Created in COMSOL Multiphysics 5.6

Doppler Shift

Introduction

You can notice the Doppler effect when an ambulance or a fire engine passes by with its sirens blaring. The siren's pitch suddenly drops the moment the ambulance starts to move away from you. Another effect you can hear is how the siren's sound suddenly becomes markedly quieter as soon as the ambulance passes.

In this example, the observer and air are at rest while the sound source, the ambulance, moves with the speed V. This gives the same effect as if the sound source were at rest and the observer and air were moving at the same speed but in the opposite direction.

Model Definition

This is an axisymmetric problem with a point source at rest at the origin, $(r, z) = (0, 0)$, emitting spherical sound waves with the frequency $f = 100$ Hz. The surrounding air moves at $V = 50$ m/s (180 km/h or roughly 112 miles/hour) in the negative z direction. With this setup, the rz-plane is the horizontal plane at the level of the source and the observer, and the effects of reflections at the ground are neglected.

Assume, furthermore, that the observer stands 1 m from where the ambulance passes by. In the model geometry, this situation amounts to the observer moving with the flow along the line $r = 1$.

The boundary conditions are absorbing because there is no physical boundary around the source. This is modeled using perfectly matched layers.

Results and Discussion

The acoustic wavelength decreases for a wavefront moving in the opposite direction of the airflow. This situation corresponds to the approach stage of the ambulance, which, for the stationary observer on the ground, implies a perceived frequency that is higher than the nominal source frequency f. Conversely, the wavelength increases and the perceived frequency decreases when the acoustic wave moves with the flow during the departing stage. These two stages correspond, respectively, to the solid and dashed curves in Figure 1.

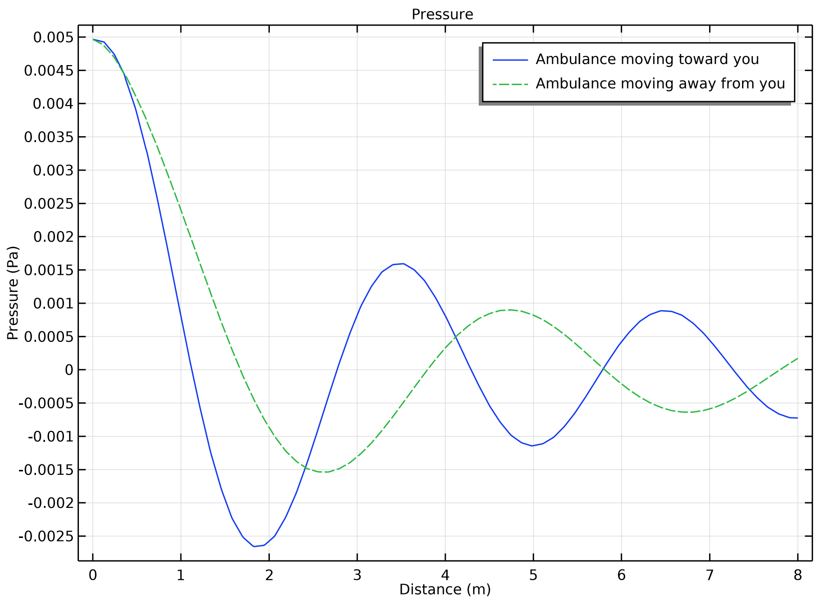


Figure 1: The x-axis represents the distance between the ambulance and the point where it passes the observer. The solid line shows the pressure perceived by the observer as the ambulance is moving toward it. The dashed line shows the pressure as the ambulance is moving away from the observer.

An inspection of Figure 1 also shows that the amplitude drops off at a faster rate when the ambulance is moving away from the observer than when it is moving toward it. This effect is also visible in Figure 2 and Figure 3, which both show the sound pressure level.

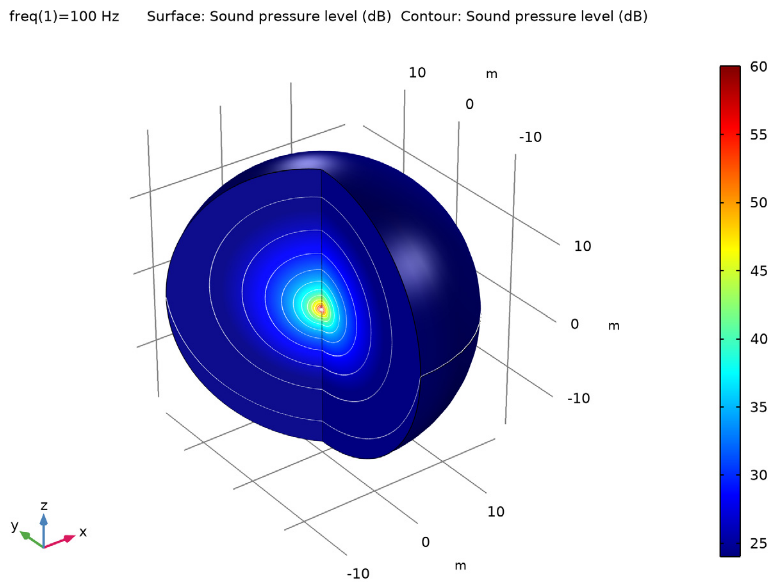


Figure 2: Sound pressure level around the point source, represented by colors and contour lines. Note how the outermost contour runs from well inside the physical domain to the PML, showing that the sound is greater below than above the source.

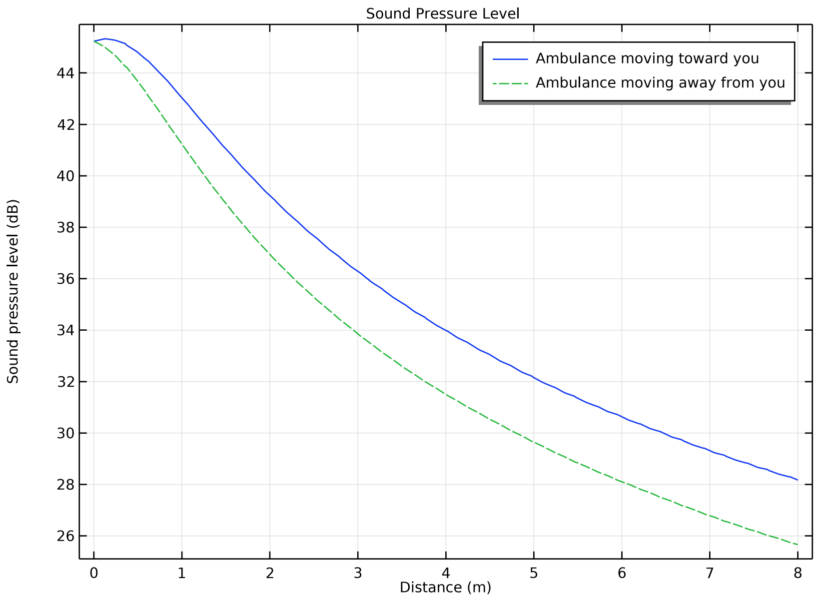


Figure 3: Sound pressure level at the observer's position during the ambulance's approach (solid, blue line) and departing (dashed, green line) versus distance from the position (r, z) = (1 m, 0) *(where the observer-ambulance distance is the smallest).*

Application Library path: `Acoustics_Module/Aeroacoustics_and_Noise/doppler_shift`

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 **2D Axisymmetric**.
2. In the **Select Physics** tree, select **Acoustics>Aeroacoustics>Linearized Potential Flow, Frequency Domain (ae)**.

3 Click **Add**.

4 Click **Study**.

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

6 Click **Done**.

GLOBAL DEFINITIONS

Define parameters for the background flow conditions, the signal frequency, and the geometry.

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
V	50[m/s]	50 m/s	Ambulance speed
f0	100[Hz]	100 Hz	Signal frequency
R0	20[m]	20 m	Computational domain radius
dRpml	2[m]	2 m	PML thickness

GEOMETRY 1

Circle 1 (c1)

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

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

3 In the **Radius** text field, type R0.

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

5 Locate the **Rotation Angle** section. In the **Rotation** text field, type -90.

6 Click to expand the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (m)
Layer 1	dRpml

Point 1 (pt1)

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

2 In the **Settings** window for **Point**, click **Build All Objects**.

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>Air**.

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

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

DEFINITIONS

Perfectly Matched Layer 1 (pml1)

1 In the **Definitions** toolbar, click **Perfectly Matched Layer**.

2 Select Domains 1 and 3 only.

LINEARIZED POTENTIAL FLOW, FREQUENCY DOMAIN (AE)

Linearized Potential Flow Model 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Linearized Potential Flow, Frequency Domain (ae)** click **Linearized Potential Flow Model 1**.

2 In the **Settings** window for **Linearized Potential Flow Model**, locate the **Linearized Potential Flow Model** section.

3 Specify the **V** vector as

-V	z

Mass Flow Point Source 1

1 In the **Physics** toolbar, click **Points** and choose **Mass Flow Point Source**.

2 Select Point 3 only.

3 In the **Settings** window for **Mass Flow Point Source**, locate the **Mass Flow Point Source** section.

4 In the m' text field, type `1e-4`.

Now, set up a mesh for the model. The maximal mesh size is dictated by the shortest wavelength in the model divided by 12 to produce smoother results, but this factor can be reduced to 4 if the main focus is the general trend of the model. In the PML region, use a mapped mesh with 8 layers.

MESH 1

Free Triangular 1

1 In the **Mesh** toolbar, click **Free Triangular**.
2 In the **Settings** window for **Free Triangular**, locate the **Domain Selection** section.
3 From the **Geometric entity level** list, choose **Domain**.
4 Select Domain 2 only.

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 `(343[m/s]-V)/f0/12`.
5 Click **Build All**.

Mapped 1

In the **Mesh** toolbar, click **Mapped**.

Distribution 1

1 Right-click **Mapped 1** and choose **Distribution**.
2 Select Boundary 5 only.
3 In the **Settings** window for **Distribution**, locate the **Distribution** section.
4 In the **Number of elements** text field, type `8`.
5 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

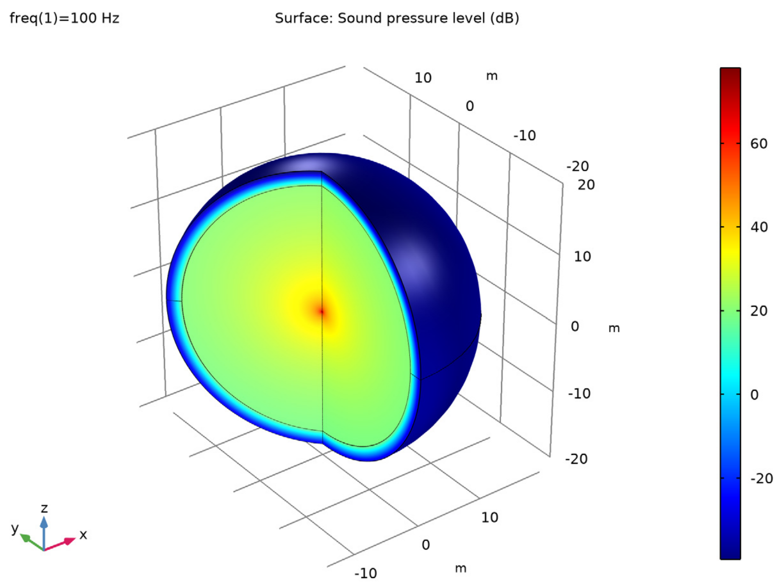
The default plot groups contain plots of the pressure and the sound pressure level, in 2D and 3D.

Sound Pressure Level, 3D (ae)

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

2 In the **Model Builder** window, under **Results** click **Sound Pressure Level, 3D (ae)**.

3 In the **Sound Pressure Level, 3D (ae)** toolbar, click **Plot**.



Contour 1

1 Right-click **Sound Pressure Level, 3D (ae)** 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)> Linearized Potential Flow, Frequency Domain>Pressure and sound pressure level>ae.Lp - Sound pressure level - dB**.

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

4 From the **Color** list, choose **White**.

5 Clear the **Color legend** check box.

6 In the **Sound Pressure Level, 3D (ae)** toolbar, click **Plot**.

The plot is now dominated by the roughly 50 dB losses in the PML. To see only the physical domain, make a selection as follows.

Study 1/Solution 1 (sol1)

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

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.

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

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

4 Select Domain 2 only.

Sound Pressure Level, 3D (ae)

Removing the PML from the visualization moves the bias in the color scale toward the value in the source point. Mathematically, the pressure in the vicinity of this point is inversely proportional to the distance from the point. In the point itself, this means an infinitely high pressure. The discretization results in a finite but completely mesh-dependent value (the finer the mesh, the higher the pressure). The flow from the point however is well-defined and results in a converging pressure distribution at any finite distance away from the point. To suppress the highest values and get a better picture of the sound pressure level distribution, you can set the plot range manually.

Surface

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

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

3 Select the **Manual color range** check box.

4 In the **Minimum** text field, type 24.

5 In the **Maximum** text field, type 60.

6 In the **Sound Pressure Level, 3D (ae)** toolbar, click **Plot**.

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

In order to recreate the line plots in the Results and Discussion section, you first need to create two cut lines, one going up and one going down from the starting point 1 m out from the source.

Cut Line 2D 1

1 In the **Results** toolbar, click **Cut Line 2D**.

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

3 In row **Point 1**, set **R** to 1 and **z** to 0.

4 In row **Point 2**, set **R** to 1 and **z** to 8.

5 Click **Plot**.

Cut Line 2D 2

1 In the **Results** toolbar, click **Cut Line 2D**.

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

3 In row **Point 1**, set **R** to `1` and **z** to `0`.

4 In row **Point 2**, set **R** to `1` and **z** to `-8`.

5 Click **Plot**.

With the cut lines defined, create a 1D plot group for the first plot.

Pressure on Cut Lines

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

2 In the **Settings** window for **1D Plot Group**, type `Pressure on Cut Lines` in the **Label** text field.

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

4 In the **Title** text area, type `Pressure`.

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

6 In the associated text field, type `Distance (m)`.

Line Graph 1

1 Right-click **Pressure on Cut Lines** and choose **Line Graph**.

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

3 From the **Dataset** list, choose **Cut Line 2D 1**.

4 Click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Linearized Potential Flow, Frequency Domain>Pressure and sound pressure level>ae.p - Pressure - Pa**.

5 Click to expand the **Legends** section.

Line Graph 2

1 Right-click **Line Graph 1** and choose **Duplicate**.

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

3 From the **Dataset** list, choose **Cut Line 2D 2**.

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

Add legends to the plot.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

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

3 Select the **Show legends** check box.

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

5 In the table, enter the following settings:

Legends
`Ambulance moving toward you`

Line Graph 2

1 In the **Model Builder** window, click **Line Graph 2**.

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

3 Select the **Show legends** check box.

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

5 In the table, enter the following settings:

Legends
`Ambulance moving away from you`

Create another plot group for the second line plot.

6 In the **Pressure on Cut Lines** toolbar, click **Plot**.

SPL on Cut Lines

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

2 In the **Settings** window for **1D Plot Group**, type `SPL on Cut Lines` in the **Label** text field.

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

4 In the **Title** text area, type `Sound Pressure Level`.

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

6 In the associated text field, type `Distance (m)`.

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

8 In the associated text field, type `Sound pressure level (dB)`.

Line Graph 1

1 Right-click **SPL on Cut Lines** and choose **Line Graph**.

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

3 From the **Dataset** list, choose **Cut Line 2D 1**.

4 Click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Linearized Potential Flow, Frequency Domain>Pressure and sound pressure level>ae.Lp - Sound pressure level - dB**.

Line Graph 2

1 Right-click **Line Graph 1** and choose **Duplicate**.

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

3 From the **Dataset** list, choose **Cut Line 2D 2**.

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

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

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

3 Select the **Show legends** check box.

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

5 In the table, enter the following settings:

Legends
`Ambulance moving toward you`

Line Graph 2

1 In the **Model Builder** window, click **Line Graph 2**.

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

3 Select the **Show legends** check box.

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

5 In the table, enter the following settings:

Legends
`Ambulance moving away from you`

6 In the **SPL on Cut Lines** toolbar, click **Plot**.