Created in COMSOL Multiphysics 6.1

Submarine High-Frequency Asymptotic Scattering

Introduction

The primary defense of a submarine lies in its capacity to remain hidden during operation. As radio waves are strongly absorbed by sea water, sound navigation and ranging, or SONAR, is one of the main methods used for the detection of submarines. SONAR systems are also used for underwater exploration as well as in the fishing industry.

Designers analyze the way acoustic waves are reflected in order to minimize the equivalent reflecting area of the submarine. This tutorial studies the scattering off the BeTTSi benchmark submarine (Benchmark Target Echo Strength Simulation).

This model uses the high-frequency approximation of the *Pressure Acoustics, Asymptotic Scattering* interface. The analysis is fast and a good approximation at high frequencies, where the wavelength is much smaller than the scattering object.

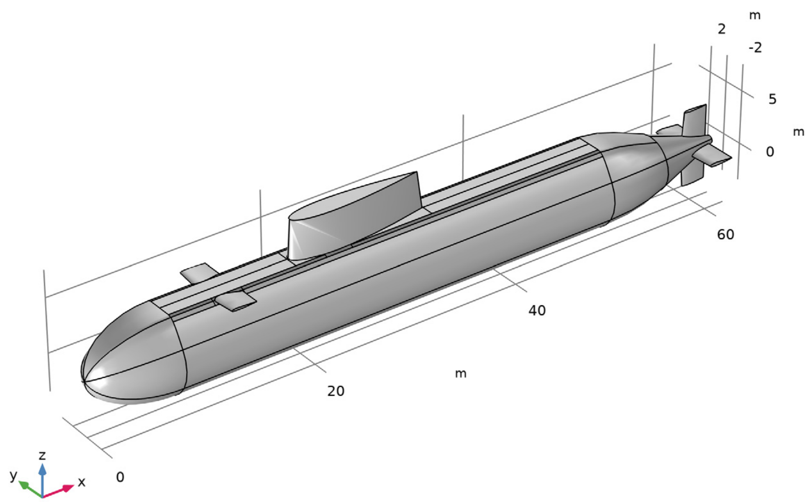


Figure 1: BeTSSi submarine geometry.

Model Definition

The target strength, or TS, is a measure of the area of a sonar target. In most submarines, reduction of the backscatter signal is achieved through the application of absorbing materials to the outer surfaces of the submarine. In this model, the target strength is computed for a single angle of incidence and frequency. The model can be readily extended with a sweep over frequencies and source locations.

The tutorial is based on the BeTTSi benchmark submarine (Benchmark Target Echo Strength Simulation) presented in Ref. 1 and Ref. 2. The geometry, shown in Figure 1, is also used and discussed in detail the *Submarine Target Strength* tutorial model in the Application Library.

In the present tutorial, the scattering problem is solved with the Pressure Acoustics, Asymptotic Scattering physics interface. The interface relies on a high-frequency approximation where the sound field is assumed to be locally plane. This is valid as long as the wavelength is much smaller than the important geometry details as well as the radius of curvature of important surfaces. Reflections are treated analytically at surfaces and the radiated/scattered field is computed using the Kirchhoff-Helmholtz integral. This approach is also sometimes referred to as high-frequency BEM or HFB.

In this model, the surface properties of the submarine are defined through an angle dependent absorption coefficient $\alpha(\theta)$. The angle dependency is included using the built-in variable `paas.thetai`. The absorption data is generic and is here given in an interpolation function. The absorption data can be based on measurements or computed using a sub-model. An example of the sub-model approach is given in the *Anechoic Coating* model gallery tutorial:

- https://www.comsol.com/model/anechoic-coating-44201

Results and Discussion

The full 3D radiation pattern, evaluated at 100 m is depicted in Figure 2. Notice the main lobe corresponding to the specular reflection on the main part of the submarine body. The corresponding radiation pattern in the xy-plane, evaluated at a source distance of 1000 m is depicted in Figure 3. The near-field total pressure and the near-field scattered sound pressure level is depicted in Figure 4 and Figure 7, respectively.

The asymptotic scattering approach relies on a visibility computation, that is, the portion of the scattering object surfaces that have a directly incident background field. The visibility for the current configuration is depicted in Figure 5 (top left). For the visible surfaces, the angle of incidence of the incident field as well as the corresponding absorption coefficient is depicted in the top right and the bottom figures, respectively.

Finally, the ballistic target strength (TS) for the current configuration of source and scatterer is depicted in Figure 6.

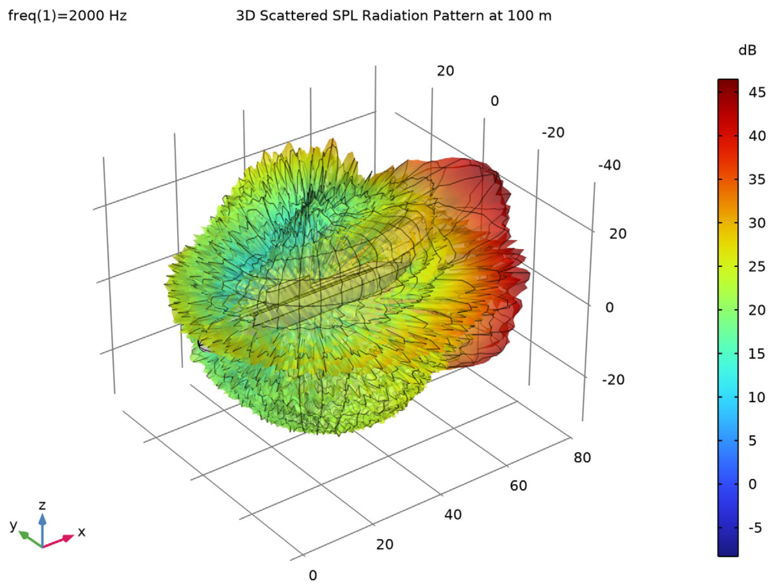


Figure 2: Radiation pattern evaluated at 100 m from the submarine.

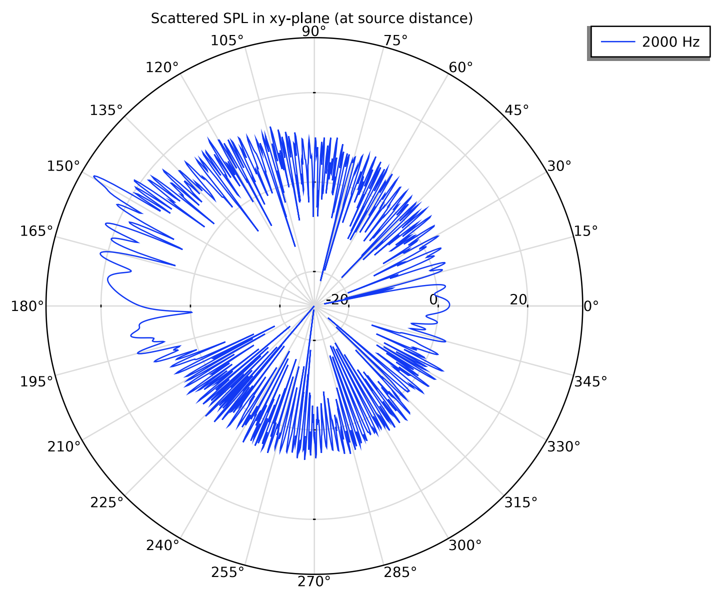


Figure 3: Radiation pattern in the xy-plane, evaluated at the source distance (1 km).

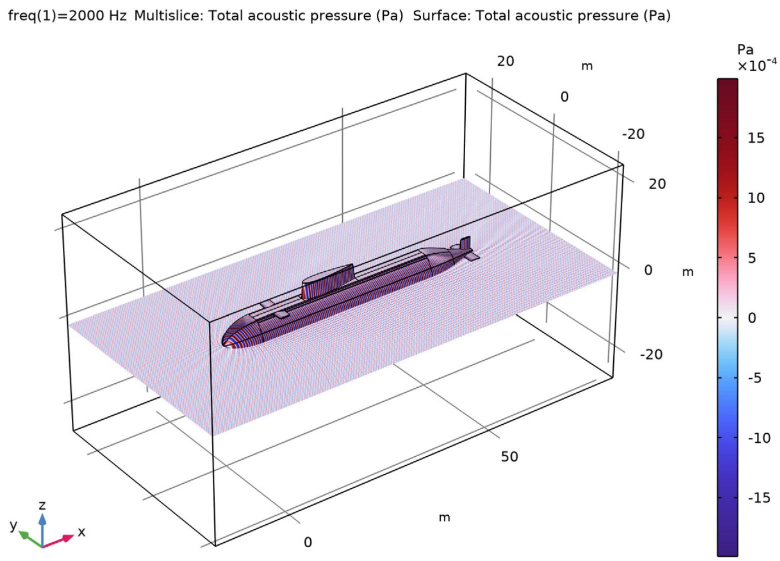


Figure 4: Total acoustic pressure (incident and scattered) evaluated at the submarine surface and in the z = 0 plane. The evaluation grid is slightly under resolving the pattern.

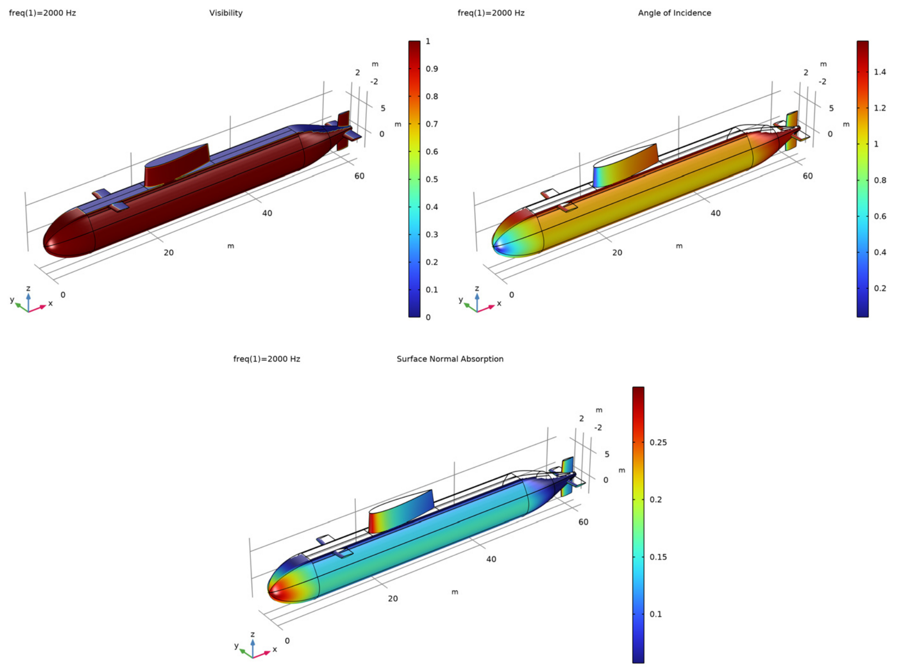


Figure 5: The surface visibility (top left); the angle of incidence of the incident acoustic field on the visible surfaces (top right); and the absorption including the angle dependency (bottom)

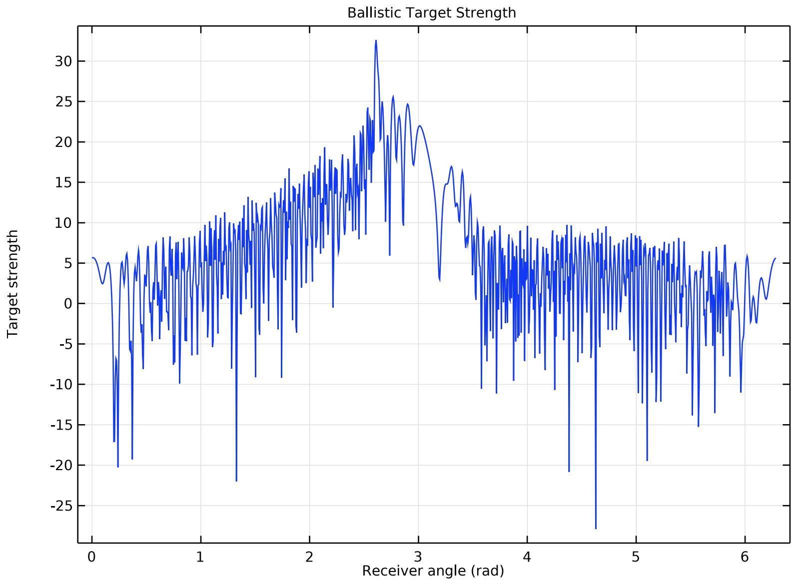


Figure 6: The plot shows the target strength TS.

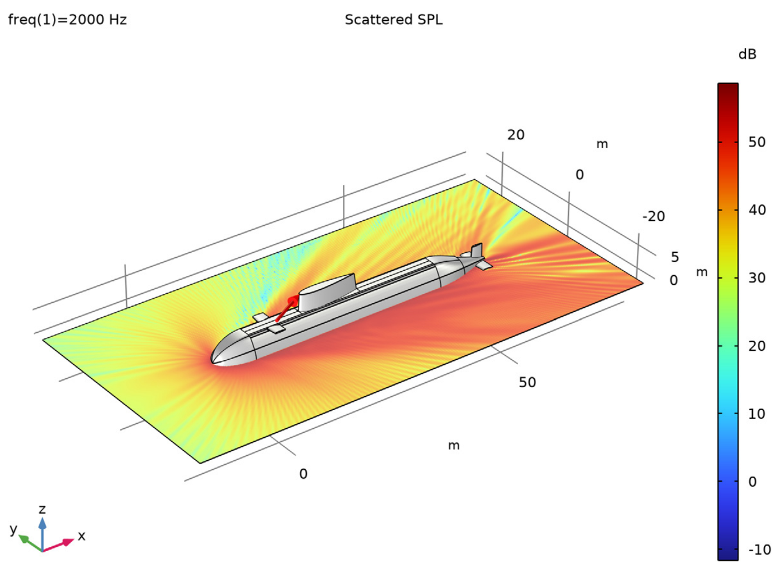


Figure 7: The scattered SPL in the z = 0 plane in the region around the submarine.

Notes About the COMSOL Implementation

- The walls (visible) of the scattering object can be characterized in terms of a reflection coefficient R (complex valued), a normal impedance Z_n (complex valued), or an absorption coefficient α and phase. The reflection coefficient and the absorption coefficient can have a dependency on the angle of incidence using the built-in variable `paas.theta`. If multiple sources are defined, the variable will automatically take the differences into account. Variables also exist for the source defined by the individual background pressure field features, for example, for the first feature `paas.bpf1.theta` (using the item scope).
- When postprocessing using either a grid dataset or a radiation patter plot, it is important to resolve the wave pattern. This is particularly so since the method is used for high-frequency problems where the wavelength is much smaller than the scattering objects. The spatial resolution can be set on the grid dataset as well as in the radiation pattern plot. Remember that rendering each data point is time consuming.

Reference

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, https://doi.org/10.1016/j.cma.2019.112670.

Application Library path: `Acoustics_Module/Underwater_Acoustics/submarine_asymptotic_scattering`

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 **Acoustics>Pressure Acoustics>Pressure Acoustics, Asymptotic Scattering**.

3 Click **Add**.

4 Click **Study**.

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

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

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

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

3 Click **Load from File**.

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

Interpolation 1 (int1)

1 In the **Home** toolbar, click f(x) **Functions** and choose **Global>Interpolation**.

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

3 From the **Data source** list, choose **File**.

4 Click **Browse**.

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

6 Click **Import**.

7 In the **Function name** text field, type `alpha`.

8 Locate the **Interpolation and Extrapolation** section. From the **Interpolation** list, choose **Cubic spline**.

9 Locate the **Units** section. In the **Function** table, enter the following settings:

Function	Unit
alpha	1

10 In the **Argument** table, enter the following settings:

Argument	Unit
t	deg

GEOMETRY 1

The model uses an external mphbin file with the geometry. The instructions for building the submarine geometry can be found in the Submarine Target Strength tutorial.

Import 1 (imp1)

1 In the **Home** toolbar, click **Import**.
2 In the **Settings** window for **Import**, locate the **Import** section.
3 Click **Browse**.
4 Browse to the model's Application Libraries folder and double-click the file `submarine_asymptotic_scattering.mphbin`.
5 Click **Build All Objects**.

Use **Virtual Operations** to simplify the geometry for meshing.

Form Composite Faces 1 (cmf1)

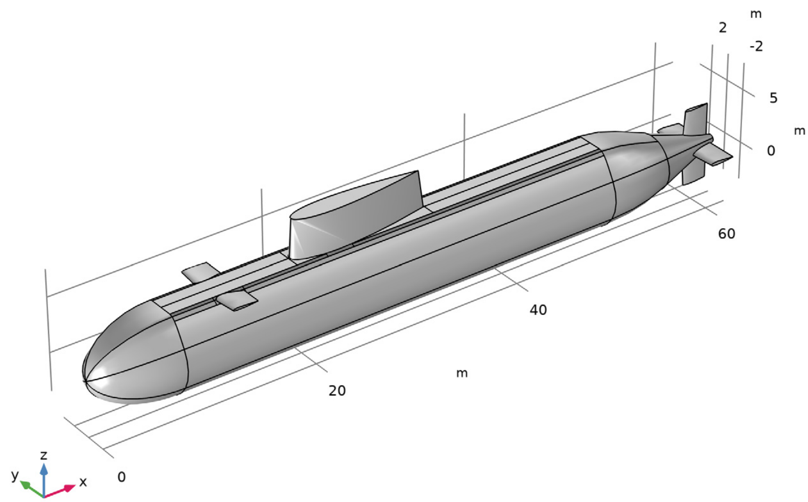
1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Form Composite Faces**.
2 On the object **fin**, select Boundaries 1–10, 69–73, and 79–83 only.
3 In the **Settings** window for **Form Composite Faces**, click **Build Selected**.

Form Composite Faces 2 (cmf2)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Form Composite Faces**.
2 On the object **cmf1**, select Boundaries 4–7, 13–16, 24–27, 49, 50, 62, 63, 65, 66, and 84–87 only.

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

The geometry should look like this.



DEFINITIONS

Variables 1

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Definitions** node.

2 Right-click **Definitions** and choose **Variables**.

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

4 Click **Load from File**.

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

Average 1 (aveop1)

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **Average**.

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

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

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

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Built-in>Water, liquid**.

4 Click **Add to Component** in the window toolbar.

5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Water, liquid (mat1)

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

2 From the **Selection** list, choose **All voids**.

PRESSURE ACOUSTICS, ASYMPTOTIC SCATTERING (PAAS)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Pressure Acoustics, Asymptotic Scattering (paas)**.

2 In the **Settings** window for **Pressure Acoustics, Asymptotic Scattering**, locate the **Sound Pressure Level Settings** section.

3 From the **Reference pressure for the sound pressure level** list, choose **Use reference pressure for water**.

Pressure Acoustics 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Pressure Acoustics, Asymptotic Scattering (paas)** click **Pressure Acoustics 1**.

2 In the **Settings** window for **Pressure Acoustics**, locate the **Pressure Acoustics Model** section.

3 From the **Fluid model** list, choose **Ocean attenuation**.

Note that material properties cannot be space dependent when used in the Pressure Acoustics, Asymptotic Scattering interface.

Background Pressure Field 1

1 In the **Model Builder** window, click **Background Pressure Field 1**.

2 In the **Settings** window for **Background Pressure Field**, locate the **Background Pressure Field** section.

3 From the **Pressure field type** list, choose **Spherical wave**.

4 In the p_0 text field, type `p_ref`.

5 Specify the $\mathbf{x}_0$ vector as

`-d_source*cos(phi)+L/2`	x
`-d_source*sin(phi)`	y
`0`	z

The boundary conditions applicable to the scattering object are added as **Wall** subfeatures to the **Scattering Object**. Modify the default **Wall** condition to include an angle dependent surface absorption.

Wall 1

1. In the **Model Builder** window, expand the **Scattering Object 1** node, then click **Wall 1**.
2. In the **Settings** window for **Wall**, locate the **Wall** section.
3. From the **Type** list, choose **Absorption coefficient**.
4. In the α_n text field, type `alpha(paas.theta)`.

   Note the use of the general `paas.theta` variable that defines the angle of incidence. When plotting the angle in postprocessing, the item scope of the **Background Pressure Field** has to be added (each background field defines its associated angle of incidence). This is shown when analyzing the results.

In this model, the mesh is set up manually. Proceed by directly adding the desired mesh component. Four elements per wavelength is adequate for the formulation in this model.

MESH 1

Mapped 1

In the **Mesh** toolbar, click **Boundary** and choose **Mapped**.

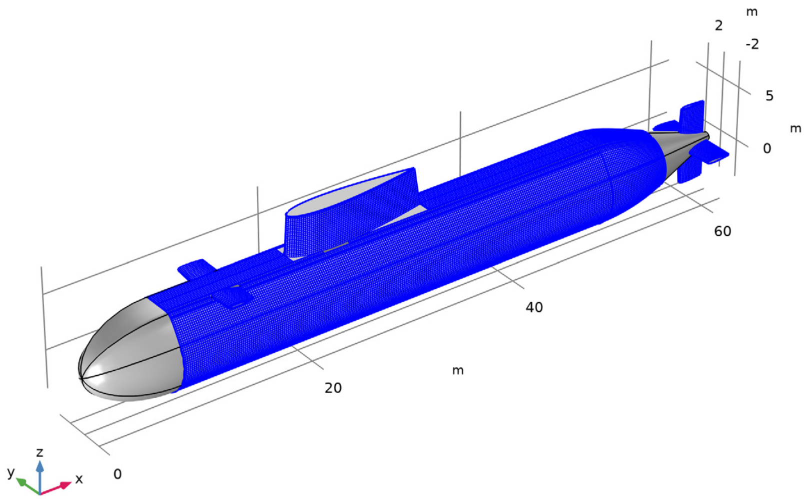
Size

1. In the **Model Builder** window, click **Size**.
2. In the **Settings** window for **Size**, locate the **Element Size** section.
3. Click the **Custom** button.
4. Locate the **Element Size Parameters** section. In the **Maximum element size** text field, type `lam0/4`.
5. In the **Minimum element size** text field, type `50[mm]`.

Mapped 1

1. In the **Model Builder** window, click **Mapped 1**.
2. Select Boundaries 8–15, 18, 19, 24–27, 32–35, 38, 39, 42, 43, 46–55, and 62–69 only.

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



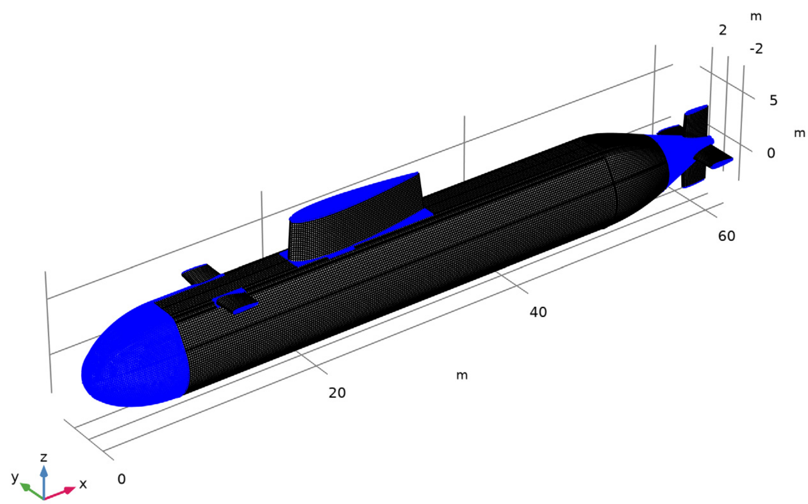
Free Triangular 1

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: Frequency Domain

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

2 In the **Settings** window for **Frequency Domain**, locate the **Study Settings** section.

3 In the **Frequencies** text field, type `f0`.

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

RESULTS

In Pressure Acoustics, Asymptotic Scattering models, the time consuming computations are not to solve the model. The actual solution time lies in evaluating the results in postprocessing (through the exterior field feature). To get information about the rendering/plotting time turn on the **Plot Information Section**. On each plot, an **Information** section will appear where the data is displayed (expand the section). This option applies to the whole COMSOL installation; if selected, the **Plot Information Section** will also appear in other models opened at a later stage.

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

2 In the **Show More Options** dialog box, select **Results>Plot Information Section** in the tree.

3 In the tree, select the check box for the node **Results>Plot Information Section**.

4 Click **OK**.

It can be useful to select the **Only plot when requested** option on the **Results** node when working with the plots, since the rendering times can be large. Also, on the **Results** node, turning on **Save plot data** is recommended; the plots will be saved rendered in the file.

5 In the **Model Builder** window, click **Results**.

6 In the **Settings** window for **Results**, locate the **Update of Results** section.

7 Select the **Only plot when requested** check box.

8 Locate the **Save Data in the Model** section. From the **Save plot data** list, choose **On**.

3D Scattered SPL Radiation Pattern at 100 m

Proceed by modifying the default plots, then add some additional plots.

1 In the **Model Builder** window, under **Results** click **Exterior-Field Sound Pressure Level (paas)**.

2 In the **Settings** window for **3D Plot Group**, type `3D Scattered SPL Radiation Pattern at 100 m` in the **Label** text field.

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

Radiation Pattern 1

1 In the **Model Builder** window, expand the **3D Scattered SPL Radiation Pattern at 100 m** node, then click **Radiation Pattern 1**.

2 In the **Settings** window for **Radiation Pattern**, locate the **Evaluation** section.

3 Find the **Angles** subsection. In the **Number of elevation angles** text field, type `90`.

4 In the **Number of azimuth angles** text field, type `180`.

5 Find the **Sphere** subsection. From the **Sphere** list, choose **Manual**.

6 In the **X** text field, type `L/2`.

7 In the **Radius** text field, type `100[m]`.

8 Locate the **Coloring and Style** section. From the **Grid** list, choose **Finer**.

Transparency 1

Right-click **Radiation Pattern 1** and choose **Transparency**.

Surface 1

1 In the **Model Builder** window, right-click **3D Scattered SPL Radiation Pattern at 100 m** and choose **Surface**.

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

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

4 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

5 From the **Color** list, choose **Gray**.

Line 1

1 Right-click **3D Scattered SPL Radiation Pattern at 100 m** and choose **Line**.

2 In the **Settings** window for **Line**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

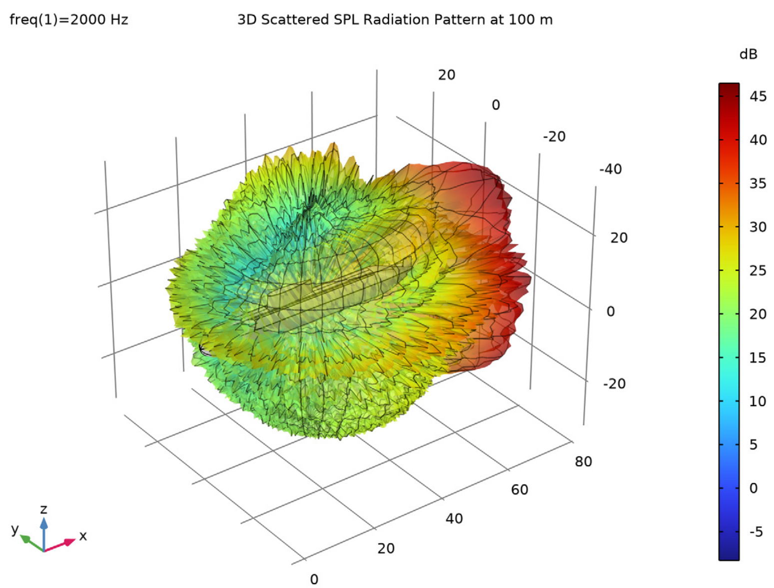
4 Locate the **Expression** section. In the **Expression** text field, type 1.

5 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

6 From the **Color** list, choose **Black**.

7 In the **3D Scattered SPL Radiation Pattern at 100 m** toolbar, click **Plot**.

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



Exterior-Field Pressure at 100 m

1 In the **Model Builder** window, under **Results** click **Exterior-Field Pressure (paas)**.

2 In the **Settings** window for **2D Plot Group**, type `Exterior-Field Pressure at 100 m` in the **Label** text field.

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

Radiation Pattern 1

1 In the **Model Builder** window, expand the **Exterior-Field Pressure at 100 m** node, then click **Radiation Pattern 1**.

2 In the **Settings** window for **Radiation Pattern**, locate the **Evaluation** section.

3 Find the **Angles** subsection. In the **Number of elevation angles** text field, type `90`.

4 In the **Number of azimuth angles** text field, type `180`.

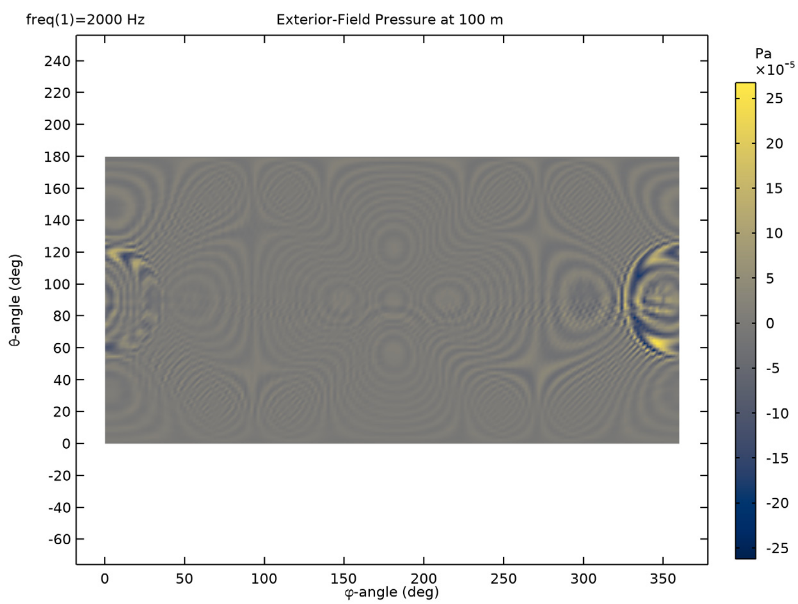
5 Find the **Sphere** subsection. From the **Sphere** list, choose **Manual**.

6 In the **X** text field, type `L/2`.

7 In the **Radius** text field, type `100[m]`.

8 In the **Exterior-Field Pressure at 100 m** toolbar, click **Plot**.

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



Scattered SPL in xy-plane (at source distance)

1 In the **Model Builder** window, under **Results** click **Exterior-Field Sound Pressure Level xy-plane (paas)**.

2 In the **Settings** window for **Polar Plot Group**, type `Scattered SPL in xy-plane (at source distance)` in the **Label** text field.

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

Radiation Pattern 1

1 In the **Model Builder** window, expand the **Scattered SPL in xy-plane (at source distance)** node, then click **Radiation Pattern 1**.

2 In the **Settings** window for **Radiation Pattern**, locate the **Evaluation** section.

3 Find the **Angles** subsection. In the **Number of angles** text field, type `1800`.

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

5 Find the **Evaluation distance** subsection. In the **Radius** text field, type `d_source`.

6 Find the **Reference direction** subsection. In the **x** text field, type `-1`.

7 Click **Preview Evaluation Plane**.

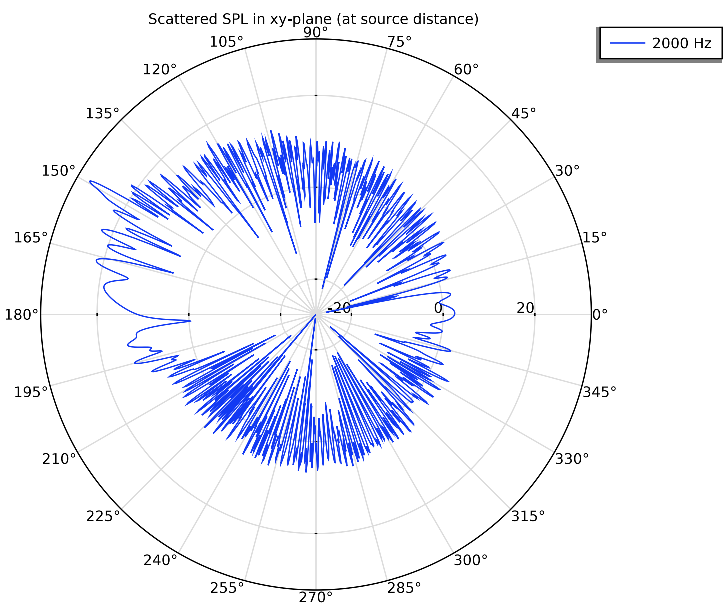
The preview plot generated when clicking the **Preview Evaluation Plane** shows the orientation of the circle where the radiation pattern is visualized.

8 Click **Zoom Extents** in the window toolbar.

Radiation Pattern 1

1 In the **Model Builder** window, click **Radiation Pattern 1**.

2 In the **Scattered SPL in xy-plane (at source distance)** toolbar, click **Plot**.



Grid 3D 1

1 In the **Model Builder** window, expand the **Results>Datasets** node, then click **Grid 3D 1**.

2 In the **Settings** window for **Grid 3D**, locate the **Parameter Bounds** section.

3 Find the **First parameter** subsection. In the **Minimum** text field, type `-20`.

4 In the **Maximum** text field, type `80`.

5 Find the **Second parameter** subsection. In the **Minimum** text field, type `-25`.

6 In the **Maximum** text field, type `25`.

7 Find the **Third parameter** subsection. In the **Minimum** text field, type `-25`.

8 In the **Maximum** text field, type `25`.

9 Click to expand the **Grid** section. In the **x resolution** text field, type `400`.

10 In the **y resolution** text field, type `200`.

11 In the **z resolution** text field, type `2`.

The grid resolution should in general be adequate to resolve the wave pattern (wavelength) in the plots. Here, the grid resolution is set to 2 in the z direction in order to reduce the overall grid points to evaluate. The plots only contain xy-plane cuts.

Multislice 1

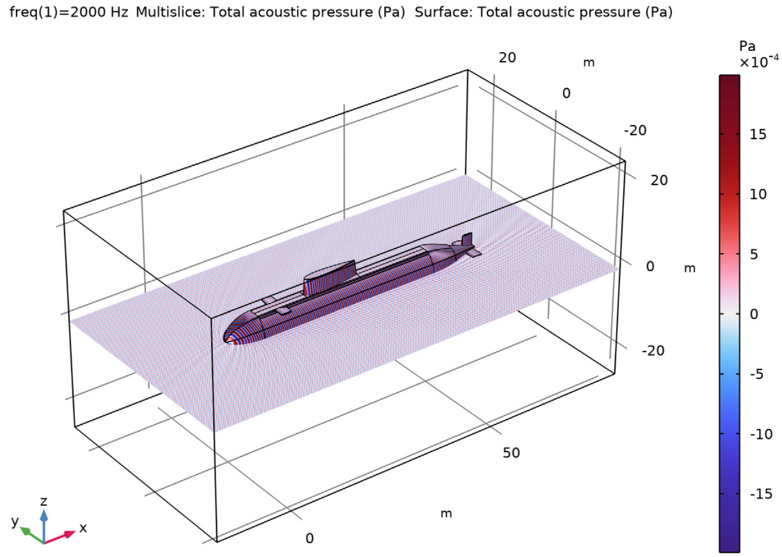
1 In the **Model Builder** window, expand the **Acoustic Pressure (paas)** node, then click **Multislice 1**.

2 In the **Settings** window for **Multislice**, locate the **Multiplane Data** section.

3 Find the **x-planes** subsection. In the **Planes** text field, type `0`.

4 Find the **y-planes** subsection. In the **Planes** text field, type `0`.

5 In the **Acoustic Pressure (paas)** toolbar, click **Plot**.



Visibility

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Visibility` in the **Label** text field.

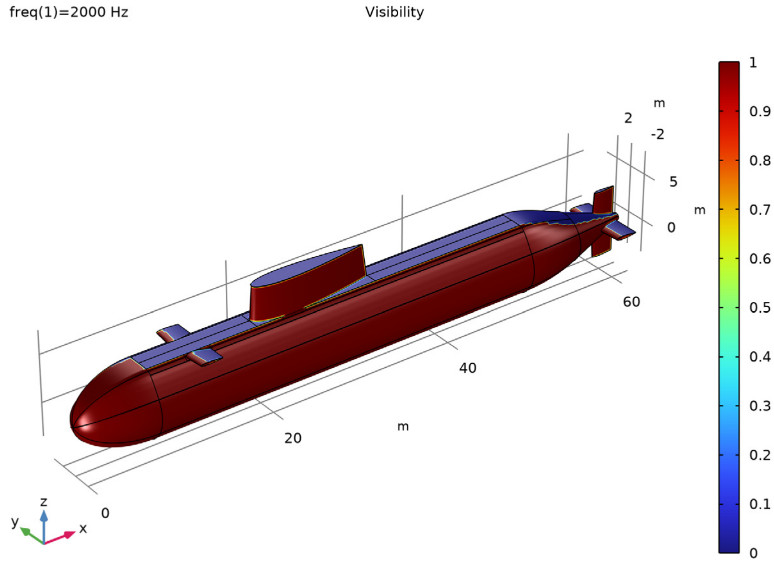
3 Click to expand the **Title** section. From the **Title type** list, choose **Label**.

Surface 1

1 Right-click **Visibility** 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)>Pressure Acoustics, Asymptotic Scattering>Background Pressure Field 1>paas.bpf1.visibility - Visibility**.

3 In the **Visibility** toolbar, click **Plot**.



Angle of Incidence

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Angle of Incidence` in the **Label** text field.

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

Surface 1

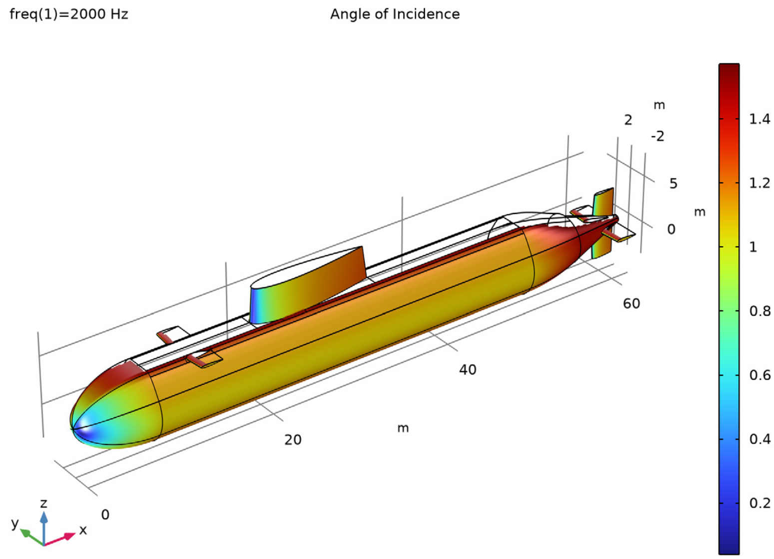
1 Right-click **Angle of Incidence** and choose **Surface**.

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)> Pressure Acoustics, Asymptotic Scattering>Background Pressure Field 1>paas.bpf1.theta - Incident angle - rad**.

To only view the angle on the visible surfaces, replace the expression with the following.

3 Locate the **Expression** section. In the **Expression** text field, type `if(paas.bpf1.visibility,paas.bpf1.theta,NaN)`.

4 In the **Angle of Incidence** toolbar, click **Plot**.



Surface Normal Absorption

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Surface Normal Absorption` in the **Label** text field.

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

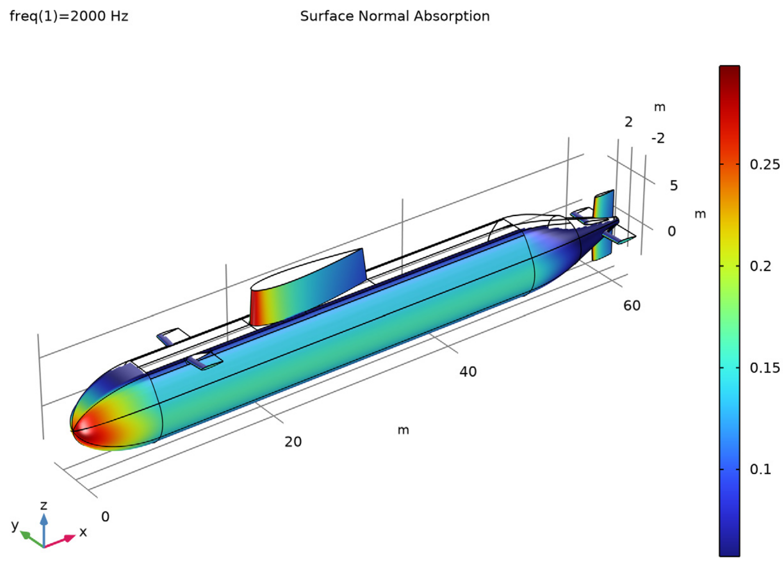
Surface 1

1 Right-click **Surface Normal Absorption** and choose **Surface**.

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

3 In the **Expression** text field, type `if(paas.bpf1.visibility, alpha(paas.bpf1.theta),NaN)`.

4 In the **Surface Normal Absorption** toolbar, click **Plot**.



Parameterized Curve 3D 1

1 In the **Results** toolbar, click **More Datasets** and choose **Parameterized Curve 3D**.

2 In the **Settings** window for **Parameterized Curve 3D**, locate the **Parameter** section.

3 In the **Maximum** text field, type `2*pi`.

4 Locate the **Expressions** section. In the **x** text field, type `-d_source*cos(s)+L/2`.

5 In the **y** text field, type `-d_source*sin(s)`.

6 Select the **Only evaluate globally defined expressions** check box.

Cut Plane 1

1 In the **Results** toolbar, click **Cut Plane**.

2 In the **Settings** window for **Cut Plane**, locate the **Data** section.

3 From the **Dataset** list, choose **Grid 3D 1**.

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

Ballistic Target Strength

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

2 In the **Settings** window for **1D Plot Group**, type `Ballistic Target Strength` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Parameterized Curve 3D 1**.

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

Line Graph 1

1 Right-click **Ballistic Target Strength** and choose **Line Graph**.

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

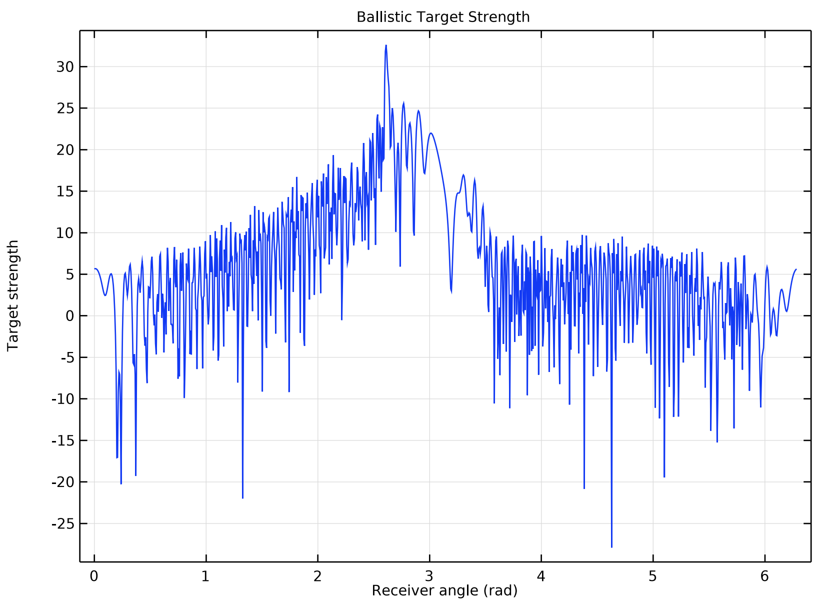
3 In the **Expression** text field, type `TS`.

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

5 In the **Expression** text field, type `s[rad]`.

6 Select the **Description** check box. In the associated text field, type `Receiver angle`.

7 In the **Ballistic Target Strength** toolbar, click **Plot**.



Scattered SPL

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Scattered SPL` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Cut Plane 1**.

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

5 Locate the **Color Legend** section. Select the **Show units** check box.

Surface 1

1. Right-click **Scattered SPL** and choose **Surface**.
2. In the **Settings** window for **Surface**, locate the **Expression** section.
3. In the **Expression** text field, type `paas.Lp_s`.

Surface 2

1. In the **Model Builder** window, right-click **Scattered SPL** and choose **Surface**.
2. In the **Settings** window for **Surface**, locate the **Data** section.
3. From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.
4. Locate the **Expression** section. In the **Expression** text field, type `1`.

Material Appearance 1

1. Right-click **Surface 2** 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 **Steel**.

Line 1

1. In the **Model Builder** window, right-click **Scattered SPL** and choose **Line**.
2. In the **Settings** window for **Line**, locate the **Data** section.
3. From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.
4. Locate the **Expression** section. In the **Expression** text field, type `1`.
5. Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.
6. From the **Color** list, choose **Black**.

Scattered SPL

In the **Model Builder** window, click **Scattered SPL**.

Arrow Point 1

1. In the **Scattered SPL** toolbar, click **More Plots** and choose **Arrow Point**.
2. In the **Settings** window for **Arrow Point**, locate the **Data** section.
3. From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.
4. Locate the **Expression** section. In the **X component** text field, type `10*cos(phi)`.
5. In the **Y component** text field, type `10*sin(phi)`.
6. In the **Z component** text field, type `0`.
7. Locate the **Coloring and Style** section. From the **Arrow base** list, choose **Head**.

8 Select the **Scale factor** check box.

Selection 1

1 Right-click **Arrow Point 1** and choose **Selection**.

2 Select Point 44 only.

3 In the **Scattered SPL** toolbar, click **Plot**.