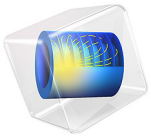


Model created in COMSOL Multiphysics 6.4

Magnetic Signature of a Submarine

Introduction

A vessel traveling on the surface or under water gives rise to detectable local disturbances in Earth's magnetic field. These disturbances can be used to trigger weapon systems. The magnetic signature of a ship can be reduced by generating a counteracting magnetic field of suitable strength and direction based on prior knowledge of the magnetic properties of the vessel. An important step in the design of a naval ship is therefore to predict its magnetic signature. Another application where magnetic signatures are of great importance is in urban traffic control: magnetic sensors, buried in our streets, are used to sense vehicles and control traffic lights.

Ships and cars are both to a large extent made of sheet metal. This makes them hard to simulate using standard finite element analysis because volume meshes of thin extended structures are difficult to generate and tend to become very large. This application demonstrates a powerful technique that circumvents the problem by modeling the sheet metal as 2D faces embedded in a 3D geometry. Thus it is only necessary to create comparatively inexpensive 2D face meshes in addition to the 3D volume mesh used for the surrounding medium. A tangential projection of the 3D equation is then solved on the 2D face mesh.

Figure 1: Submarine HMAS Collins. Image courtesy of Kockums AB.

This application also demonstrates the use of the *reduced field formulation* available in the AC/DC Module. This feature provides a convenient way to obtain the magnetic signature of the submarine by allowing the user to define the background field as a predefined quantity and solving only for the perturbations in this field.

In magnetostatic problems, where no currents are present, the problem can be solved using a scalar magnetic potential. This application demonstrates a special technique for modeling thin sheets of high-permeability materials and also shows the use of the reduced field formulation in the AC/DC Module for conveniently modeling perturbations in a known background field.

The model geometry is shown in Figure 2 and consists of face objects representing the submarine. The submarine geometry is based on the BeTSSi (Benchmark Target Echo Strength Simulation) benchmark submarine, as shown in Ref. 1 and Ref. 2, and does not represent a specific submarine class. A 3D box representing the surrounding water encloses the vessel (not shown).

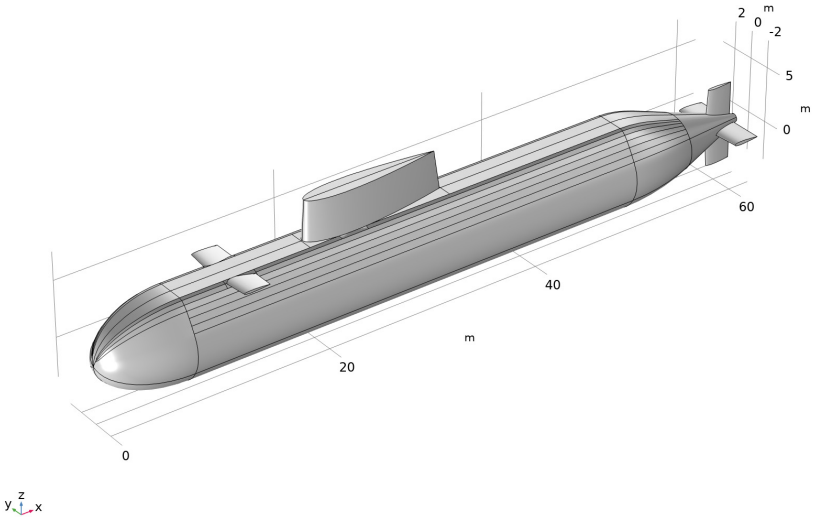


Figure 2: The model geometry based on the BeTSSi submarine geometry.

DOMAIN EQUATIONS

In a current-free region, where

$$\nabla \times \mathbf{H} = \mathbf{0}$$

it is possible to define the scalar magnetic potential, V_{m}, from the relation

$$\mathbf{H} = -\nabla V_m$$

This is analogous to the definition of the electric potential for static electric fields. Using the constitutive relation between the magnetic flux density and magnetic field

$$\mathbf{B} = \mu_0 \mu_r \mathbf{H}$$

together with the equation

$$\nabla \cdot \mathbf{B} = 0$$

an equation for V_m can be derived,

$$-\nabla \cdot (\mu_0 \mu_r \nabla V_m) = 0$$

In this model, you use the reduced field formulation, which means that you only solve for the potential V_m corresponding to the perturbation (reduced) field, so the equation you solve reads as

$$-\nabla \cdot (\mu_0 \mu_r \nabla V_m + \mathbf{B}_{ext}) = 0$$

where $\mathbf{B}_{ext}$ is a known background field, in this case, Earth's magnetic field of 0.5 G.

Boundary Conditions

The exterior boundaries of the box are insulating for the reduced magnetic field:

$$-\mathbf{n} \cdot \mathbf{B}_{red} = 0$$

On the face objects representing the hull of the submarine, you apply a 2D tangential projection of the 3D domain equation where the thickness and permeability of the hull are introduced as parameters. This is readily available in the used formulation as a shielding boundary condition, which is useful for modeling highly permeable thin sheets. Corresponding boundary conditions are available in the Electric Currents and Electrostatics interfaces for modeling of thin sheets with high conductance and high permittivity, respectively.

Results and Discussion

Figure 3 shows the total magnetic flux density in a horizontal slice plot 30 m below the submarine. A distinct field perturbation due to the presence of the vessel can be seen. The magnitude of the tangential magnetic field on the hull of the vessel is shown using contour lines. The reduced field is visualized as a streamline of the reduced magnetic potential

surrounding the submarine. This gives a good picture of the perturbation caused by the presence of the submarine in the background field.

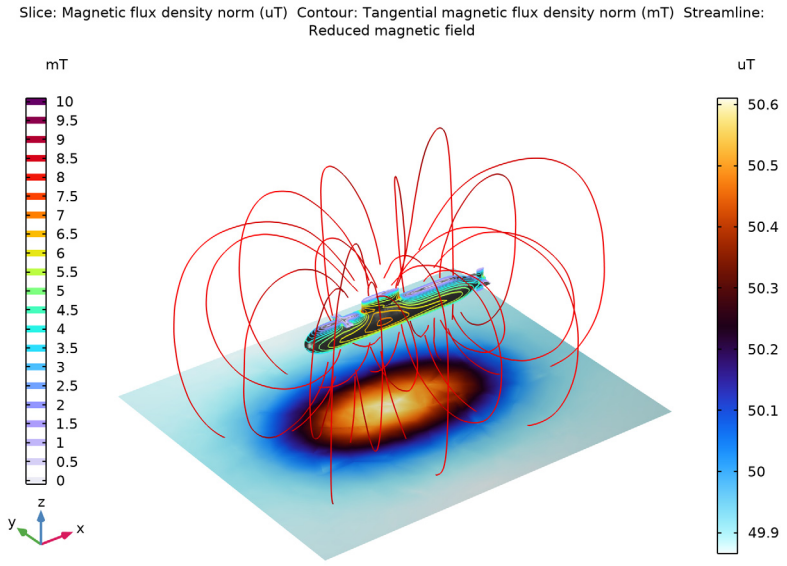


Figure 3: The slice color plot shows the total magnetic flux density (right color legend, uT). The contours on the submarine show the strength of the tangential magnetic field in the hull (left color legend, mT). The red streamlines show the reduced magnetic field.

Notes About the COMSOL Implementation

The model uses an MPHBIN-file as the starting geometry. It is possible to generate this geometry using COMSOL functionality. The instructions to do so are covered in the Appendix — Geometry Modeling Instructions. Due to the complexity of the geometry and the use of **Cap Face** operations, the generation of the geometry requires the *CAD Import Module* and the *Design Module*. The steps and operations for building the geometry include some geometry information like parameters, coordinates, and curve parameterizations, found in Appendix C of Ref. 2. The steps for building the geometry, using the COMSOL Geometry operations, do differ in some aspects from those in Ref. 2.

References

1. B. Nolte, I. Schäfer, C. de Jong, and L. Gilroy, "BeTSSi II benchmark on target strength simulation," *Proceedings of Forum Acusticum*, 2014.

2. J.V. Venås and T. Kvamsdal, "Isogeometric boundary element method for acoustic scattering by a submarine," *Comp. Meth. Appl. Mech. Eng.*, vol. 359, p. 112670, 2020, doi.org/10.1016/j.cma.2019.112670.

Application Library path: `ACDC_Module/Introductory_Magnetostatics/magnetic_signature_submarine`

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 **AC/DC** > **Magnetic Fields, No Currents** > **Magnetic Fields, No Currents (mfnc)**.

3 Click **Add**.

4 Click **Study**.

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

6 Click **Done**.

GLOBAL DEFINITIONS

Define a parameter for the strength of the geomagnetic field and the dimensions of the water domain surrounding the submarine.

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
gB	-5e-5[T]	-5E-5 T	Geomagnetic field

Name	Expression	Value	Description
dw	100[m]	100 m	Water domain width
dl	120[m]	120 m	Water domain length

GEOMETRY 1

The model uses an external geometry file with the submarine geometry added to a water domain.

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 `dl`.

4 In the **Depth** text field, type `dw`.

5 In the **Height** text field, type `dw`.

6 Locate the **Position** section. From the **Base** list, choose **Center**.

7 In the **x** text field, type `dl/4`.

8 In the **Model Builder** window, click **Geometry 1**.

9 In the **Settings** window for **Geometry**, locate the **Cleanup** section.

10 Clear the **Automatic detection of small details** checkbox.

Import 1 (imp1)

1 In the **Home** toolbar, click **Import**.

2 In the **Settings** window for **Import**, locate the **Source** section.

3 Click **Browse**.

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

5 Click **Import**.

DEFINITIONS

Submarine

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

For later use, define a boundary selection that corresponds to the submarine hull.

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

3 From the **Output entities** list, choose **Adjacent boundaries**.

4 Select Domain 2 only.

5 In the **Label** text field, type `Submarine`.

GEOMETRY 1

Form Union (fin)

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

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

3 Click the **Wireframe Rendering** button in the **Graphics** toolbar.

MATERIALS

Domain Material

1 In the **Materials** toolbar, click **Blank Material**.

2 In the **Settings** window for **Material**, type `Domain Material` in the **Label** text field.

3 Click to expand the **Material Properties** section. In the **Material properties** tree, select **Basic Properties** > **Relative Permeability**.

4 Click **Add to Material**.

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

Property	Variable	Value	Unit	Property group
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	I	Basic

Hull Metal

1 In the **Model Builder** window, right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Hull Metal` in the **Label** text field.

Select the boundary selection named as **Submarine** as defined earlier.

3 Locate the **Geometric Entity Selection** section. From the **Geometric entity level** list, choose **Boundary**.

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

5 Locate the **Material Properties** section. In the **Material properties** tree, select **Basic Properties** > **Relative Permeability**.

6 Click **Add to Material**.

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

Property	Variable	Value	Unit	Property group
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	700	1	Basic

MAGNETIC FIELDS, NO CURRENTS (MFNC)

Apply a background magnetic field corresponding to Earth's geomagnetic field.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Magnetic Fields, No Currents (mfnc)**.

2 In the **Settings** window for **Magnetic Fields, No Currents**, locate the **Background Magnetic Field** section.

3 From the **Solve for** list, choose **Reduced field**.

4 Specify the $\mathbf{H}_b$ vector as

0	x
0	y
gB/mu0_const	z

The **External Magnetic Flux Density** feature imposes boundary conditions matching the specified background field.

External Magnetic Flux Density 1

1 In the **Physics** toolbar, click **Boundaries** and choose **External Magnetic Flux Density**.

2 In the **Settings** window for **External Magnetic Flux Density**, locate the **Boundary Selection** section.

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

Zero Magnetic Scalar Potential 1

1 In the **Physics** toolbar, click **Points** and choose **Zero Magnetic Scalar Potential**.

2 Select Point 3 only.

The **Magnetic Shielding** feature models a thin layer of high-permeability material, such as the metal constituting the submarine hull.

Magnetic Shielding 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Magnetic Shielding**.

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

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

4 Locate the **Magnetic Shielding** section. In the d_s text field, type `0.05`.

5 Click the **Wireframe Rendering** button in the **Graphics** toolbar.

Hide the boundaries of the water domain to show only the submarine.

6 Click the **Click and Hide** button in the **Graphics** toolbar.

7 In the **Graphics** window toolbar, click next to **Select Boundaries**, then choose **Select Boundaries**.

8 Select the exterior boundaries of the box (Boundaries 1, 2, and 4).

9 Click the **Click and Hide** button in the **Graphics** toolbar.

MESH 1

The default mesh settings will adequately resolve the region around the submarine hull.

Information

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Build All**.

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

STUDY 1

Disable the automatic generation of default plots. Instead, you will create a custom plot when the solver has finished.

1 In the **Settings** window for **Study**, locate the **Study Settings** section.

2 Clear the **Generate default plots** checkbox.

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

RESULTS

3D Plot Group 1

1 In the **Model Builder** window, expand the **Results** node.

2 Right-click **Results** and choose **3D Plot Group**.

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

4 Select the **Show units** checkbox.

5 Locate the **Plot Settings** section. Clear the **Plot dataset edges** checkbox.

First, create a slice plot to visualize the magnetic signature of the submarine 30 m away.

Slice 1

1 Right-click **3D Plot Group 1** and choose **Slice**.

2 In the **Settings** window for **Slice**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Magnetic Fields, No Currents** > **Magnetic** > **mfnc.normB - Magnetic flux density norm - T**.

3 Locate the **Expression** section. In the **Unit** field, type `uT`.

4 Locate the **Plane Data** section. From the **Plane** list, choose **xy-planes**.

5 From the **Entry method** list, choose **Coordinates**.

6 In the **z-coordinates** text field, type `-30`.

7 Locate the **Coloring and Style** section. From the **Color table** list, choose **ThermalWaveDark**.

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

3D Plot Group 1

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

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

3 From the **Position** list, choose **Alternating**.

The submarine can be represented by adding a material appearance to the surface.

Surface 1

1 Right-click **3D Plot Group 1** and choose **Surface**.

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

3 In the **Expression** text field, type `1`.

Selection 1

1 Right-click **Surface 1** and choose **Selection**.

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

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

Surface 1

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

2 In the **Settings** window for **Surface**, click to expand the **Title** section.

3 From the **Title type** list, choose **None**.

Material Appearance 1

1 Right-click **Surface 1** and choose **Material Appearance**.

2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.

3 From the **Appearance** list, choose **Custom**.

4 From the **Material type** list, choose **Iron (scratched)**.

3D Plot Group 1

Next, plot the tangential magnetic flux density across the hull of the submarine.

Contour 1

1 In the **Model Builder** window, right-click **3D Plot Group 1** and choose **Contour**.

2 In the **Settings** window for **Contour**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Magnetic Fields, No Currents** > **Magnetic** > **mfnc.normtB - Tangential magnetic flux density norm - T**.

3 Locate the **Levels** section. From the **Entry method** list, choose **Levels**.

4 In the **Levels** text field, type `range(0,0.5,10)`.

5 Locate the **Expression** section. From the **Unit** list, choose **mT**.

6 Locate the **Coloring and Style** section. From the **Color table** list, choose **Prism**.

3D Plot Group 1

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

Streamline 1

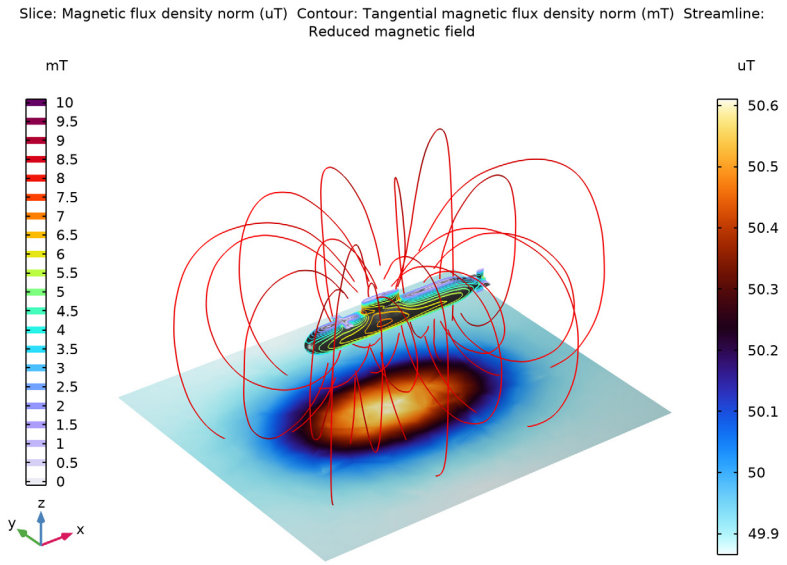
1 In the **3D Plot Group 1** toolbar, click **Streamline**.

2 In the **Settings** window for **Streamline**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)** > **Magnetic Fields, No Currents** > **Magnetic** > **mfnc.redHx,...,mfnc.redHz - Reduced magnetic field**.

3 Locate the **Streamline Positioning** section. From the **Positioning** list, choose **Magnitude controlled**.

4 Click the **Show Grid** button in the **Graphics** toolbar.

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



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

To visualize the perturbation of the background magnetic field, we can plot the scalar magnetic potential using the previous plot as a starting point.

3D Plot Group 2

1 Right-click **3D Plot Group 1** and choose **Duplicate**.

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

3 Click the **Orthographic Projection** button in the **Graphics** toolbar.

Slice 1

1 In the **Model Builder** window, expand the **3D Plot Group 2** node, then click **Slice 1**.

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

3 In the **Expression** text field, type `Vm`.

4 Locate the **Plane Data** section. From the **Plane** list, choose **zx-planes**.

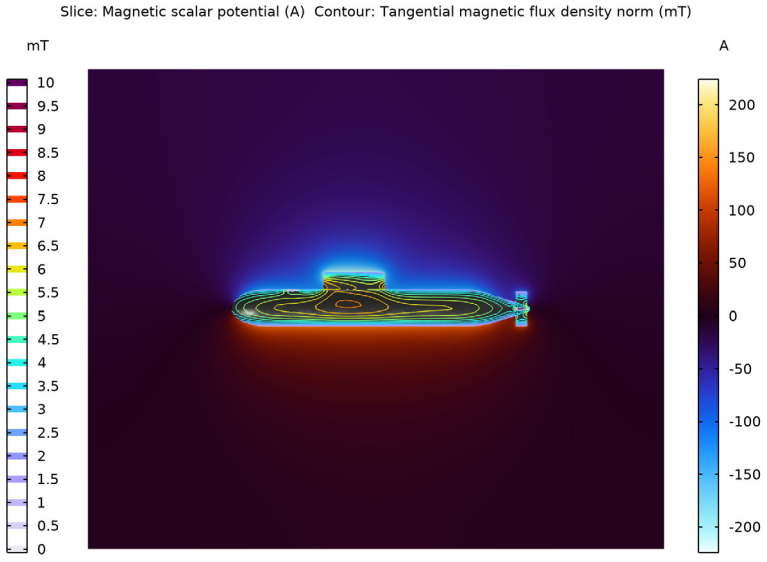
5 In the **Planes** text field, type `1`.

6 Locate the **Coloring and Style** section. From the **Scale** list, choose **Linear symmetric**.

Streamline 1

1 In the **Model Builder** window, right-click **Streamline 1** and choose **Disable**.

2 In the **3D Plot Group 2** toolbar, click **Plot**.



The plot shows the effect of the submarine's hull on the geomagnetic field.

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 Click **Done**.

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Advanced** section.

3 From the **Geometry representation** list, choose **CAD kernel**.

Disable the analysis of the geometry as the remaining small geometric details can be kept.

4 Locate the **Cleanup** section. Clear the **Automatic detection of small details** checkbox.

GLOBAL DEFINITIONS

Geometry Parameters

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 `magnetic_signature_submarine_geom_sequence_parameters.txt`.

5 In the **Label** text field, type `Geometry Parameters`.

GEOMETRY 1

Work Plane 1 (wp1)

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

Work Plane 1 (wp1) > Plane Geometry

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

Work Plane 1 (wp1) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `b`.

5 In the **b-semiaxis** text field, type `a`.

6 In the **Sector angle** text field, type `90`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Locate the **Rotation Angle** section. In the **Rotation** text field, type `90`.

9 Click **Build Selected**.

Work Plane 1 (wp1) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 On the object **e1**, select Point 1 only.

3 In the **Settings** window for **Line Segment**, locate the **Endpoint** section.

4 From the **Specify** list, choose **Coordinates**.

5 In the **xw** text field, type `a+L`.

6 In the **yw** text field, type `b`.

7 Click **Build Selected**.

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

Work Plane 1 (wp1) > Circle 1 (c1)

1 In the **Work Plane** toolbar, click **Circle**.

2 In the **Settings** window for **Circle**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **Radius** text field, type `g2/sin(alpha)`.

5 In the **Sector angle** text field, type `alpha`.

6 Locate the **Position** section. In the **xw** text field, type `a+L`.

7 In the **yw** text field, type `b-g2/sin(alpha)`.

8 Locate the **Rotation Angle** section. In the **Rotation** text field, type `90-alpha`.

9 Click **Build Selected**.

Work Plane 1 (wp1) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 On the object **c1**, select Point 1 only.

3 In the **Settings** window for **Line Segment**, locate the **Endpoint** section.

4 From the **Specify** list, choose **Coordinates**.

5 In the **xw** text field, type `a+L+g2+g3`.

6 In the **yw** text field, type `(b-(1-cos(alpha))*g2/sin(alpha))-g3*tan(alpha)`.

7 Click **Build Selected**.

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

Work Plane 1 (wp1) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **c1**, select Boundaries 2 and 3 only.

3 On the object **e1**, select Boundaries 2 and 3 only.

4 In the **Work Plane** toolbar, click **Build All**.

Revolve 1 (rev1)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 1 (wp1)** and choose **Revolve**.

2 In the **Settings** window for **Revolve**, locate the **Revolution Angles** section.

3 Click the **Angles** button.

4 In the **Start angle** text field, type `60[deg]`.

5 In the **End angle** text field, type `180[deg]`.

6 Locate the **Revolution Axis** section. Find the **Direction of revolution axis** subsection. In the **xw** text field, type `1`.

7 In the **yw** text field, type `0`.

8 Click **Build Selected**.

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 From the **Plane** list, choose **zy-plane**.

4 In the **x-coordinate** text field, type `a`.

5 Click **Build Selected**.

Work Plane 2 (wp2) > Plane Geometry

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

Work Plane 2 (wp2) > Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Object Type** section.

3 From the **Type** list, choose **Open curve**.

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

xw (m)	yw (m)
0	c_deck
s_deck	c_deck
-(-sin(theta)*b+s_deck)/6+s_deck	c_deck-(p_a*((-sin(theta)*b+s_deck)/6)^3+p_b*((-sin(theta)*b+s_deck)/6)^2)
-(-sin(theta)*b+s_deck)*2/6+s_deck	c_deck-(p_a*((-sin(theta)*b+s_deck)*2/6)^3+p_b*((-sin(theta)*b+s_deck)*2/6)^2)
-(-sin(theta)*b+1.2[m])*3/6+s_deck	c_deck-(p_a*((-sin(theta)*b+s_deck)*3/6)^3+p_b*((-sin(theta)*b+s_deck)*3/6)^2)
-(-sin(theta)*b+1.2[m])*4/6+s_deck	c_deck-(p_a*((-sin(theta)*b+s_deck)*4/6)^3+p_b*((-sin(theta)*b+s_deck)*4/6)^2)
-(-sin(theta)*b+1.2[m])*5/6+s_deck	c_deck-(p_a*((-sin(theta)*b+s_deck)*5/6)^3+p_b*((-sin(theta)*b+s_deck)*5/6)^2)
-(-sin(theta)*b+1.2[m])*6/6+s_deck	c_deck-(p_a*((-sin(theta)*b+s_deck)*6/6)^3+p_b*((-sin(theta)*b+s_deck)*6/6)^2)

5 Click **Build Selected**.

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

Extrude 1 (ext1)

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

2 In the **Settings** window for **Extrude**, locate the **Distances** section.

3 In the table, enter the following settings:

Distances (m)
L

4 Select the **Reverse direction** checkbox.

5 Click **Build Selected**.

Work Plane 3 (wp3)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **y** to `cos(theta)`.

5 In row **Point 3**, set **z** to `sin(theta)`.

Work Plane 3 (wp3) > Plane Geometry

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

Work Plane 3 (wp3) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L+g2`.

5 In the **yw** text field, type `(b-(1-cos(alpha))*g2/sin(alpha))`.

6 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

7 In the **xw** text field, type `a+L+g2+g3`.

8 In the **yw** text field, type `(b-(1-cos(alpha))*g2/sin(alpha))-g3*tan(alpha)`.

9 Click **Build Selected**.

Revolve 2 (rev2)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 3 (wp3)** and choose **Revolve**.

2 In the **Settings** window for **Revolve**, locate the **Revolution Angles** section.

3 Click the **Angles** button.

4 In the **End angle** text field, type `-60`.

5 Locate the **Revolution Axis** section. Find the **Direction of revolution axis** subsection. In the **xw** text field, type `1`.

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

7 Click **Build Selected**.

Work Plane 4 (wp4)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **x** to `7`.

5 In row **Point 3**, set **y** to `c_deck`.

6 In row **Point 3**, set **z** to `s_deck`.

7 Click **Build Selected**.

Work Plane 4 (wp4) > Plane Geometry

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

Work Plane 4 (wp4) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `sqrt(c_deck^2+s_deck^2)`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 4 (wp4) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
`a+L-0.1[m]`	`sqrt(c_deck^2+s_deck^2)`
`a+L`	`sqrt(c_deck^2+s_deck^2)`
`a+L+g2`	`(b-(1-cos(alpha))*g2/sin(alpha))`
`a+L+g2+0.1[m]`	`(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)`

4 Click **Build Selected**.

Work Plane 4 (wp4) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 4 (wp4) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L+g2`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L+g2`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 4 (wp4) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 4 (wp4) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 4 (wp4)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 4 (wp4)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 5 (wp5)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **x** to 7.

5 In row **Point 3**, set **y** to `c_deck-(p_a*((-sin(theta)*b+s_deck)/6)^3+p_b*((-sin(theta)*b+s_deck)/6)^2)`.

6 In row **Point 3**, set **z** to `-(-sin(theta)*b+s_deck)/6+s_deck`.

7 Click **Build Selected**.

Work Plane 5 (wp5) > Plane Geometry

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

Work Plane 5 (wp5) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)/6)^3+p_b*((-sin(theta)*b+s_deck)/6)^2))^2+(-(-sin(theta)*b+s_deck)/6+s_deck)^2)`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 5 (wp5) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
`a+L-0.1[m]`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)/6)^3+p_b*((-sin(theta)*b+s_deck)/6)^2))^2+(-(-sin(theta)*b+s_deck)/6+s_deck)^2)`
`a+L`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)/6)^3+p_b*((-sin(theta)*b+s_deck)/6)^2))^2+(-(-sin(theta)*b+s_deck)/6+s_deck)^2)`
`a+L+g2`	`(b-(1-cos(alpha))*g2/sin(alpha))`
`a+L+g2+0.1[m]`	`(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)`

4 Click **Build Selected**.

Work Plane 5 (wp5) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 5 (wp5) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L+g2`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L+g2`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 5 (wp5) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 5 (wp5) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 5 (wp5)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 5 (wp5)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 6 (wp6)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **x** to 7.

5 In row **Point 3**, set **y** to `c_deck-(p_a*((-sin(theta)*b+s_deck)*2/6)^3+p_b*((-sin(theta)*b+s_deck)*2/6)^2)`.

6 In row **Point 3**, set **z** to `-(-sin(theta)*b+s_deck)*2/6+s_deck`.

7 Click **Build Selected**.

Work Plane 6 (wp6) > Plane Geometry

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

Work Plane 6 (wp6) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*2/6)^3+p_b*((-sin(theta)*b+s_deck)*2/6)^2))^2+(-(-sin(theta)*b+s_deck)*2/6+s_deck)^2)`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 6 (wp6) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
`a+L-0.1[m]`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*2/6)^3+p_b*((-sin(theta)*b+s_deck)*2/6)^2))^2+(-(-sin(theta)*b+s_deck)*2/6+s_deck)^2)`
`a+L`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*2/6)^3+p_b*((-sin(theta)*b+s_deck)*2/6)^2))^2+(-(-sin(theta)*b+s_deck)*2/6+s_deck)^2)`
`a+L+g2`	`(b-(1-cos(alpha))*g2/sin(alpha))`
`a+L+g2+0.1[m]`	`(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)`

4 Click **Build Selected**.

Work Plane 6 (wp6) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 6 (wp6) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L+g2`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L+g2`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 6 (wp6) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 6 (wp6) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 6 (wp6)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 6 (wp6)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 7 (wp7)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **x** to `7`.

5 In row **Point 3**, set **y** to `c_deck-(p_a*((-sin(theta)*b+s_deck)*3/6)^3+p_b*((-sin(theta)*b+s_deck)*3/6)^2)`.

6 In row **Point 3**, set **z** to `-(-sin(theta)*b+s_deck)*3/6+s_deck`.

7 Click **Build Selected**.

Work Plane 7 (wp7) > Plane Geometry

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

Work Plane 7 (wp7) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*3/6)^3+p_b*((-sin(theta)*b+s_deck)*3/6)^2))^2+(-(-sin(theta)*b+s_deck)*3/6+s_deck)^2)`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 7 (wp7) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
`a+L-0.1[m]`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*3/6)^3+p_b*((-sin(theta)*b+s_deck)*3/6)^2))^2+(-(-sin(theta)*b+s_deck)*3/6+s_deck)^2)`
`a+L`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*3/6)^3+p_b*((-sin(theta)*b+s_deck)*3/6)^2))^2+(-(-sin(theta)*b+s_deck)*3/6+s_deck)^2)`

xw (m)	yw (m)
a+L+g2	(b-(1-cos(alpha))*g2/sin(alpha))
a+L+g2+0.1[m]	(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)

4 Click **Build Selected**.

Work Plane 7 (wp7) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 7 (wp7) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L+g2`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L+g2`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 7 (wp7) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 7 (wp7) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 7 (wp7)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 7 (wp7)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 8 (wp8)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **x** to 7.

5 In row **Point 3**, set **y** to `c_deck-(p_a*((-sin(theta)*b+s_deck)*4/6)^3+p_b*((-sin(theta)*b+s_deck)*4/6)^2)`.

6 In row **Point 3**, set **z** to `-(-sin(theta)*b+s_deck)*4/6+s_deck`.

7 Click **Build Selected**.

Work Plane 8 (wp8) > Plane Geometry

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

Work Plane 8 (wp8) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*4/6)^3+p_b*((-sin(theta)*b+s_deck)*4/6)^2))^2+(-(-sin(theta)*b+s_deck)*4/6+s_deck)^2)`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 8 (wp8) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
a+L-0.1[m]	sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*4/6)^3+p_b*((-sin(theta)*b+s_deck)*4/6)^2))^2+(-(-sin(theta)*b+s_deck)*4/6+s_deck)^2)
a+L	sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*4/6)^3+p_b*((-sin(theta)*b+s_deck)*4/6)^2))^2+(-(-sin(theta)*b+s_deck)*4/6+s_deck)^2)
a+L+g2	(b-(1-cos(alpha))*g2/sin(alpha))
a+L+g2+0.1[m]	(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)

4 Click **Build Selected**.

Work Plane 8 (wp8) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type a+L.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type a+L.

7 In the **yw** text field, type c_deck+s_deck.

8 Click **Build Selected**.

Work Plane 8 (wp8) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type a+L+g2.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type a+L+g2.

7 In the **yw** text field, type c_deck+s_deck.

8 Click **Build Selected**.

Work Plane 8 (wp8) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 8 (wp8) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 8 (wp8)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 8 (wp8)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 9 (wp9)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane type** list, choose **Coordinates**.

4 In row **Point 3**, set **x** to `7`.

5 In row **Point 3**, set **y** to `c_deck-(p_a*((-sin(theta)*b+s_deck)*5/6)^3+p_b*((-sin(theta)*b+s_deck)*5/6)^2)`.

6 In row **Point 3**, set **z** to `-(-sin(theta)*b+s_deck)*5/6+s_deck`.

7 Click **Build Selected**.

Work Plane 9 (wp9) > Plane Geometry

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

Work Plane 9 (wp9) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*5/6)^3+p_b*((-sin(theta)*b+s_deck)*5/6)^2))^2+(-(-sin(theta)*b+s_deck)*5/6+s_deck)^2)`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 9 (wp9) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
`a+L-0.1[m]`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*5/6)^3+p_b*((-sin(theta)*b+s_deck)*5/6)^2))^2+(-(-sin(theta)*b+s_deck)*5/6+s_deck)^2)`
`a+L`	`sqrt((c_deck-(p_a*((-sin(theta)*b+s_deck)*5/6)^3+p_b*((-sin(theta)*b+s_deck)*5/6)^2))^2+(-(-sin(theta)*b+s_deck)*5/6+s_deck)^2)`
`a+L+g2`	`(b-(1-cos(alpha))*g2/sin(alpha))`
`a+L+g2+0.1[m]`	`(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)`

4 Click **Build Selected**.

Work Plane 9 (wp9) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 9 (wp9) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type `a+L+g2`.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type `a+L+g2`.

7 In the **yw** text field, type `c_deck+s_deck`.

8 Click **Build Selected**.

Work Plane 9 (wp9) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 9 (wp9) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 9 (wp9)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 9 (wp9)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 10 (wp10)

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

Work Plane 10 (wp10) > Plane Geometry

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

Work Plane 10 (wp10) > Ellipse 1 (e1)

1 In the **Work Plane** toolbar, click **Ellipse**.

2 In the **Settings** window for **Ellipse**, locate the **Object Type** section.

3 From the **Type** list, choose **Curve**.

4 Locate the **Size and Shape** section. In the **a-semiaxis** text field, type `a`.

5 In the **b-semiaxis** text field, type `c_deck`.

6 In the **Sector angle** text field, type `180`.

7 Locate the **Position** section. In the **xw** text field, type `a`.

8 Click **Build Selected**.

Work Plane 10 (wp10) > Interpolation Curve 1 (ic1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Interpolation Curve**.

2 In the **Settings** window for **Interpolation Curve**, locate the **Interpolation Points** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
a+L-0.1[m]	c_deck
a+L	c_deck
a+L+g2	(b-(1-cos(alpha))*g2/sin(alpha))
a+L+g2+0.1[m]	(b-(1-cos(alpha))*g2/sin(alpha))-0.1[m]*tan(alpha)

4 Click **Build Selected**.

Work Plane 10 (wp10) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type a+L.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type a+L.

7 In the **yw** text field, type c_deck+s_deck.

8 Click **Build Selected**.

Work Plane 10 (wp10) > Line Segment 2 (ls2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **xw** text field, type a+L+g2.

5 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

6 In the **xw** text field, type a+L+g2.

7 In the **yw** text field, type c_deck+s_deck.

8 Click **Build Selected**.

Work Plane 10 (wp10) > Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Work Plane 10 (wp10) > Delete Entities 1 (del1)

1 Right-click **Plane Geometry** and choose **Delete Entities**.

2 On the object **uni1**, select Boundaries 1–6, 8, 9, and 11 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Work Plane 10 (wp10)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 10 (wp10)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Union 1 (uni1)

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

2 Click the **Select All** button in the **Graphics** toolbar.

3 In the **Settings** window for **Union**, click **Build Selected**.

Cap Faces 1 (cap1)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **uni1**, select Edges 46–48 and 60 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 2 (cap2)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap1**, select Edges 44, 45, 48, and 59 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 3 (cap3)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap2**, select Edges 42, 43, 45, and 58 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 4 (cap4)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap3**, select Edges 40, 41, 43, and 57 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 5 (cap5)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap4**, select Edges 38, 39, 41, and 56 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 6 (cap6)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap5**, select Edges 36, 37, 39, and 55 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 7 (cap7)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap6**, select Edges 34, 35, 37, and 53 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 8 (cap8)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 In the **Settings** window for **Cap Faces**, locate the **Cap Faces** section.

3 Click the **Clear Selection** button for **Bounding edges**.

4 On the object **cap7**, select Edges 9, 10, and 27 only.

5 Click **Build Selected**.

Cap Faces 9 (cap9)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap8**, select Edges 8, 10, and 25 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 10 (cap10)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap9**, select Edges 7, 8, and 23 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 11 (cap11)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap10**, select Edges 6, 7, and 21 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 12 (cap12)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap11**, select Edges 5, 6, and 19 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 13 (cap13)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap12**, select Edges 4, 5, and 17 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Cap Faces 14 (cap14)

1 In the **Geometry** toolbar, click **Defeaturing and Repair** and choose **Cap Faces**.

2 On the object **cap13**, select Edges 3, 4, and 15 only.

3 In the **Settings** window for **Cap Faces**, click **Build Selected**.

Work Plane 11 (wp11)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **zx-plane**.

4 In the **y-coordinate** text field, type `c_deck`.

5 Click to expand the **Local Coordinate System** section. In the **Rotation** text field, type `90`.

6 Click **Build Selected**.

Work Plane 11 (wp11) > Plane Geometry

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

Work Plane 11 (wp11) > Parametric Curve 1 (pc1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `s_x1+s_l1*s`.

4 In the **yw** text field, type `-(5*2*s_deck/s_l1*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*s_l1`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 11 (wp11)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 11 (wp11)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 12 (wp12)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **zx-plane**.

4 In the **y-coordinate** text field, type `c_deck+s_h`.

5 Locate the **Local Coordinate System** section. In the **Rotation** text field, type `90`.

6 Click **Build Selected**.

Work Plane 12 (wp12) > Plane Geometry

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

Work Plane 12 (wp12) > Parametric Curve 1 (pc1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `s_x2+s_l2*s`.

4 In the **yw** text field, type `-(5*s_w2/s_l1*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*s_l2`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 12 (wp12) > Line Segment 1 (ls1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 Click to select the **Activate Selection** toggle button for **Start vertex**.

4 On the object **pc1**, select Point 1 only.

5 Locate the **Endpoint** section. Click to select the **Activate Selection** toggle button for **End vertex**.

6 On the object **pc1**, select Point 2 only.

7 Click **Build Selected**.

Work Plane 12 (wp12) > Convert to Solid 1 (csol1)

1 In the **Work Plane** toolbar, click **Conversions** and choose **Convert to Solid**.

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

3 In the **Settings** window for **Convert to Solid**, click **Build Selected**.

Work Plane 12 (wp12)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 12 (wp12)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Loft 1 (loft1)

1 In the **Geometry** toolbar, click **Loft**.

2 In the **Settings** window for **Loft**, locate the **General** section.

3 Clear the **Unite with input objects** checkbox.

4 Click to expand the **Start Profile** section. From the **Geometric entity level** list, choose **Edge**.

5 On the object **wp12**, select Edge 2 only.

6 Click to expand the **End Profile** section. From the **Geometric entity level** list, choose **Edge**.

7 On the object **wp11**, select Edge 1 only.

8 Click **Build Selected**.

Work Plane 13 (wp13)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **yz-plane**.

4 In the **x-coordinate** text field, type `a+L+g2+g3`.

Work Plane 13 (wp13) > Plane Geometry

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

Work Plane 13 (wp13) > 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 `(b-(1-cos(alpha))*g2/sin(alpha))-g3*tan(alpha)`.

4 In the **Sector angle** text field, type `180`.

5 Click **Build Selected**.

Work Plane 13 (wp13)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 13 (wp13)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 14 (wp14)

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

Work Plane 14 (wp14) > Plane Geometry

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

Work Plane 14 (wp14) > Parametric Curve 1 (pc1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `r_x1+r_l1*s`.

4 In the **yw** text field, type `-(5*r_w1/r_l1*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*r_l1`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 14 (wp14) > Parametric Curve 2 (pc2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `r_x1+r_l1*s`.

4 In the **yw** text field, type `+(5*r_w1/r_l1*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*r_l1`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 14 (wp14)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 14 (wp14)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 15 (wp15)

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 `r_h`.

4 Click **Build Selected**.

Work Plane 15 (wp15) > Plane Geometry

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

Work Plane 15 (wp15) > Parametric Curve 1 (pc1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `r_x2+r_l2*s`.

4 In the **yw** text field, type `-(5*r_w2/r_l2*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*r_l2`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 15 (wp15) > Parametric Curve 2 (pc2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `r_x2+r_l2*s`.

4 In the **yw** text field, type `+(5*r_w2/r_l2*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*r_l2`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 15 (wp15) > Convert to Solid 1 (csol1)

1 In the **Work Plane** toolbar, click **Conversions** and choose **Convert to Solid**.

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

3 In the **Settings** window for **Convert to Solid**, click **Build Selected**.

Work Plane 15 (wp15)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 15 (wp15)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Loft 2 (loft2)

1 In the **Geometry** toolbar, click **Loft**.

2 In the **Settings** window for **Loft**, locate the **General** section.

3 Clear the **Unite with input objects** checkbox.

4 Locate the **Start Profile** section. From the **Geometric entity level** list, choose **Edge**.

5 On the object **wp15**, select Edge 2 only.

6 Locate the **End Profile** section. From the **Geometric entity level** list, choose **Edge**.

7 On the object **wp14**, select Edge 2 only.

8 Click **Build Selected**.

Loft 3 (loft3)

1 In the **Geometry** toolbar, click **Loft**.

2 In the **Settings** window for **Loft**, locate the **General** section.

3 Clear the **Unite with input objects** checkbox.

4 Locate the **Start Profile** section. From the **Geometric entity level** list, choose **Edge**.

5 On the object **wp15**, select Edge 1 only.

6 Locate the **End Profile** section. From the **Geometric entity level** list, choose **Edge**.

7 On the object **wp14**, select Edge 1 only.

8 Click **Build Selected**.

Rotate 1 (rot1)

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

2 Select the objects **loft2**, **loft3**, and **wp15** only.

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

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

5 Click **Range**.

6 In the **Range** dialog, choose **Number of values** from the **Entry method** list.

7 In the **Start** text field, type 0.

8 In the **Stop** text field, type 270.

9 In the **Number of values** text field, type 4.

10 Click **Replace**.

11 In the **Settings** window for **Rotate**, click **Build Selected**.

Union 2 (uni2)

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

2 Select the objects **rot1(1)**, **rot1(10)**, **rot1(11)**, **rot1(12)**, **rot1(2)**, **rot1(3)**, **rot1(4)**, **rot1(5)**, **rot1(6)**, **rot1(7)**, **rot1(8)**, and **rot1(9)** only.

3 In the **Settings** window for **Union**, click **Build Selected**.

Convert to Solid 1 (csol1)

1 In the **Geometry** toolbar, click **Conversions** and choose **Convert to Solid**.

2 Select the object **uni2** only.

3 In the **Settings** window for **Convert to Solid**, click **Build Selected**.

Work Plane 16 (wp16)

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 `b_h1`.

4 Click **Build Selected**.

Work Plane 16 (wp16) > Plane Geometry

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

Work Plane 16 (wp16) > Parametric Curve 1 (pc1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `b_x1+b_l1*s`.

4 In the **yw** text field, type `-(5*b_w1/b_l1*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*b_l1+b_d`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 16 (wp16) > Parametric Curve 2 (pc2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `b_x1+b_l1*s`.

4 In the **yw** text field, type `+(5*b_w1/b_l1*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*b_l1+b_d`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 16 (wp16)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 16 (wp16)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Work Plane 17 (wp17)

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 `b_h2`.

4 Click **Build Selected**.

Work Plane 17 (wp17) > Plane Geometry

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

Work Plane 17 (wp17) > Parametric Curve 1 (pc1)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `b_x2+b_l2*s`.

4 In the **yw** text field, type `-(5*b_w2/b_l2*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*b_l2+b_d`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 17 (wp17) > Parametric Curve 2 (pc2)

1 In the **Work Plane** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Expressions** section.

3 In the **xw** text field, type `b_x2+b_l2*s`.

4 In the **yw** text field, type `+(5*b_w2/b_l2*(a0*s^0.5-a1*s-a2*s^2+a3*s^3-a4*s^4))*b_l2+b_d`.

5 Locate the **Advanced Settings** section. Select the **Reparameterize using arc length** checkbox.

6 Click **Build Selected**.

Work Plane 17 (wp17) > Convert to Solid 1 (csol1)

1 In the **Work Plane** toolbar, click **Conversions** and choose **Convert to Solid**.

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

3 In the **Settings** window for **Convert to Solid**, click **Build Selected**.

Work Plane 17 (wp17)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Work Plane 17 (wp17)**.

2 In the **Settings** window for **Work Plane**, click **Build Selected**.

Loft 4 (loft4)

1 In the **Geometry** toolbar, click **Loft**.

2 In the **Settings** window for **Loft**, locate the **General** section.

3 Clear the **Unite with input objects** checkbox.

4 Locate the **Start Profile** section. From the **Geometric entity level** list, choose **Edge**.

5 On the object **wp17**, select Edge 2 only.

6 Locate the **End Profile** section. From the **Geometric entity level** list, choose **Edge**.

7 On the object **wp16**, select Edge 2 only.

8 Click **Build Selected**.

Loft 5 (loft5)

1 In the **Geometry** toolbar, click **Loft**.

2 In the **Settings** window for **Loft**, locate the **General** section.

3 Clear the **Unite with input objects** checkbox.

4 Locate the **Start Profile** section. From the **Geometric entity level** list, choose **Edge**.

5 On the object **wp17**, select Edge 1 only.

6 Locate the **End Profile** section. From the **Geometric entity level** list, choose **Edge**.

7 On the object **wp16**, select Edge 1 only.

8 Click **Build Selected**.

Union 3 (uni3)

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

2 Select the objects **cap14**, **loft1**, **loft4**, **loft5**, **wp12**, **wp16**, and **wp17** only.

3 In the **Settings** window for **Union**, click **Build Selected**.

Delete Entities 1 (del1)

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

2 On the object **uni3**, select Boundaries 19, 20, 22, 24, 26, and 29 only.

3 In the **Settings** window for **Delete Entities**, click **Build Selected**.

Mirror 1 (mir1)

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

2 Select the objects **del1** and **wp13** only.

3 In the **Settings** window for **Mirror**, locate the **Input** section.

4 Select the **Keep input objects** checkbox.

5 Click **Build Selected**.

Union 4 (uni4)

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

2 Select the objects **del1**, **mir1(1)**, **mir1(2)**, and **wp13** only.

3 In the **Settings** window for **Union**, click **Build Selected**.

Convert to Solid 2 (csol2)

1 In the **Geometry** toolbar, click **Conversions** and choose **Convert to Solid**.

2 Select the object **uni4** only.

3 In the **Settings** window for **Convert to Solid**, click **Build Selected**.

Union 5 (uni5)

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

2 Select the objects **csol1** and **csol2** only.

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

4 Clear the **Keep interior boundaries** checkbox.

5 Click **Build Selected**.

Rotate the submarine to facilitate the visualization.

Rotate 2 (rot2)

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

2 Select the object **uni5** only.

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

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

5 In the **Angle** text field, type `90`.

6 Click **Build Selected**.

The geometry is now finished. The following steps are only needed to improve the quality of the mesh.

Work Plane 18 (wp18)

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

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **yz-plane**.

4 In the **x-coordinate** text field, type `b_x1-0.1[m]`.

5 Click **Build Selected**.

Partition Faces 1 (parf1)

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

2 On the object **rot2**, select Boundaries 31–34 only.

3 In the **Settings** window for **Partition Faces**, locate the **Partition Faces** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click **Build Selected**.

Work Plane 19 (wp19)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 18 (wp18)** and choose **Duplicate**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **x-coordinate** text field, type `b_x1+b_l1+0.1[m]`.

4 Click **Build Selected**.

Partition Faces 2 (parf2)

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

2 On the object **parf1**, select Boundaries 37, 40, 47, and 48 only.

3 In the **Settings** window for **Partition Faces**, locate the **Partition Faces** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click **Build Selected**.

Work Plane 20 (wp20)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 19 (wp19)** and choose **Duplicate**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **x-coordinate** text field, type `s_x1-0.1[m]`.

4 Click **Build Selected**.

Partition Faces 3 (parf3)

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

2 On the object **parf2**, select Boundaries 27 and 29 only.

3 In the **Settings** window for **Partition Faces**, locate the **Partition Faces** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click **Build Selected**.

Work Plane 21 (wp21)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 20 (wp20)** and choose **Duplicate**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **x-coordinate** text field, type `s_x1+s_l1+0.1[m]`.

Partition Faces 4 (parf4)

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

2 On the object **parf3**, select Boundaries 59 and 60 only.

3 In the **Settings** window for **Partition Faces**, locate the **Partition Faces** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click  **Build Selected**.

Work Plane 22 (wp22)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 21 (wp21)** and choose **Duplicate**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **x-coordinate** text field, type `s_x1+3*s_l1/10-1.25[m]`.

Partition Faces 5 (parf5)

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

2 On the object **parf4**, select Boundaries 50, 51, 53, and 54 only.

3 In the **Settings** window for **Partition Faces**, locate the **Partition Faces** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click  **Build Selected**.

Work Plane 23 (wp23)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 22 (wp22)** and choose **Duplicate**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **x-coordinate** text field, type `s_x1+3*s_l1/10+1.25[m]`.

Partition Faces 6 (parf6)

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

2 On the object **parf5**, select Boundaries 59 and 62–64 only.

3 In the **Settings** window for **Partition Faces**, locate the **Partition Faces** section.

4 From the **Partition with** list, choose **Work plane**.

5 Click **Build Selected**.

Form Union (fin)

1 In the **Model Builder** window, click **Form Union (fin)**.

2 In the **Settings** window for **Form Union/Assembly**, click **Build Selected**.

Add some selections based on coordinates for the virtual operations.

Box Selection 1 (boxsel1)

1 In the **Geometry** toolbar, click **Selections** and choose **Box Selection**.

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

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

4 Locate the **Box Limits** section. In the **x minimum** text field, type `11.5`.

5 In the **x maximum** text field, type `12.5`.

6 In the **y minimum** text field, type `-2`.

7 In the **y maximum** text field, type `2`.

8 In the **z minimum** text field, type `3.9`.

9 In the **z maximum** text field, type `4.1`.

10 Locate the **Output Entities** section. From the **Include entity if** list, choose **All vertices inside box**.

Box Selection 2 (boxsel2)

1 Right-click **Box Selection 1 (boxsel1)** and choose **Duplicate**.

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

3 In the **x minimum** text field, type `21.5`.

4 In the **x maximum** text field, type `22.9`.

5 In the **y minimum** text field, type `-1.25`.

6 In the **y maximum** text field, type `-1.18`.

Box Selection 3 (boxsel3)

1 Right-click **Box Selection 2 (boxsel2)** and choose **Duplicate**.

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

3 In the **y minimum** text field, type `1.18`.

4 In the **y maximum** text field, type `1.25`.

Box Selection 4 (boxsel4)

1 Right-click **Box Selection 3 (boxsel3)** and choose **Duplicate**.

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

3 In the **x minimum** text field, type `22.9`.

4 In the **x maximum** text field, type `24.5`.

Box Selection 5 (boxsel5)

1 Right-click **Box Selection 4 (boxsel4)** and choose **Duplicate**.

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

3 In the **y minimum** text field, type `-1.25`.

4 In the **y maximum** text field, type `-1.18`.

5 Click **Build Selected**.

Union Selection 1 (unisel1)

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 **Edge**.

4 Locate the **Input Entities** section. Click **Add**.

5 In the **Add** dialog, in the **Selections to add** list, choose **Box Selection 2**, **Box Selection 3**, **Box Selection 4**, and **Box Selection 5**.

6 Click **OK**.

Ignore Edges 1 (ige1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Ignore Edges**.

2 In the **Settings** window for **Ignore Edges**, locate the **Input** section.

3 From the **Edges to ignore** list, choose **Union Selection 1**.

4 Click **Build Selected**.

Collapse Edges 1 (cle1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Collapse Edges**.

2 In the **Settings** window for **Collapse Edges**, locate the **Input** section.

3 From the **Edges to collapse** list, choose **Box Selection 1**.

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

Ignore Vertices 1 (igv1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Ignore Vertices**.

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

3 Click the **Select All** button in the **Graphics** toolbar.

4 In the **Settings** window for **Ignore Vertices**, click **Build Selected**.

Convert to COMSOL 1 (ccom1)

1 In the **Geometry** toolbar, click **Conversions** and choose **Convert to COMSOL**.

2 Select the object **parf6** only.

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

4 Click **Export**.

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

6 In the **Export[noun]** window for **Geometry**, locate the **Export** section.

7 In the **Filename** text field, type `magnetic_signature_submarine_geom_sequence.mphbin`.

8 Click the **Export entire finalized geometry** button.

9 Click **null** to produce the MPHBIN-file that is used at the beginning of the tutorial.