Created in COMSOL Multiphysics 5.6

Acoustic Levitator

Introduction

An ultrasonic standing wave levitator, also called acoustic levitator, is a device used for levitating fluid and solid particles in an acoustic field. The standing acoustic waves exert an acoustic radiation force on the particles. The force is a second order effect and stems from a combination of the time-averaged pressure and inertial interaction between the particles and the acoustic field.

By levitating a particle, it is possible to study, for example, its drying kinetics under different external conditions as temperature and humidity (see Ref. 1). The levitator has also been used to study combustion processes, the formation of ice particles and snow flakes, and is also used as an acoustic tweezer in microgravity in space missions, for example.

The model is that of a simplified 2D acoustic levitator geometry driven at a constant frequency. Small elastic particles are released uniformly in the standing acoustic field and their path is determined when influenced by the acoustic radiation force, viscous drag, and gravity.

Model Definition

The levitator consists of a transducer of width D_t and a concave reflector of width D_r and curvature $1/R$. The distance between the reflector and the transducer is H. The driving frequency of the system is f_0 = 58 kHz and the system is filled with air at 20°C. The geometry is shown in Figure 1. Standard values for the dimensions of the levitator are given in Ref. 2 and are as follows in the model:

TABLE 1: STANDARD DIMENSIONS AND PHYSICAL VALUES.

SYMBOL	VALUE	DESCRIPTION
c_0	343 m/s	Speed of sound
f_0	58 kHz	Driving frequency
λ_0	5.9 mm	Wavelength
$D_t = 2\lambda_0$	11.8 mm	Transducer diameter
$D_r = 3\lambda_0$	17.7 mm	Reflector diameter
$H = 5\lambda_0/2$	14.8 mm	Reflector-transducer distance
$R = H$	14.8 mm	Radius of curvature of reflector

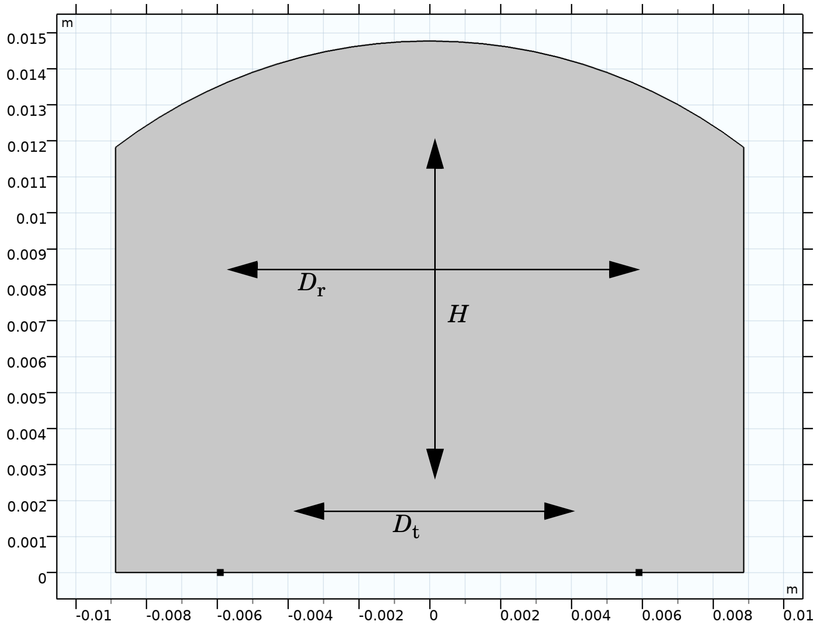


Figure 1: Levitator geometry.

In this model, the particle diameter d_p is assumed to be small compared to the wavelength λ_0 as they are modeled as point particles. The condition $d_p << \lambda_0$ is also necessary for the acoustic radiation force term to be physically correct. The second condition is that the particle diameter d_p should be larger than the acoustic viscous boundary layer thickness δ_v. In the present system δ_v is of the order 10 µm. Table 2 lists the particle properties uses in this model.

TABLE 2: PARTICLE PROPERTIES.

SYMBOL	**VALUE**	**DESCRIPTION**
d_p	0.6 mm	Particle diameter
ρ_p	500 kg/m^3	Particle density
K_p	2.2 GPa	Particle bulk modulus

The particles are released in the standing acoustic wave field in the levitator. The pressure field is shown in Figure 2, with plane wave radiation conditions at the open boundaries. The corresponding sound pressure level in the system is shown in Figure 3.

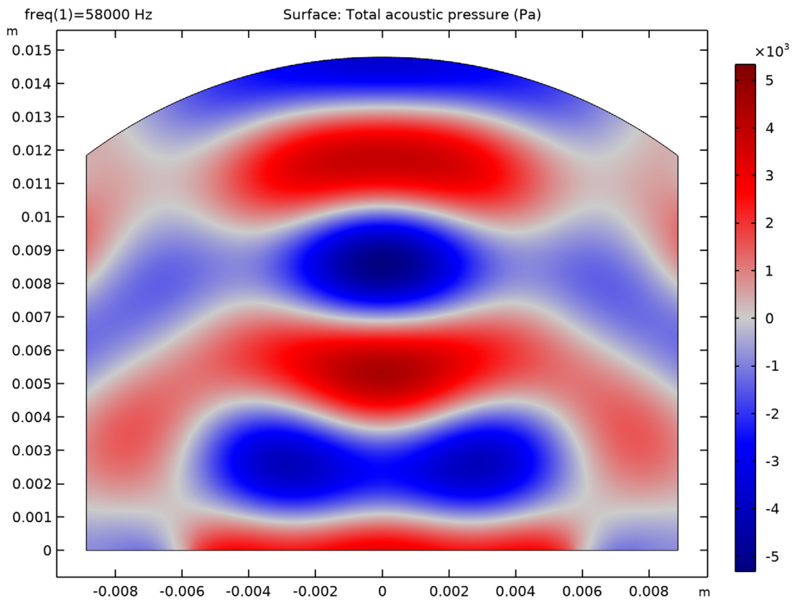


Figure 2: Real part of the pressure field, Re(p).

Note that the sound pressure level reaches as much as 166 dB SPL. Fortunately for the practical application of this device, this is outside the human auditory range. By tuning the amplitude of the normal acceleration of the transducer `a0` (under parameters in the model tree), it is possible to determine the value at which the radiation force is no longer large enough to levitate the particles.

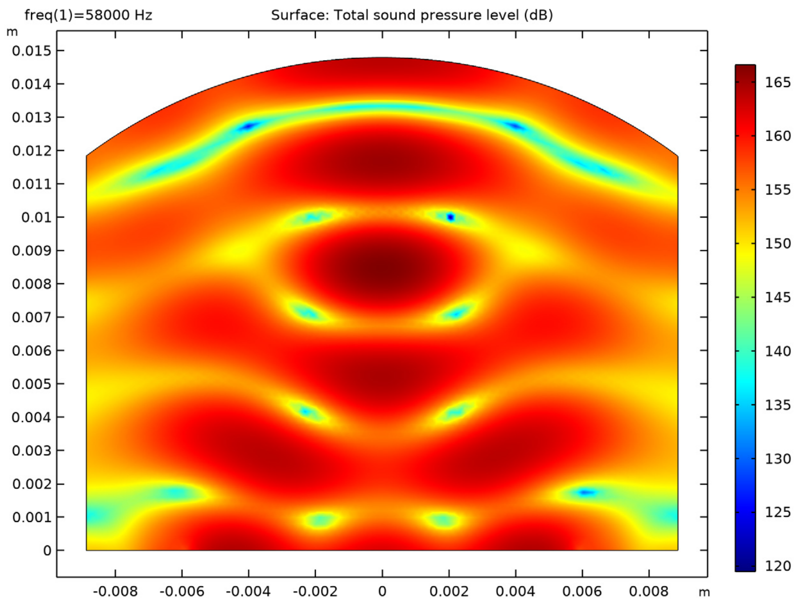
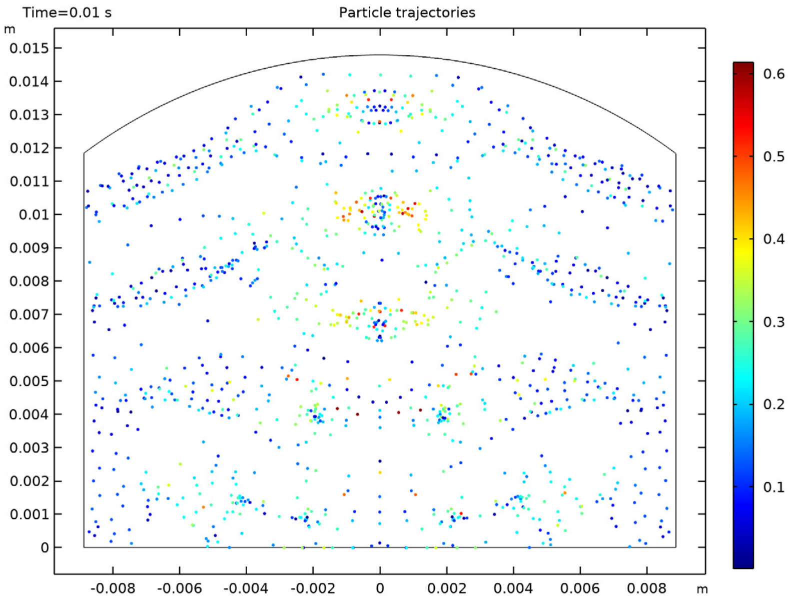


Figure 3: Sound pressure levels in the levitator.

The positions of the particles at $t = 0.01$ s and $t = 0.3$ s are shown in Figure 4.



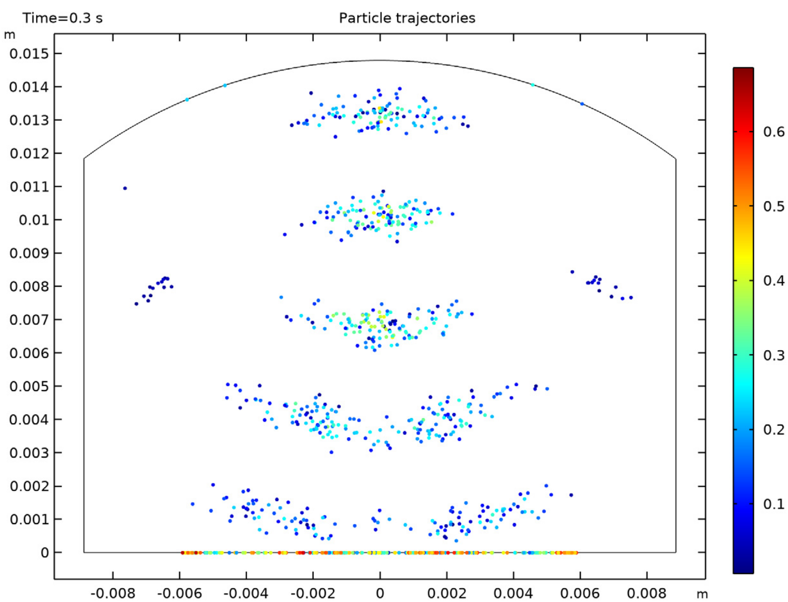


Figure 4: Positions of the particles at t = 0.01 s (top) and t = 0.3 s (bottom). The colors refer to the instantaneous particle velocities.

Finally, the particle position and their trajectories is shown in Figure 5 using the magnitude of the radiation potential as color legend. Since the radiation force is defined as the gradient of the radiation potential, it is clear that the particles tend toward the lowest potential value.

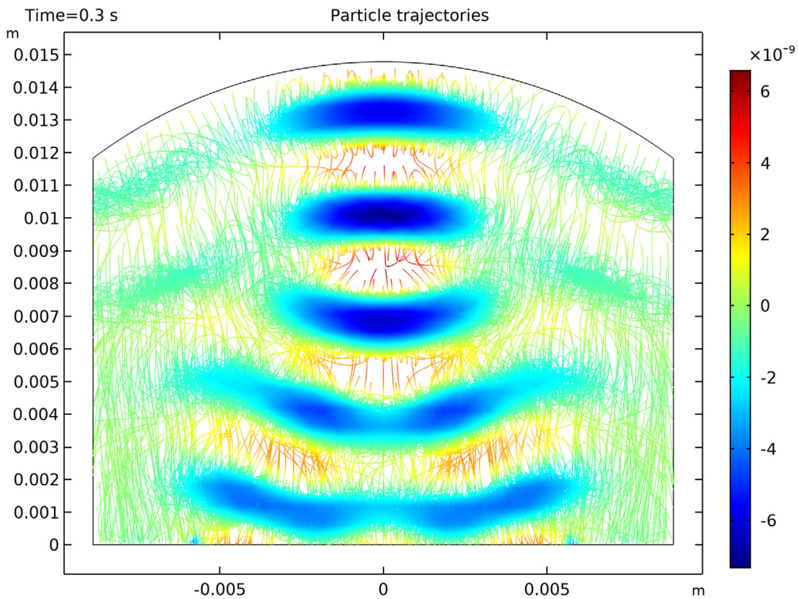


Figure 5: Particle position and trajectories plotted using the radiation potential as coloring.

References

1. A. Brask, T. Ullum, P. Thybo, and M. Wahlberg, "High-Temperature Ultrasonic Lavitator for Investigating Drying Kinetics of Single Droplets", *6th Int. Conf. on Multiphase Flow, ICMF 2007, (Leipzig, July 9-13)*, paper 789, 2007.

2. E.G. Lierke and L. Holitzner, "Perspectives of an Acoustic-Electrostatic/ Electrodynamic Hybrid Levitator for Small Fluid and Solid Samples", *Meas. Sci. Technol.*, vol. 19, p. 115803, 2008.

Application Library path: `Particle_Tracing_Module/Fluid_Flow/acoustic_levitator`

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

NEW

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

MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.

2 In the **Select Physics** tree, select **Acoustics>Pressure Acoustics>Pressure Acoustics, Frequency Domain (acpr)**.

3 Click **Add**.

4 In the **Select Physics** tree, select **Fluid Flow>Particle Tracing>Particle Tracing for Fluid Flow (fpt)**.

5 Click **Add**.

6 Click **Study**.

7 In the **Select Study** tree, select **Preset Studies for Some Physics Interfaces>Frequency Domain**.

8 Click **Done**.

STUDY 1

In this model, you first solve for the acoustic field in the frequency domain. Therefore, deselect the Particle Tracing for Fluid Flow physics.

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 **Physics and Variables Selection** section.

3 In the table, clear the **Solve for** check box for **Particle Tracing for Fluid Flow (fpt)**.

As a second step, you solve for the particle movement in the time domain.

ADD STUDY

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

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

3 Find the **Physics interfaces in study** subsection. In the table, clear the **Solve** check box for **Pressure Acoustics, Frequency Domain (acpr)**.

4 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies> Time Dependent**.

5 Click **Add Study** in the window toolbar.

6 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

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 `acoustic_levitator_parameters.txt`.

The parameters loaded here define the geometrical dimensions, the driving frequency, typical wavelength, and particle properties. Because the geometry is now parameterized, changing the dimensions in the parameters list will update the geometry automatically.

GEOMETRY 1

Circle 1 (c1)

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

2 Right-click **Geometry 1** and choose **Circle**.

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

4 In the **Radius** text field, type `H`.

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

6 Click **Build Selected**.

Rectangle 1 (r1)

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

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

3 In the **Width** text field, type `Dr`.

4 In the **Height** text field, type `H`.

5 Locate the **Position** section. In the **x** text field, type `-Dr/2`.

6 Click **Build Selected**.

Intersection 1 (int1)

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

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

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

Point 1 (pt1)

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

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

3 In the **x** text field, type `-Dt/2`.

4 Click **Build Selected**.

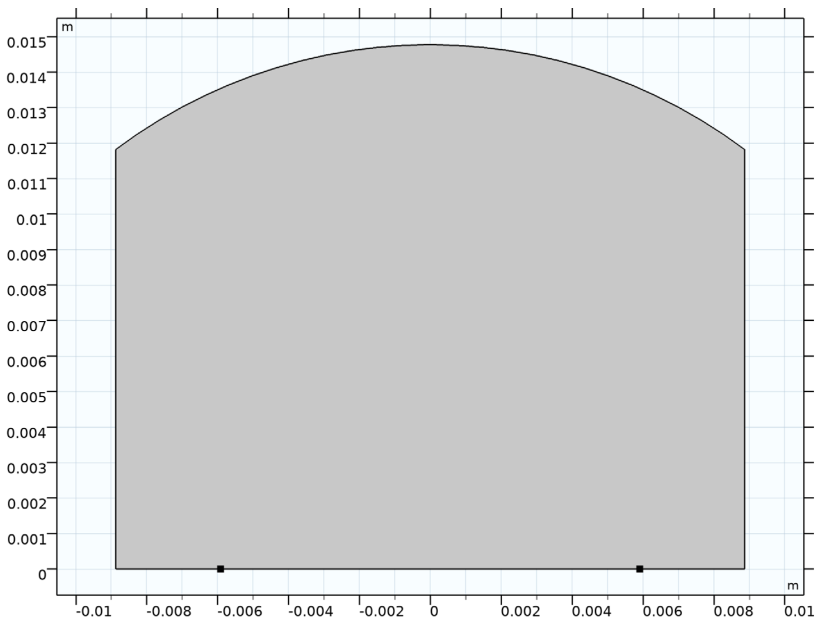
Point 2 (pt2)

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

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

3 In the **x** text field, type `Dt/2`.

4 Click **Build Selected**.



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.

PRESSURE ACOUSTICS, FREQUENCY DOMAIN (ACPR)

Normal Acceleration 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Pressure Acoustics, Frequency Domain (acpr)** and choose **Normal Acceleration**.

2 Select Boundaries 3 and 4 only.

3 In the **Settings** window for **Normal Acceleration**, locate the **Normal Acceleration** section.

4 In the a_n text field, type `a0`.

Plane Wave Radiation 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Plane Wave Radiation**.

2 Select Boundaries 1, 2, 5, and 6 only.

PARTICLE TRACING FOR FLUID FLOW (FPT)

Particle Properties 1

1 In the **Model Builder** window, under **Component 1 (comp1)> Particle Tracing for Fluid Flow (fpt)** click **Particle Properties 1**.

2 In the **Settings** window for **Particle Properties**, locate the **Particle Properties** section.

3 From the ρ_p list, choose **User defined**. In the associated text field, type `rho_p`.

4 In the d_p text field, type `d_p`.

Wall 2

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

2 Select Boundaries 1, 2, 5, and 6 only.

3 In the **Settings** window for **Wall**, locate the **Wall Condition** section.

4 From the **Wall condition** list, choose **Disappear**.

Particles are set to freeze on the solid walls but they disappear where the system is open (at the radiation boundaries).

Release 1

1 In the **Physics** toolbar, click **Domains** and choose **Release**.

2 Select Domain 1 only.

Acoustophoretic Radiation Force 1

1 In the **Physics** toolbar, click **Domains** and choose **Acoustophoretic Radiation Force**.

2 In the **Settings** window for **Acoustophoretic Radiation Force**, locate the **Acoustic Fields** section.

3 From the p list, choose **Pressure (acpr)**.

4 From the $\mathbf{u}$ list, choose **Total acoustic velocity (acpr/fpam1)**.

5 Locate the **Advanced Settings** section. Select the **Use piecewise polynomial recovery on field** check box.

6 Select Domain 1 only.

Gravity Force 1

1 In the **Physics** toolbar, click **Domains** and choose **Gravity Force**.

2 Select Domain 1 only.

Drag Force 1

1 In the **Physics** toolbar, click **Domains** and choose **Drag Force**.

2 Select Domain 1 only.

MESH 1

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

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

3 From the **Sequence type** list, choose **User-controlled mesh**.

Size

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

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

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section. In the **Maximum element size** text field, type `lam0/8`.

Free Triangular 1

In the **Model Builder** window, right-click **Free Triangular 1** and choose **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

Acoustic Pressure (acpr)

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

This first figure should look like the one in Figure 2.

Sound Pressure Level (acpr)

The sound pressure level plot should look like Figure 3.

STUDY 2

Step 1: Time Dependent

1 In the **Model Builder** window, under **Study 2** click **Step 1: Time Dependent**.

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

3 In the **Output times** text field, type `range(0,0.0005,0.3)`.

4 Click to expand the **Values of Dependent Variables** section. Find the **Values of variables not solved for** subsection. From the **Settings** list, choose **User controlled**.

5 From the **Method** list, choose **Solution**.

6 From the **Study** list, choose **Study 1, Frequency Domain**.

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

RESULTS

Particle Trajectories (fpt)

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

2 From the **Time (s)** list, choose **0.01**.

3 In the **Particle Trajectories (fpt)** toolbar, click **Plot**.

The particle position at t = 0.01s is reproduced in Figure 4 (top).

4 From the **Time (s)** list, choose **0.3**.

5 In the **Particle Trajectories (fpt)** toolbar, click **Plot**.

The particle position at t = 0.3s is reproduced in Figure 4 (bottom).

As an optional extension of the model, you can go on to the **Export** node and animate the particle plot.