

Supplemental Material for “Vortex Modes in Acoustofluidic Cylindrical Resonators”

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This document contains the report generated by COMSOL Multiphysics (Version 6.1, COMSOL AB, Sweden) for the finite element simulation of the dual vortex mode $(200) + (100)$ using a three-dimensional mesh. The simulation was conducted using the *Thermoviscous Acoustics* module under the adiabatic assumption for the fluid. The number of degrees of freedom (DOFs) in this simulation is 2217476, requiring a moderate computational system (with at least 200 GB of memory) to efficiently perform the calculations. The report provides a summarized overview of the main steps required to set up and execute the simulation, including key computational parameters, boundary conditions, and solver settings. This supplementary material aims to enhance the reproducibility of our numerical results and facilitate further exploration of vortex mode behavior in acoustofluidic resonators.

Mode (200)+(100)



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Company

GAFM

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1 Global Definitions

USED PRODUCTS

Acoustics Module
COMSOL Multiphysics

1.1 PARAMETERS

PARAMETERS 1

Name	Expression	Value	Description
f	2.992[MHz]	2.992E6 Hz	frequency
r_c	0.97219 *h_c	2.4305E-4 m	radius of cavity
h_c	250[um]	2.5E-4 m	height of cavity
rho_a	997 [kg/m^3]	997 kg/m ³	water density
c_a	1496.7[m/s]	1496.7 m/s	speed of sound in the water
n_ordem	2	2	Bessel order
lambda	c_a/f	5.0023E-4 m	wavelength
visc.d	sqrt(etas/(f_base*rho_a*pi))	3.0654E-7 m	boundary layer
etas	0.88[mPa*s]	8.8E-4 Pa*s	Shear viscosity
etab	2.47[mPa*s]	0.00247 Pa*s	Bulk viscosity
f_base	2.99[MHz]	2.99E6 Hz	frequency base
kr20	3.05424/r_c	12566 1/m	wavenumber
va	1[mm/s]	0.001 m/s	excitation velocity
P0	1[atm]	1.0133E5 Pa	equilibrium pressure
T0	293.15[K]	293.15 K	equilibrium temperature

2 Component 1

2.1 DEFINITIONS

1. Variables

Variables 1

SELECTION

Geometric entity level	Entire model
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Name	Expression	Unit	Description
j2	besselj(n_ordem, kr20*sys2.r)		

2. Coordinate Systems

Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

COORDINATE NAMES

First	Second	Third
t1	t2	n

Cylindrical System 2

Coordinate system type	Cylindrical system
Tag	sys2

COORDINATE NAMES

First	Second	Third
r	phi	a

SETTINGS

x (m)	y (m)	z (m)
0	0	0

SETTINGS

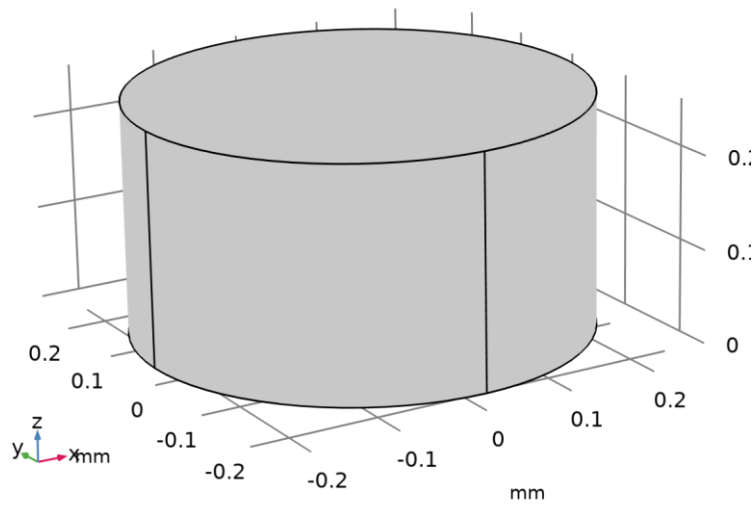
x	y	z
0	0	1

SETTINGS

x	y	z
---	---	---

x	y	z
1	0	0

2.2 GEOMETRY 1



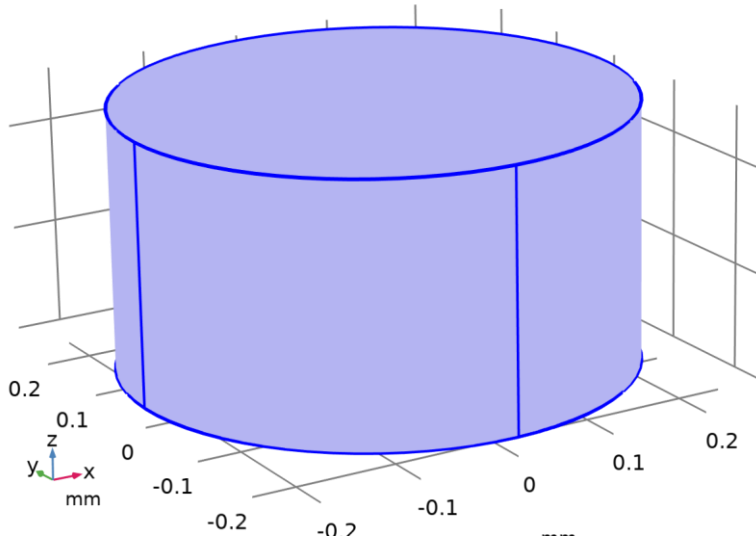
Geometry 1

UNITS

Length unit	mm
Angular unit	deg

2.3 MATERIALS

3. Water, liquid



Water, liquid

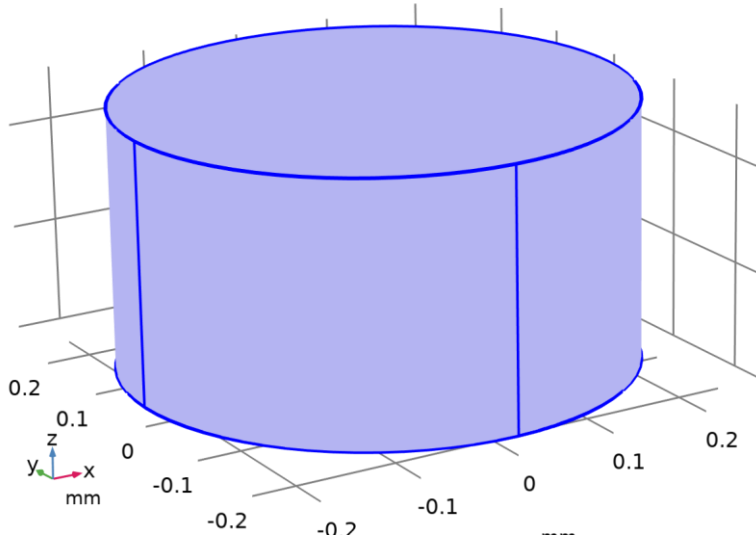
SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 3: All domains

MATERIAL PARAMETERS

Name	Value	Unit	Property group
Bulk viscosity	etab	Pa·s	Basic
Dynamic viscosity	etas	Pa·s	Basic
Density	rho_a	kg/m ³	Basic
Speed of sound	c_a	m/s	Basic

2.4 THERMOVISCOUS ACOUSTICS, FREQUENCY DOMAIN



Thermoviscous Acoustics, Frequency Domain

EQUATIONS

$$i\omega\rho_t + \nabla \cdot (\rho_0 \mathbf{u}_t) = 0$$

$$i\omega\rho_0 \mathbf{u}_t = \nabla \cdot \boldsymbol{\sigma}$$

$$\boldsymbol{\sigma} = -p_t \mathbf{I} + \mu (\nabla \mathbf{u}_t + (\nabla \mathbf{u}_t)^T) - \left(\frac{2}{3}\mu - \mu_B\right) (\nabla \cdot \mathbf{u}_t) \mathbf{I}$$

$$\rho_t = \rho_0 (\beta_T p_t - \alpha_p T_t)$$

$$\alpha_p = \frac{1}{c} \sqrt{\frac{C_p(\gamma - 1)}{T_0}}$$

$$\beta_T = \frac{1}{\rho_0} \frac{\gamma}{c^2}$$

Fluid Properties

SETTINGS

Description	Value	Unit
Equilibrium density	From material	
Dynamic viscosity	From material	
Bulk viscosity	From material	
Heat capacity at constant pressure	User defined	
Heat capacity at constant pressure	1	J/(kg·K)

Thermal Expansion and Compressibility

SETTINGS

Description	Value
Coefficient of thermal expansion	From speed of sound
Isothermal compressibility	From speed of sound
Speed of sound	From material
Ratio of specific heats	User defined
Ratio of specific heats	1

Model Input

SETTINGS

Description	Value	Unit
Equilibrium pressure	User defined	
Absolute pressure	P0	Pa
Equilibrium temperature	User defined	
Temperature	T0	K

PROPERTIES FROM MATERIAL

Property	Material	Property group
Dynamic viscosity	Water, liquid	Basic
Bulk viscosity	Water, liquid	Basic
Density	Water, liquid	Basic
Speed of sound	Water, liquid	Basic

FEATURES

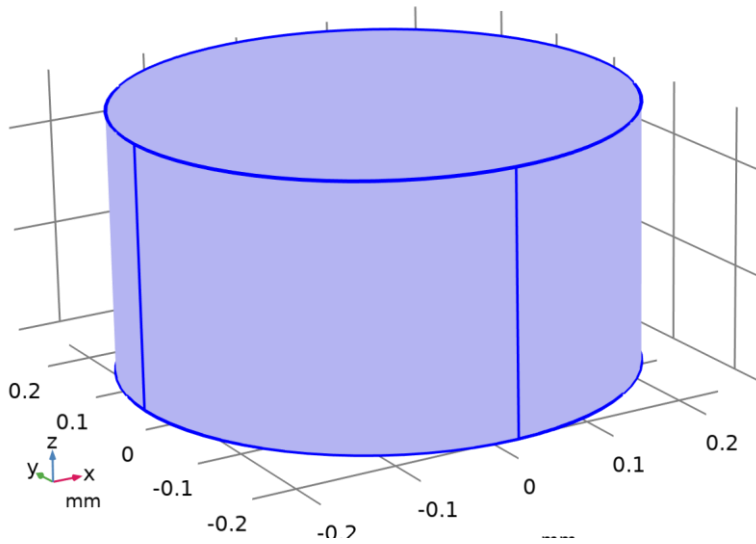
Name	Level
Thermoviscous Acoustics Model 1	Domain
Wall 1	Boundary
Initial Values 1	Domain
Velocity 1	Boundary

Thermoviscous Acoustics Equation Settings

SETTINGS

Description	Value
Adiabatic formulation	On

2.4.1 Wall 1



Wall 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 2: All boundaries

EQUATIONS

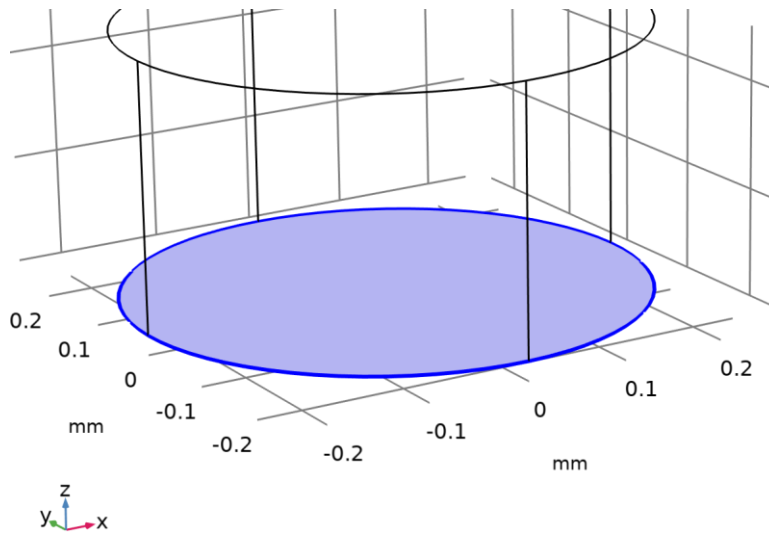
$$\mathbf{u}_t = \mathbf{0}$$

Mechanical

SETTINGS

Description	Value
Mechanical condition	No slip

2.4.2 Velocity 1



Velocity 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 2: Boundary 3

EQUATIONS

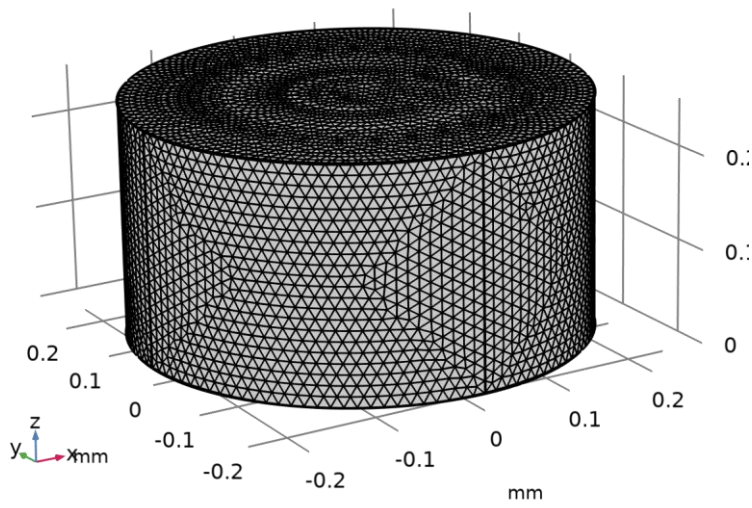
$$\begin{aligned} u_{tr} &= u_{0r} \\ u_{tphi} &= u_{0phi} \\ u_{ta} &= u_{0a} \end{aligned}$$

Velocity

SETTINGS

Description	Value	Unit
Prescribed in r direction	On	
Prescribed in phi direction	On	
Prescribed in a direction	On	
Velocity constraint, r-component	0	m/s
Velocity constraint, phi-component	0	m/s
Velocity constraint, a-component	$va \cdot (1 + j2 \cdot \exp(i \cdot n_ordem \cdot \text{sys2} \cdot \text{phi}))$	m/s

2.5 MESH 1



Mesh 1

3 Study 13

COMPUTATION INFORMATION

Computation time	2 h 10 min 45 s
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3.1 FREQUENCY DOMAIN

Frequencies (MHz)

f

STUDY SETTINGS

Description	Value
Include geometric nonlinearity	Off

STUDY SETTINGS

Description	Value
Frequency unit	MHz

SETTINGS

Description	Value
Frequencies	2.992E6

PHYSICS AND VARIABLES SELECTION

Physics interface	Solve for	Equation form
Thermoviscous Acoustics, Frequency Domain (ta)	On	Automatic (Frequency domain)

MESH SELECTION

Component	Mesh
Component 1	Mesh 1

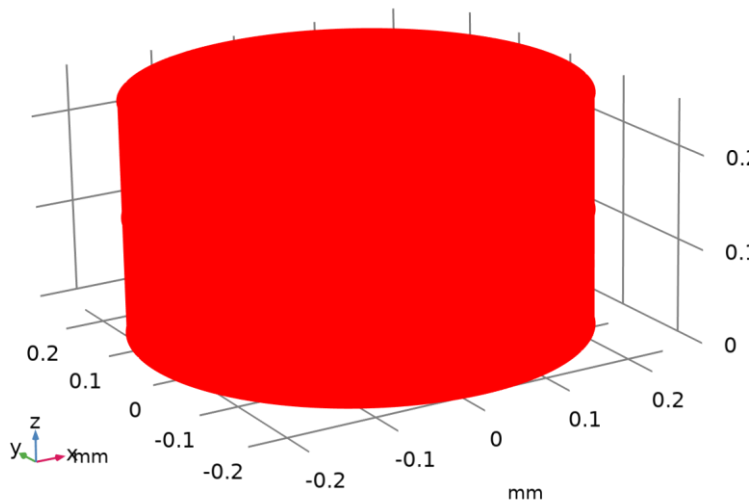
4 Results

4.1 DATASETS

4. Study 13/Solution 163

SOLUTION

Description	Value
Solution	Solution 163
Component	Component 1 (comp1)



Dataset: Study 13/Solution 163

5. Cut Plane 30

DATA

Description	Value
Dataset	Study 13/Solution 163

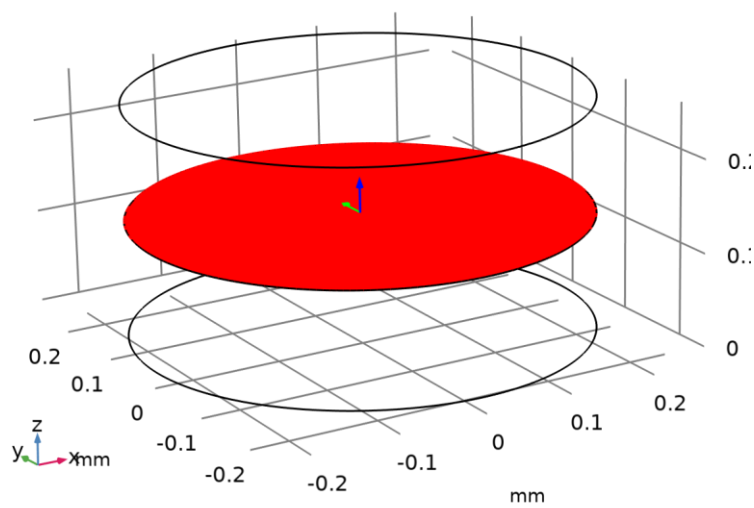
PLANE DATA

Description	Value
Plane type	Quick
Plane	XY - planes
Z-coordinate	$h_c/2$

ADVANCED

Description	Value
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Description	Value
Space variables	{cpl30x, cpl30y}
Normal variables	{cpl30nx, cpl30ny, cpl30nz}



Dataset: Cut Plane 30

4.2 TABLES

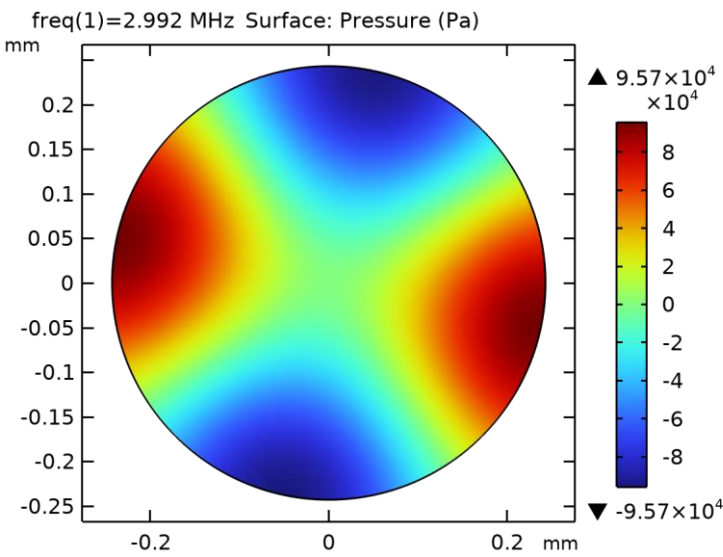
6. Evaluation 2D

Interactive 2D values

x	y	Value
0.093398	0.15786	-49423
-0.24217	0.013949	4.0879E5

4.3 PLOT GROUPS

7. Pressure



Surface: Pressure (Pa)