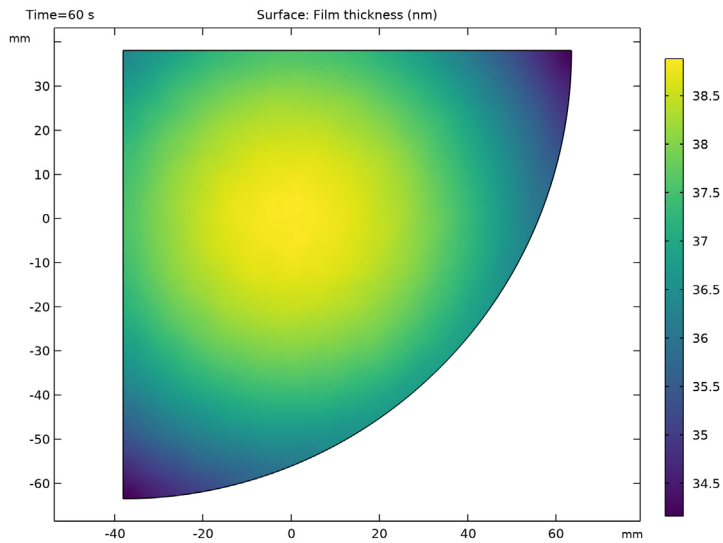


Figure 4: Film thickness on the sample, after 60 s of deposition.

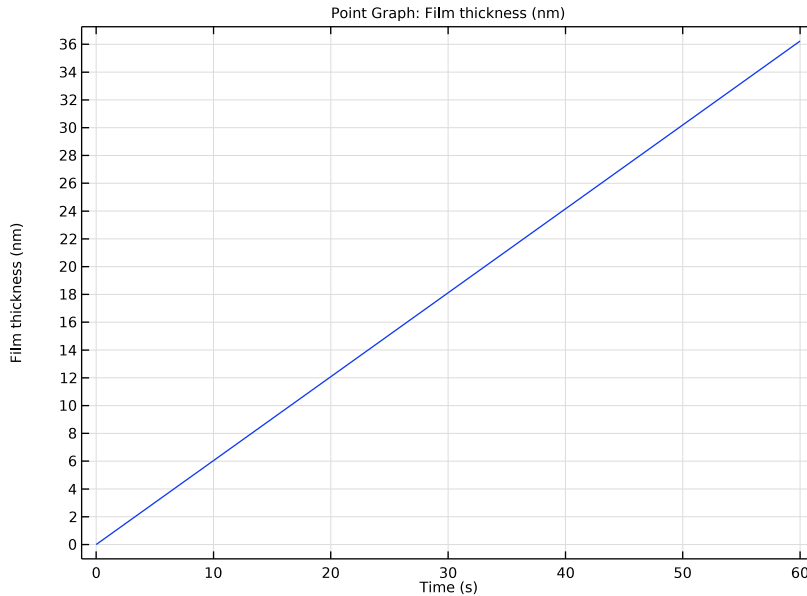


Figure 5: Film thickness vs time at a point on the corner of the sample.

The film thickness on the sample after 60 s of deposition is shown in Figure 4. The thickness varies between 34 nm and 39 nm across the sample, with radial symmetry about the midpoint of the source. As expected the film thickness at a point increases linearly with time, as shown in Figure 5.


Application Library path: Molecular_Flow_Module/Industrial_Applications/evaporator

Modeling Instructions




NOTE: This application requires at least 6 GB of RAM to run.

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 **Fluid Flow>Rarefied Flow>Free Molecular Flow (fmf)**.
- 3 Click **Add**.
- 4 Click  **Study**.
- 5 In the **Select Study** tree, select **General Studies>Time Dependent**.
- 6 Click  **Done**.

GEOMETRY I

Insert the prepared geometry sequence from file. You can read the instructions for creating the geometry in the appendix.

- 1 In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.
- 2 Browse to the model's Application Libraries folder and double-click the file `evaporator_geom_sequence.mph`.
- 3 In the **Geometry** toolbar, click  **Build All**.
- 4 Click the  **Wireframe Rendering** button in the **Graphics** toolbar.

In this model, wireframe rendering makes it easier to see inside the chamber.

GLOBAL DEFINITIONS

Parameters I

- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters I**.
- 2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
- 3 In the table, enter the following settings:


Name	Expression	Value	Description
Tamb	293.15[K]	293.15 K	Ambient temperature
Tevap	2000[K]	2000 K	Evaporation temperature
pvap	50[Pa]	50 Pa	Vapor pressure of gold
Mn0	197[g/mol]	0.197 kg/mol	Molecular weight of gold
rho0	19.3[g/cm ³]	19300 kg/m ³	Density of gold

DEFINITIONS


Boat

- 1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Definitions** and choose **Selections>Ball**.
- 2 In the **Settings** window for **Ball**, type **Boat** in the **Label** text field.
- 3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.
- 4 Locate the **Ball Radius** section. In the **Radius** text field, type 10.


All Boundaries

- 1 In the **Definitions** toolbar, click  **Explicit**.
- 2 In the **Settings** window for **Explicit**, type **All Boundaries** in the **Label** text field.
- 3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 Select the **All boundaries** check box.


Boat and Shields

- 1 In the **Definitions** toolbar, click  **Box**.
- 2 In the **Settings** window for **Box**, type **Boat** and **Shields** in the **Label** text field.
- 3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.
- 4 Locate the **Box Limits** section. In the **x minimum** text field, type -50.
- 5 In the **x maximum** text field, type 50.
- 6 In the **y minimum** text field, type -35.
- 7 In the **y maximum** text field, type 35.
- 8 In the **z minimum** text field, type -10.
- 9 In the **z maximum** text field, type 80.

Front Quadrant


- 1 In the **Definitions** toolbar, click  **Explicit**.
- 2 In the **Settings** window for **Explicit**, type **Front Quadrant** in the **Label** text field.
- 3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 Select **Boundaries 1** and **4** only.

Sample Mount Back

- 1 In the **Definitions** toolbar, click  **Explicit**.
- 2 In the **Settings** window for **Explicit**, type **Sample Mount Back** in the **Label** text field.
- 3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundaries 9, 10, 12, 44, and 52 only.

Deposition Surfaces

- 1 In the **Definitions** toolbar, click  **Difference**.
- 2 In the **Settings** window for **Difference**, type Deposition Surfaces in the **Label** text field.
- 3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.
- 4 Locate the **Input Entities** section. Under **Selections to add**, click **+ Add**.
- 5 In the **Add** dialog box, select **All Boundaries** in the **Selections to add** list.
- 6 Click **OK**.
- 7 In the **Settings** window for **Difference**, locate the **Input Entities** section.
- 8 Under **Selections to subtract**, click **+ Add**.
- 9 In the **Add** dialog box, in the **Selections to subtract** list, choose **Boat and Shields**, **Front Quadrant**, and **Sample Mount Back**.
- 10 Click **OK**.

Now set up the physics. Since the angular distribution is of particular interest in this model, increase the integration resolution to the maximum value to ensure the most accurate angular resolution when computing the flux.

FREE MOLECULAR FLOW (FMF)

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Free Molecular Flow (fmf)**.
- 2 In the **Settings** window for **Free Molecular Flow**, locate the **Integration Settings** section.
- 3 From the **Integration resolution** list, choose **4096**.
In this model the number density and pressure of the deposited species are of limited interest and will not be computed.
- 4 Locate the **Compute** section. Clear the **Number density** check box.
- 5 Clear the **Pressure** check box.

Molecular Flow I

- 1 In the **Model Builder** window, under **Component 1 (comp1)**>**Free Molecular Flow (fmf)** click **Molecular Flow I**.
- 2 In the **Settings** window for **Molecular Flow**, locate the **Molecular Weight of Species** section.
- 3 In the $M_{n,G}$ text field, type MnO.

Surface Temperature I


- 1 In the **Model Builder** window, click **Surface Temperature I**.

- 2 In the **Settings** window for **Surface Temperature**, locate the **Surface Temperature** section.
- 3 In the T text field, type T_{amb} .

Wall 1


- 1 In the **Model Builder** window, click **Wall 1**.
- 2 In the **Settings** window for **Wall**, locate the **Wall Type** section.
- 3 From the **Wall type** list, choose **Deposition**.
- 4 Locate the **Deposition** section. In the $\rho_{film,G}$ text field, type ρ_{Au} .

Evaporation 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Evaporation**.
- 2 Select Boundary 41 only.
- 3 In the **Settings** window for **Evaporation**, locate the **Evaporation** section.
- 4 In the $p_{vap,G}$ text field, type p_{vap} .

An additional **Surface Temperature** node is required to specify the temperature of the evaporating gold.

Surface Temperature 2

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Surface Temperature**.
- 2 In the **Settings** window for **Surface Temperature**, locate the **Boundary Selection** section.
- 3 From the **Selection** list, choose **Boat**.
- 4 Locate the **Surface Temperature** section. In the T text field, type T_{evap} .

MESH 1

Size 1

- 1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Boundary**.
- 4 From the **Selection** list, choose **Boat**.
- 5 Locate the **Element Size** section. From the **Predefined** list, choose **Extra fine**.

Size 2



- 1 In the **Model Builder** window, right-click **Mesh 1** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Boundary**.

- 4 From the **Selection** list, choose **Meshing 1**.
- 5 Locate the **Element Size** section. From the **Predefined** list, choose **Extra fine**.

Size 3


- 1 Right-click **Mesh 1** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Boundary**.
- 4 From the **Selection** list, choose **Meshing 2**.
- 5 Locate the **Element Size** section. From the **Predefined** list, choose **Extremely fine**.
- 6 Click the **Custom** button.
- 7 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.
- 8 In the associated text field, type 3.

Free Triangular 1

- 1 In the **Mesh** toolbar, click  **Boundary** 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, 6, 60).
- 4 In the **Home** toolbar, click  **Compute**.

RESULTS

Study 1/Solution 1 (sol1)

In the **Model Builder** window, expand the **Results>Datasets** node, then click **Study 1/Solution 1 (sol1)**.


Selection

- 1 In the **Results** toolbar, click  **Attributes** and choose **Selection**.
- 2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Boundary**.


- 4 From the **Selection** list, choose **Deposition Surfaces**.

Surface



When constant elements are used it is necessary to turn off the refinement in the postprocessing settings. This has been done automatically in the default plot, but in subsequent plots this setting will need to be changed manually.

- 1 In the **Model Builder** window, expand the **Results>Incident Molecular Flux (fmf)** node, then click **Surface**.
- 2 In the **Settings** window for **Surface**, click to expand the **Quality** section.
Note that the resolution is set to **No refinement**.
- 3 In the **Incident Molecular Flux (fmf)** toolbar, click  **Plot**.
Compare the resulting plot with that in [Figure 2](#).

Film Thickness

- 1 In the **Home** toolbar, click  **Add Plot Group** and choose **3D Plot Group**.
- 2 In the **Settings** window for **3D Plot Group**, type **Film Thickness** in the **Label** text field.


Surface 1

- 1 Right-click **Film Thickness** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Free Molecular Flow>Adsorbed/Deposited species>fmf.h_film_G - Film thickness - m**.
- 3 Locate the **Expression** section. From the **Unit** list, choose **nm**.
- 4 Locate the **Coloring and Style** section. From the **Color table** list, choose **Viridis**.
- 5 Locate the **Quality** section. From the **Resolution** list, choose **No refinement**.
- 6 In the **Film Thickness** toolbar, click  **Plot**.
Compare the resulting plot with that in [Figure 3](#).
- 7 In the **Results** toolbar, click  **More Datasets** and choose **Surface**.

Surface 1


- 1 In the **Settings** window for **Surface**, locate the **Selection** section.
- 2 From the **Selection** list, choose **Meshing 2**.
- 3 Locate the **Parameterization** section. From the **x- and y-axes** list, choose **XY-plane**.

Film Thickness on Sample


- 1 In the **Results** toolbar, click  **2D Plot Group**.

- 2 In the **Settings** window for **2D Plot Group**, type Film Thickness on Sample in the **Label** text field.


Surface 1

- 1 Right-click **Film Thickness on Sample** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **fmf.h_film_G - Film thickness - m**.
- 3 Locate the **Expression** section. From the **Unit** list, choose **nm**.
- 4 Locate the **Coloring and Style** section. From the **Color table** list, choose **Viridis**.
- 5 Click to expand the **Quality** section. From the **Resolution** list, choose **No refinement**.
- 6 In the **Film Thickness on Sample** toolbar, click  **Plot**.
Compare the resulting plot with that in [Figure 4](#).

Film Thickness vs. Time

- 1 In the **Home** toolbar, click  **Add Plot Group** and choose **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Film Thickness vs. Time in the **Label** text field.
- 3 Locate the **Plot Settings** section. Select the **x-axis label** check box.
- 4 In the associated text field, type Time (s).


Point Graph 1

- 1 Right-click **Film Thickness vs. Time** and choose **Point Graph**.
- 2 Select Point 19 only.
- 3 In the **Settings** window for **Point Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)> Free Molecular Flow>Adsorbed/Deposited species>fmf.h_film_G - Film thickness - m**.
- 4 Locate the **y-Axis Data** section. From the **Unit** list, choose **nm**.
- 5 In the **Film Thickness vs. Time** toolbar, click  **Plot**.
Compare the resulting plot with that in [Figure 5](#).

Appendix - Geometry Instructions

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

NEW

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


ADD COMPONENT

In the **Home** toolbar, click  **Add Component** and choose **3D**.


GEOMETRY 1

- 1 In the **Settings** window for **Geometry**, locate the **Units** section.
- 2 From the **Length unit** list, choose **mm**.


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 254.
- 4 In the **Height** text field, type 381.
- 5 Locate the **Position** section. In the **y** text field, type 25.4.
- 6 In the **z** text field, type -50.8.


Sphere 1 (sph1)

- 1 In the **Geometry** toolbar, click  **Sphere**.
- 2 In the **Settings** window for **Sphere**, locate the **Size** section.
- 3 In the **Radius** text field, type 254.
- 4 Locate the **Position** section. In the **y** text field, type 25.4.
- 5 In the **z** text field, type 330.2.


Union 1 (un1)

- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.
- 2 Click in the **Graphics** window and then press Ctrl+A to select both objects.
- 3 In the **Settings** window for **Union**, locate the **Union** section.
- 4 Clear the **Keep interior boundaries** check box.

Cylinder 2 (cyl2)



- 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 82.55.
- 4 In the **Height** text field, type 12.7.
- 5 Locate the **Position** section. In the **z** text field, type 279.4.

Cylinder 3 (cyl3)


- 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 19.05.
- 4 In the **Height** text field, type 50.8.
- 5 Locate the **Position** section. In the **x** text field, type -79.
- 6 In the **y** text field, type -34.8.
- 7 In the **z** text field, type -50.8.

Rotate 1 (rot1)

- 1 In the **Geometry** toolbar, click  **Transforms** and choose **Rotate**.
- 2 In the **Settings** window for **Rotate**, locate the **Input** section.
- 3 Select the **Keep input objects** check box.
- 4 Click the  **Wireframe Rendering** button in the **Graphics** toolbar.
- 5 Select the object **cyl3** only.
- 6 Locate the **Rotation** section. In the **Angle** text field, type range(0,30,60).
- 7 Locate the **Point on Axis of Rotation** section. In the **y** text field, type 102.03.

Block 1 (blk1)


- 1 In the **Geometry** toolbar, click  **Block**.
- 2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 2.54.
- 4 In the **Depth** text field, type 63.5.
- 5 In the **Height** text field, type 76.2.
- 6 Locate the **Position** section. In the **x** text field, type -34.5.
- 7 In the **y** text field, type -27.2.
- 8 In the **z** text field, type -50.8.
- 9 Locate the **Rotation Angle** section. In the **Rotation** text field, type -15.
- 10 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.
- 11 In the **New Cumulative Selection** dialog box, type Shield in the **Name** text field.
- 12 Click **OK**.

Mirror 1 (mir1)


- 1 In the **Geometry** toolbar, click  **Transforms** and choose **Mirror**.
- 2 In the **Settings** window for **Mirror**, locate the **Input** section.

- 3 From the **Input objects** list, choose **Shield**.
- 4 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. From the **Contribute to** list, choose **Shield**.
- 5 Locate the **Input** section. Select the **Keep input objects** check box.
- 6 Locate the **Normal Vector to Plane of Reflection** section. In the **x** text field, type 1.
- 7 In the **z** text field, type 0.


Block 2 (blk2)

- 1 In the **Geometry** toolbar, click  **Block**.
- 2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 12.7.
- 4 In the **Depth** text field, type 85.
- 5 In the **Height** text field, type 1.27.
- 6 Locate the **Position** section. In the **x** text field, type -6.35.
- 7 In the **y** text field, type -40.
- 8 In the **z** text field, type -1.27.


Sphere 2 (sph2)

- 1 In the **Geometry** toolbar, click  **Sphere**.
- 2 In the **Settings** window for **Sphere**, locate the **Size** section.
- 3 In the **Radius** text field, type 6.35.
- 4 Locate the **Position** section. In the **z** text field, type 2.54.

Copy 1 (copy1)


- 1 In the **Geometry** toolbar, click  **Transforms** and choose **Copy**.
- 2 Select the object **sph2** only.
- 3 In the **Settings** window for **Copy**, locate the **Displacement** section.
- 4 In the **z** text field, type 1.27.

Block 3 (blk3)



- 1 In the **Geometry** toolbar, click  **Block**.
- 2 In the **Settings** window for **Block**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 120.
- 4 In the **Depth** text field, type 34.35.
- 5 In the **Height** text field, type 1.27.

- 6 Locate the **Position** section. In the **x** text field, type -60.
- 7 In the **y** text field, type 55.2.
- 8 In the **z** text field, type -1.27.


Cylinder 4 (cyl4)

- 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 101.6.
- 4 In the **Height** text field, type 1.27.
- 5 Locate the **Position** section. In the **y** text field, type 137.2.
- 6 In the **z** text field, type -1.27.


Union 2 (uni2)

- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.
- 2 Select the objects **blk3** and **cyl4** only.
- 3 In the **Settings** window for **Union**, click  **Build Selected**.



Delete Entities 1 (del1)

- 1 In the **Geometry** toolbar, click  **Delete**.
- 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 On the object **uni2**, select Domains 1, 2, and 5 only.


Union 3 (uni3)

- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.
- 2 Select the objects **blk2** and **del1** only.
- 3 In the **Settings** window for **Union**, locate the **Union** section.
- 4 Clear the **Keep interior boundaries** check box.

Union 4 (uni4)


- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.
- 2 Select the objects **copy1**, **sph2**, and **uni3** only.
- 3 In the **Settings** window for **Union**, click  **Build Selected**.

Delete Entities 2 (del2)


- 1 In the **Geometry** toolbar, click  **Delete**.
- 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 On the object **uni4**, select Domains 2–4 and 7 only.

Union 5 (uni5)

- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.
- 2 Select the object **del2** only.
- 3 In the **Settings** window for **Union**, locate the **Union** section.
- 4 Clear the **Keep interior boundaries** check box.


Work Plane 1 (wp1)

- 1 In the **Geometry** toolbar, click  **Work Plane**.
- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 In the **z-coordinate** text field, type -1.27.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1)>Polygon 1 (pol1)

- 1 In the **Work Plane** toolbar, click  **Polygon**.
- 2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.
- 3 From the **Data source** list, choose **Vectors**.
- 4 In the **xw** text field, type -19.05 0 0 19.05 19.05 6.35 6.35 0 0 -6.35 -6.35 -19.05.
- 5 In the **yw** text field, type 63.5 82.55 82.55 63.5 63.5 45.55 45.55 44.45 44.45 45.54 45.54 63.5.

Extrude 1 (ext1)

- 1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** right-click **Work Plane 1 (wp1)** and choose **Extrude**.
- 2 In the **Settings** window for **Extrude**, locate the **Distances** section.
- 3 In the table, enter the following settings:

Distances (mm)
49.53

- 4 Select the **Reverse direction** check box.

Work Plane 2 (wp2)


- 1 In the **Geometry** toolbar, click  **Work Plane**.

- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 In the **z-coordinate** text field, type -50.8.

Work Plane 2 (wp2)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 2 (wp2)>Circle 1 (c1)

- 1 In the **Work Plane** toolbar, click  **Circle**.
- 2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.
- 3 In the **Radius** text field, type 63.5.
- 4 Locate the **Position** section. In the **yw** text field, type 203.2.

Work Plane 3 (wp3)


1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** right-click **Work Plane 2 (wp2)** and choose **Work Plane**.

- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 In the **z-coordinate** text field, type 279.4.

Work Plane 3 (wp3)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 3 (wp3)>Circle 1 (c1)


- 1 In the **Work Plane** toolbar, click  **Circle**.
- 2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.
- 3 In the **Radius** text field, type 101.6.
- 4 In the **Sector angle** text field, type 90.
- 5 Locate the **Position** section. In the **xw** text field, type -38.1.
- 6 In the **yw** text field, type 38.1.
- 7 Locate the **Rotation Angle** section. In the **Rotation** text field, type -90.

Difference 1 (dif1)



- 1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** right-click **Work Plane 3 (wp3)** and choose **Booleans and Partitions>Difference**.
- 2 Select the object **uni1** only.
- 3 In the **Settings** window for **Difference**, locate the **Difference** section.
- 4 Find the **Objects to subtract** subsection. Click to select the **Activate Selection** toggle button.

- 5 Select the objects **blk1**, **cyl2**, **cyl3**, **ext1**, **mir1**, **rot1(1)**, **rot1(2)**, **rot1(3)**, **uni5**, **wp2**, and **wp3** only.



Form Composite Faces 1 (cmf1)

- 1 In the **Geometry** toolbar, click  **Virtual Operations** and choose **Form Composite Faces**.
- 2 On the object **fin**, select Boundaries 34 and 36 only.


Form Composite Faces 2 (cmf2)

- 1 In the **Geometry** toolbar, click  **Virtual Operations** and choose **Form Composite Faces**.
- 2 On the object **cmf1**, select Boundary 1 only.
- 3 In the **Settings** window for **Form Composite Faces**, locate the **Input** section.
- 4 Click  **Clear Selection**.
- 5 On the object **cmf1**, select Boundaries 18, 19, 22, 23, 39, 40, and 60 only.


Form Composite Faces 3 (cmf3)

- 1 In the **Geometry** toolbar, click  **Virtual Operations** and choose **Form Composite Faces**.
- 2 On the object **cmf2**, select Boundary 1 only.
- 3 In the **Settings** window for **Form Composite Faces**, locate the **Input** section.
- 4 Click  **Clear Selection**.
- 5 On the object **cmf2**, select Boundaries 36 and 38 only.


Collapse Faces 1 (clf1)

- 1 In the **Geometry** toolbar, click  **Virtual Operations** and choose **Collapse Faces**.
- 2 On the object **cmf3**, select Boundaries 17 and 64 only.



Boat

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Ball Selection**.
- 2 In the **Settings** window for **Ball Selection**, locate the **Geometric Entity Level** section.
- 3 From the **Level** list, choose **Boundary**.
- 4 Locate the **Ball Radius** section. In the **Radius** text field, type 10.
- 5 In the **Label** text field, type Boat.



Geometry

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Geometry in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Object**.
- 4 Select the object **clf1** only.


All Boundaries

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Adjacent Selection**.
- 2 In the **Settings** window for **Adjacent Selection**, type All Boundaries in the **Label** text field.
- 3 Locate the **Input Entities** section. Click  **Add**.
- 4 In the **Add** dialog box, select **Geometry** in the **Input selections** list.
- 5 Click **OK**.
- 6 In the **Settings** window for **Adjacent Selection**, locate the **Output Entities** section.
- 7 Select the **Interior boundaries** check box.


Boat and Shields

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Union Selection**.
- 2 In the **Settings** window for **Union Selection**, locate the **Geometric Entity Level** section.
- 3 From the **Level** list, choose **Boundary**.
- 4 In the **Label** text field, type Boat and Shields.
- 5 Locate the **Input Entities** section. Click  **Add**.
- 6 In the **Add** dialog box, in the **Selections to add** list, choose **Shield** and **Boat**.
- 7 Click **OK**.




Front Quadrant

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Front Quadrant in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 On the object **clfl**, select Boundaries 1 and 4 only.


Sample Mount Back

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Sample Mount Back in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 Select the **Group by continuous tangent** check box.
- 5 On the object **clfl**, select Boundaries 9, 10, 12, 44, and 52 only.


Deposition Surfaces

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Difference Selection**.
- 2 In the **Settings** window for **Difference Selection**, type **Deposition Surfaces** in the **Label** text field.
- 3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.
- 4 Locate the **Input Entities** section. Click  **Add**.
- 5 In the **Add** dialog box, select **All Boundaries** in the **Selections to add** list.
- 6 Click **OK**.
- 7 In the **Settings** window for **Difference Selection**, locate the **Input Entities** section.
- 8 Click  **Add**.
- 9 In the **Add** dialog box, in the **Selections to subtract** list, choose **Boat and Shields**, **Front Quadrant**, and **Sample Mount Back**.
- 10 Click **OK**.

Meshing 1

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type **Meshing 1** in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 Select the **Group by continuous tangent** check box.
- 5 On the object **clf1**, select Boundaries 1, 2, 4, 5, 25, 42, 43, 49, 53, and 59 only.

Meshing 2

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type **Meshing 2** in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 On the object **clf1**, select Boundary 21 only.

