Acoustic Modeling using COMSOL MultiPhysics

Dr. Gopal Mathur

President, Meta Acoustic Technologies Inc., CA
Previously (Retired) Boeing Technical Fellow
Boeing Research & Technology, The Boeing Company

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Outline

- Introduction
- COMSOL Acoustic Module
- Acoustic Absorption Measurements
- Porous Absorber – 2D Model
- Porous Absorber – 3D Model
- Acoustic Model: APU Exhaust Muffler
- Summary

COMSOL: Acoustics

For Pressure Acoustics, the PDE is Helmholtz equation:

$$\nabla \cdot \left(\left(\frac{1}{\rho_0} \right) \nabla \underline{p} \right) + \left(\frac{1}{\rho_0} \right) \left(\frac{\omega}{c} \right)^2 \underline{p} = 0 \xrightarrow[\text{density}]{\text{Constant}} \nabla^2 \underline{p} + \left(\frac{\omega}{c} \right)^2 \underline{p} = 0$$

$\underline{p}(x, y, z)$ ← Solved for in Comsol

$$p(x, y, z, t) = \mathrm{Re}\left\{ \underline{p}(x, y, z) \cdot e^{j\omega t} \right\}$$

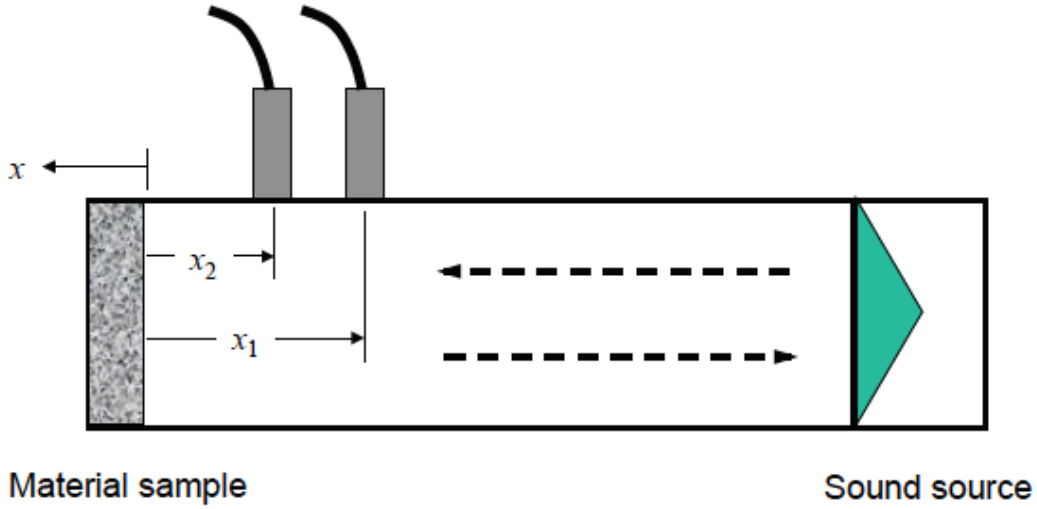
$$p_{rms}(x, y, z) = \frac{1}{\sqrt{2}} \left| \underline{p}(x, y, z) \right|$$

$$SPL(x, y, z) = 20 \log_{10} \left(\frac{p_{rms}(x, y, z)}{p_{ref}} \right)$$

Can be easily computed in post processing using post processing tools inside Comsol.

Porous Absorber – Acoustic Absorption Measurements

Measurement of Acoustic Absorption Coefficient – Impedance Tube



Total sound pressure at any point in the tube:

$$P(x) = Ae^{-jkx} + Be^{jkx}$$

+x traveling wave

-x traveling wave

The transfer function between points 1 and 2:

$$H_{12} = \frac{P(x_2)}{P(x_1)} = \frac{Ae^{-jkx_2} + Be^{jkx_2}}{Ae^{-jkx_1} + Be^{jkx_1}} = \frac{e^{-jkx_2} + Re^{jkx_2}}{e^{-jkx_1} + Re^{jkx_1}}$$

$R = \frac{B}{A}$ is the pressure reflection coefficient of the material

Measurement of Acoustic Absorption Coefficient – Impedance Tube

Solving for R:

$$R = \frac{e^{-jkx_2} - H_{12}e^{-jkx_1}}{H_{12}e^{jkx_1} - e^{jkx_2}}$$

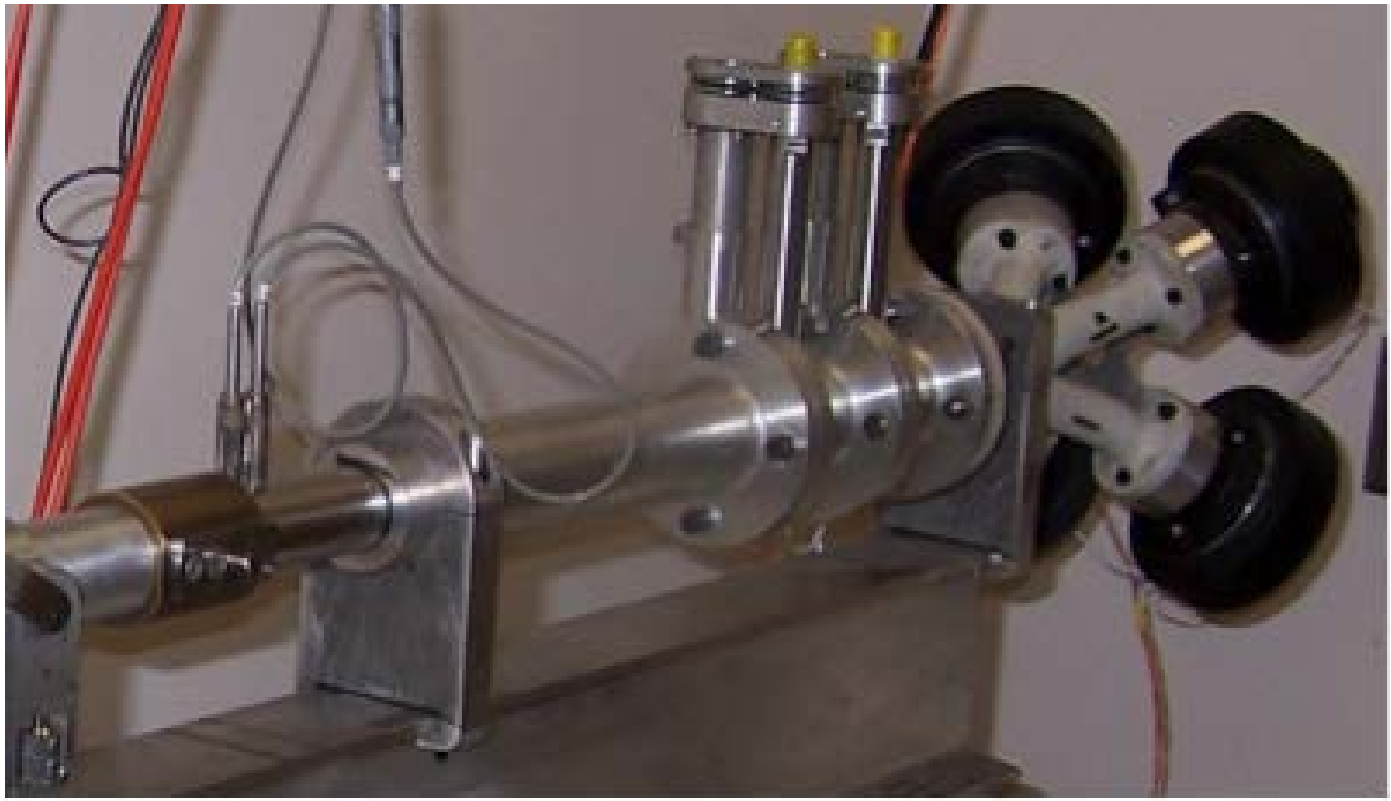
Normalized specific boundary impedance:

$$\frac{z}{\rho_o c} = \frac{1+R}{1-R}$$

Sound absorption coefficient of the material for any angle of incidence :

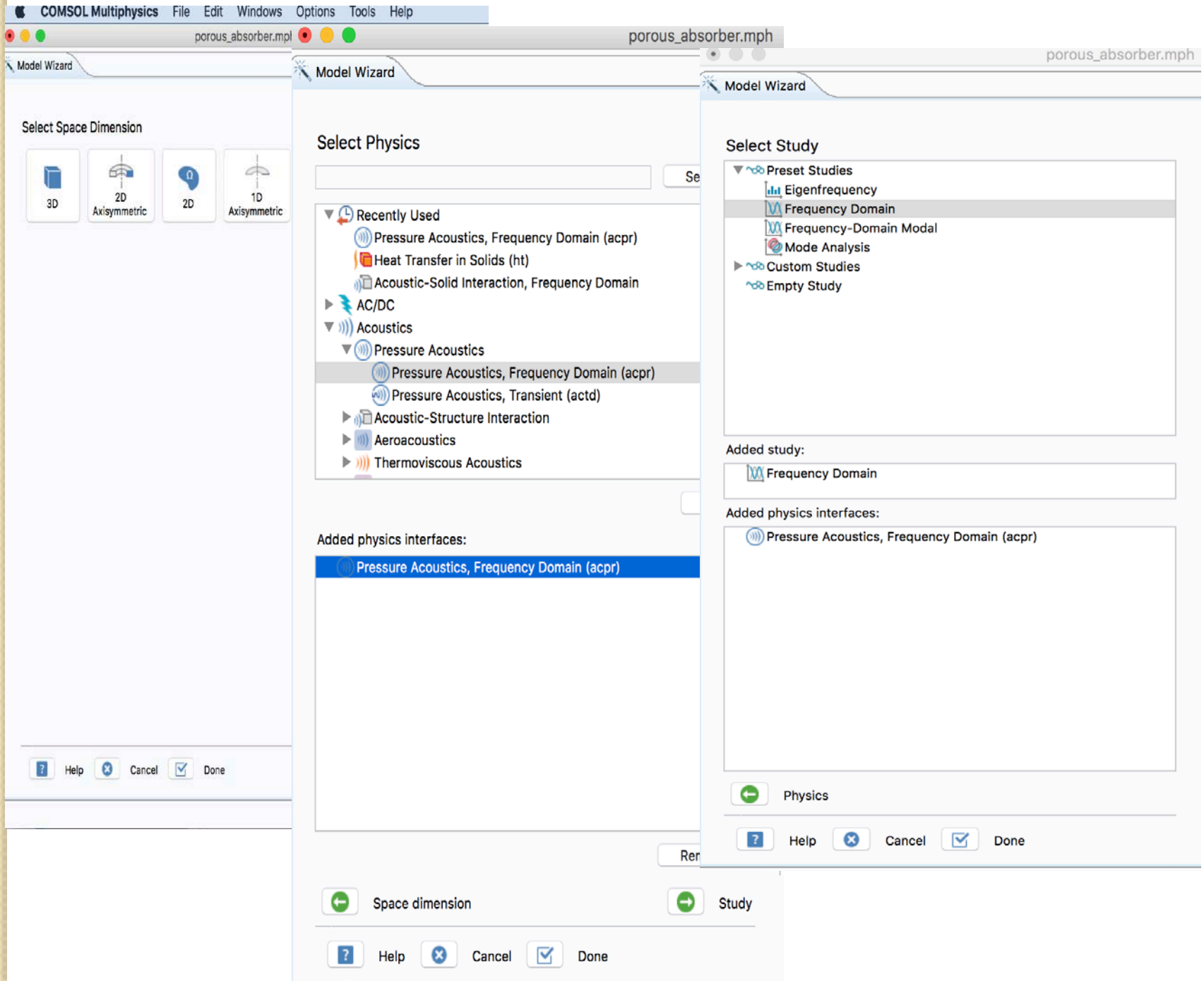
$$\alpha(\varphi) = \frac{4r'\cos\varphi}{(1+r'\cos\varphi)^2 + (x'\cos\varphi)^2} \quad \text{where} \quad r' = \frac{r}{\rho_o c} \quad x' = \frac{x}{\rho_o c}$$

Measurement of Acoustic Absorption Coefficient – Impedance Tube

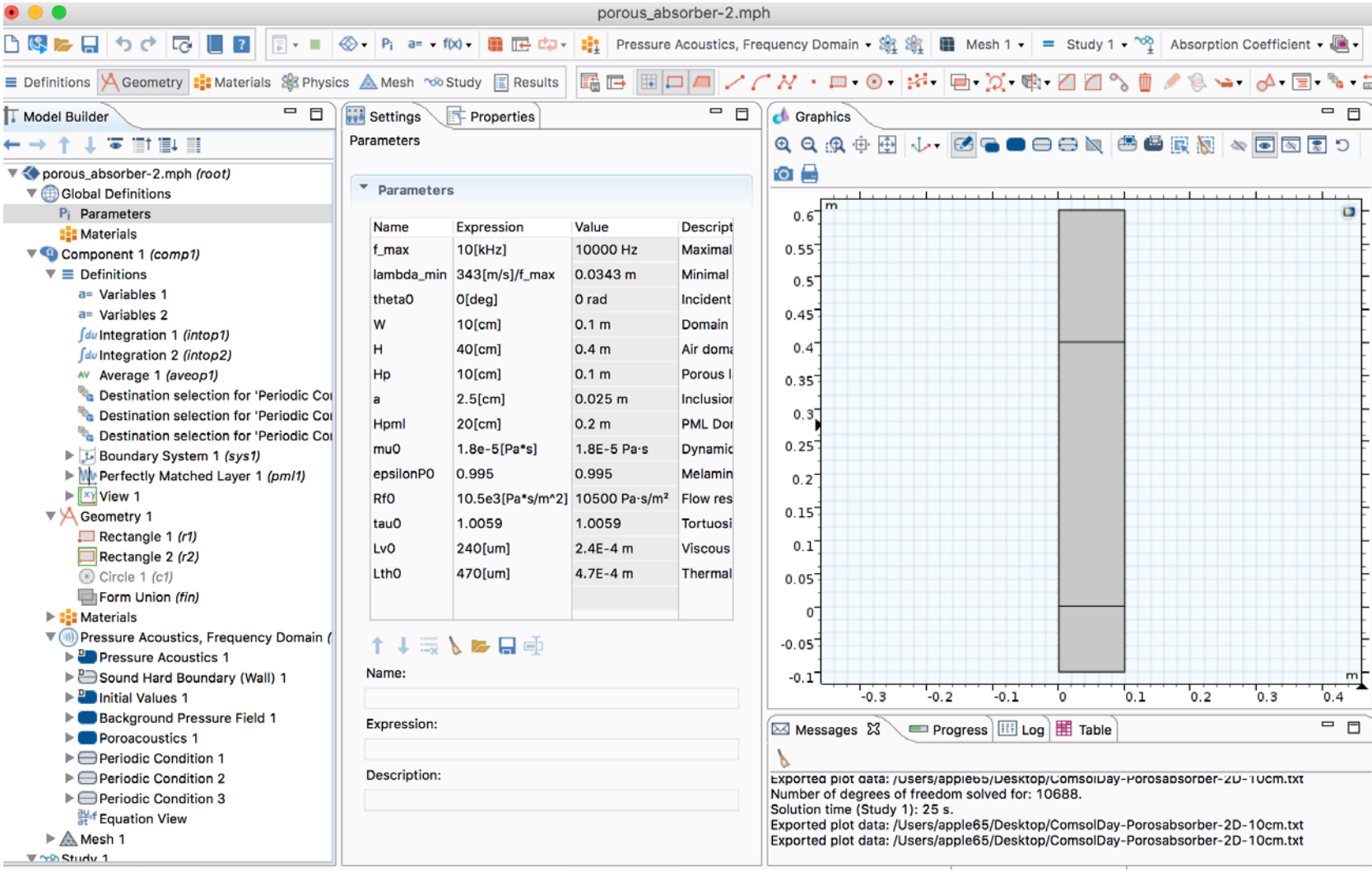


3cm Impedance Tube Facility

Porous Absorber – 2D Model


COMSOL Multiphysics File Edit Windows Options Tools Help
porous_absorber.mpl
porous_absorber.mph
Model Wizard
Select Space Dimension
3D
2D Axisymmetric
2D
1D Axisymmetric
Help
Cancel
Done
Model Wizard
Select Physics
Recently Used
Pressure Acoustics, Frequency Domain (acpr)
Heat Transfer in Solids (ht)
Acoustic-Solid Interaction, Frequency Domain
AC/DC
Acoustics
Pressure Acoustics
Pressure Acoustics, Frequency Domain (acpr)
Pressure Acoustics, Transient (actd)
Acoustic-Structure Interaction
Aeroacoustics
Thermoviscous Acoustics
Added physics interfaces:
Pressure Acoustics, Frequency Domain (acpr)
Space dimension
Study
Help
Cancel
Done
porous_absorber.mph
Model Wizard
Select Study
Preset Studies
Eigenfrequency
Frequency Domain
Frequency-Domain Modal
Mode Analysis
Custom Studies
Empty Study
Added study:
Frequency Domain
Added physics interfaces:
Pressure Acoustics, Frequency Domain (acpr)
Physics
Help
Cancel
Done

COMSOL – 2D Model

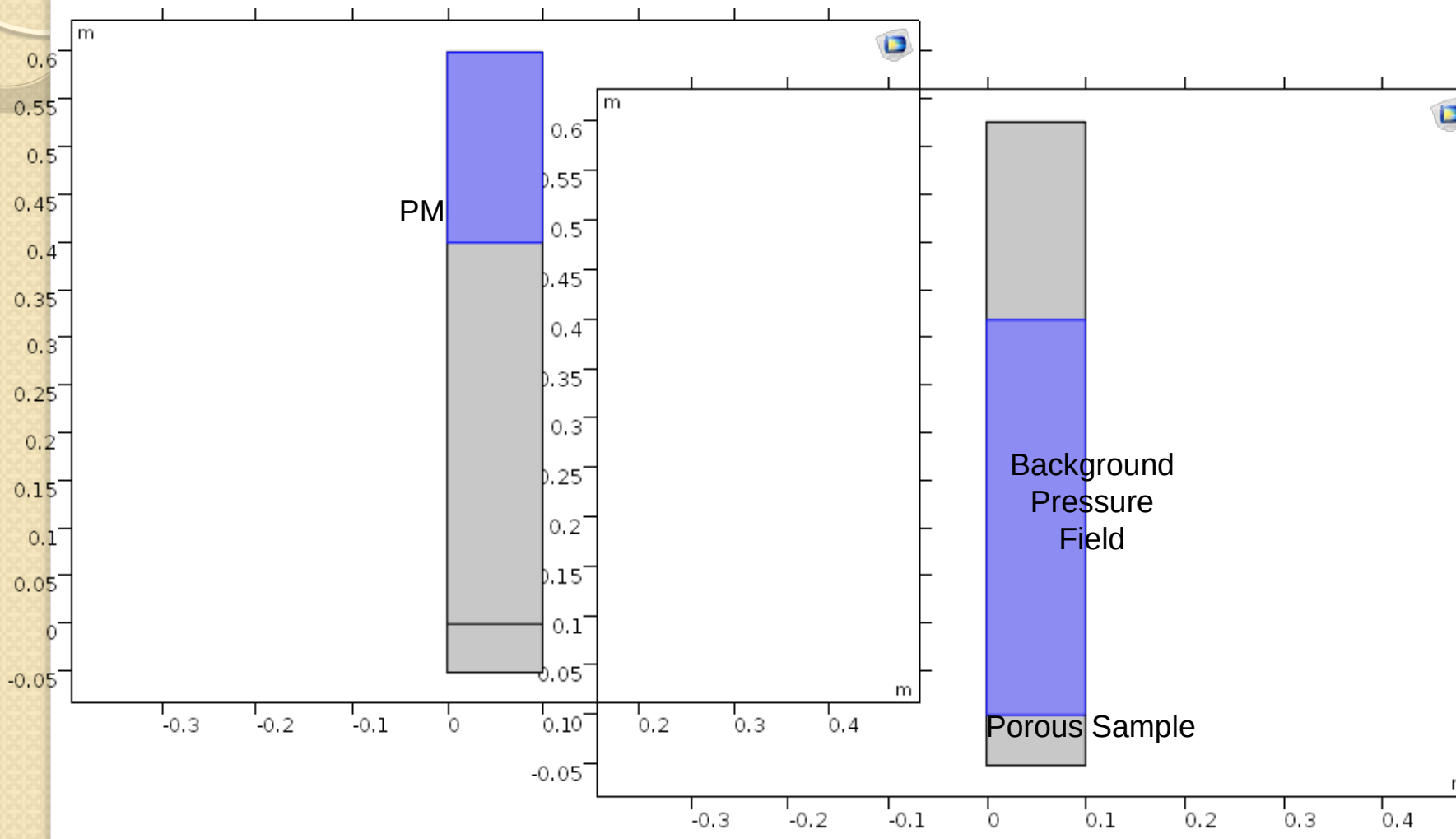


Material Parameters

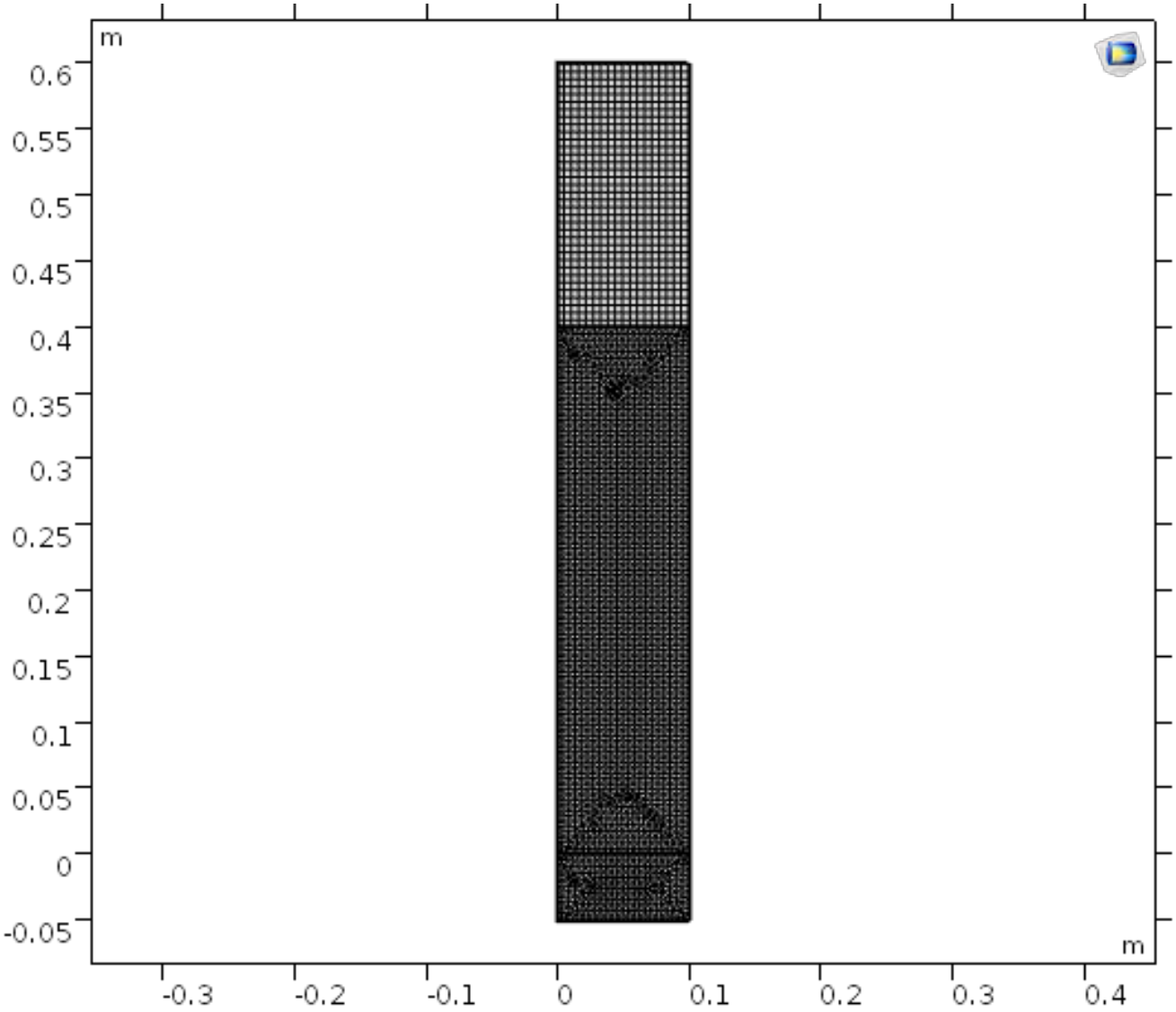
TABLE I: MELAMINE FOAM MATERIAL PARAMETERS

SYMBOL	VALUE	DESCRIPTION
ε_p	0.995	Porosity
R_f	10,500 Pa·s/m^2	Flow resistivity
s	0.49	Viscous characteristic length parameter
L_{th}	470 μm	Thermal characteristic length
L_v	240 μm	Viscous characteristic length
τ	1.0059	Tortuosity factor

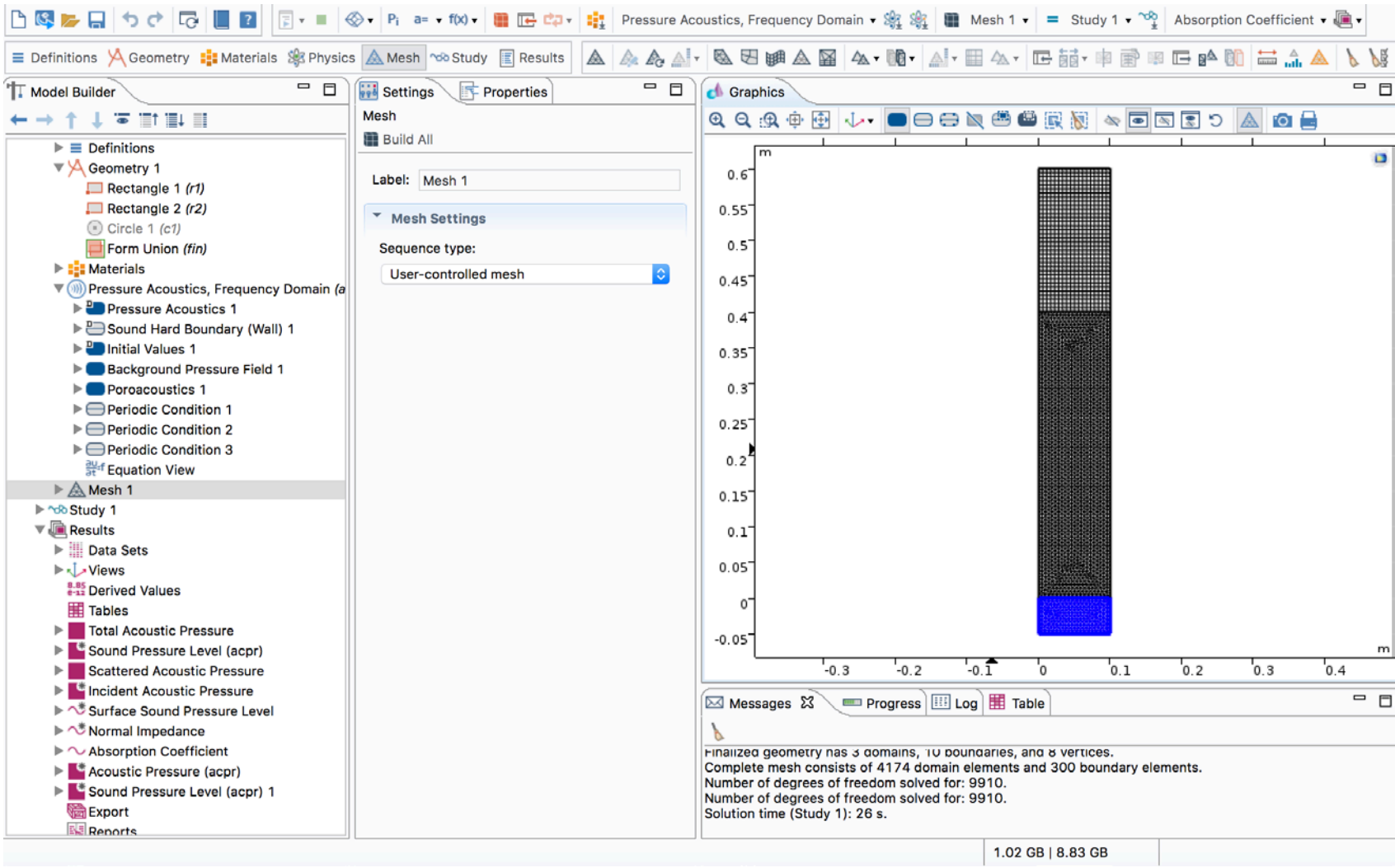
Comsol Model: PML and Excitation Field



FE MESH

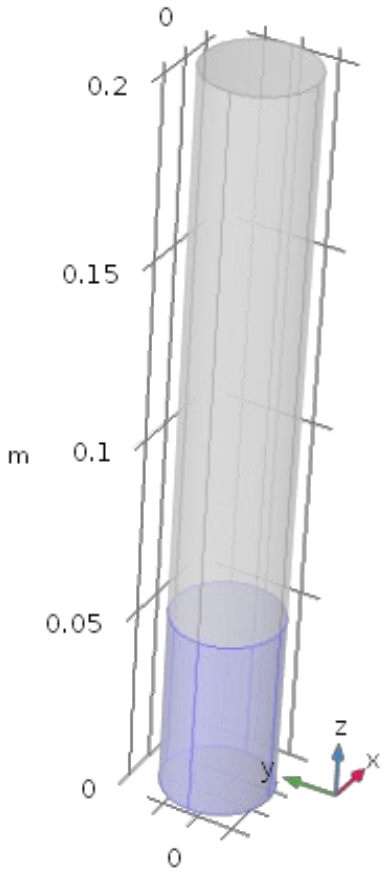

m
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
m
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4

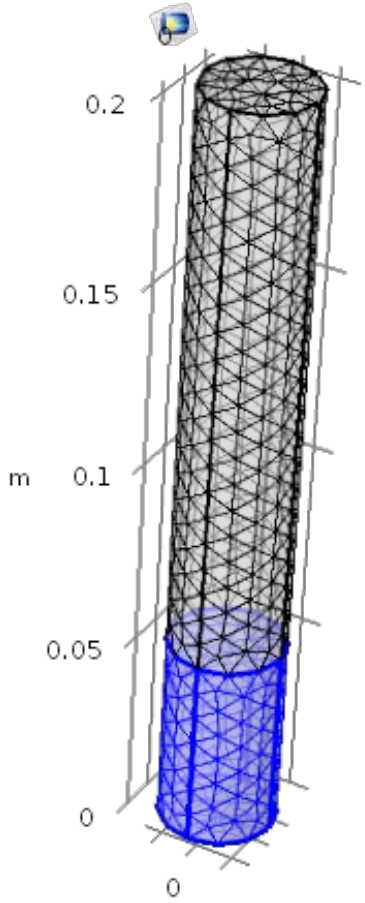
COMSOL – 2D Model



Porous Absorber – 3D Model

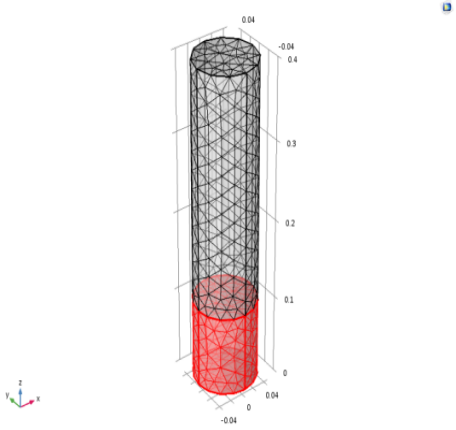
Porous Absorber – 3D Model

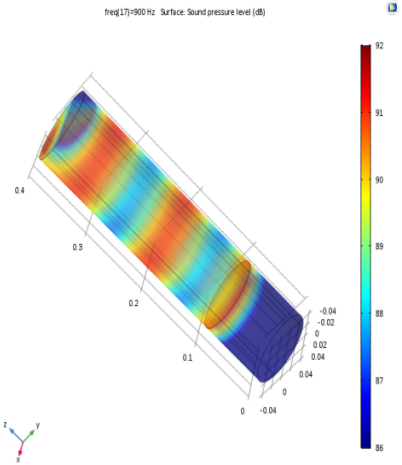


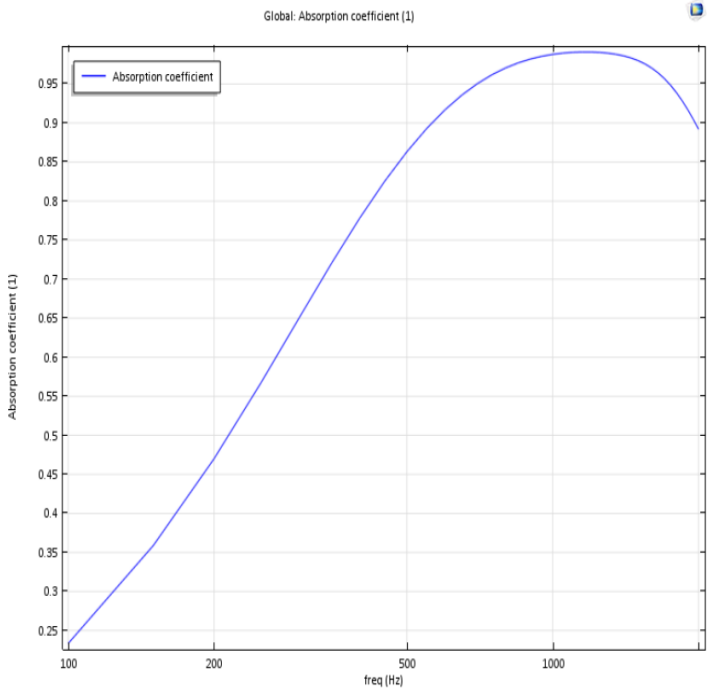


Porous Absorber – 3D Model

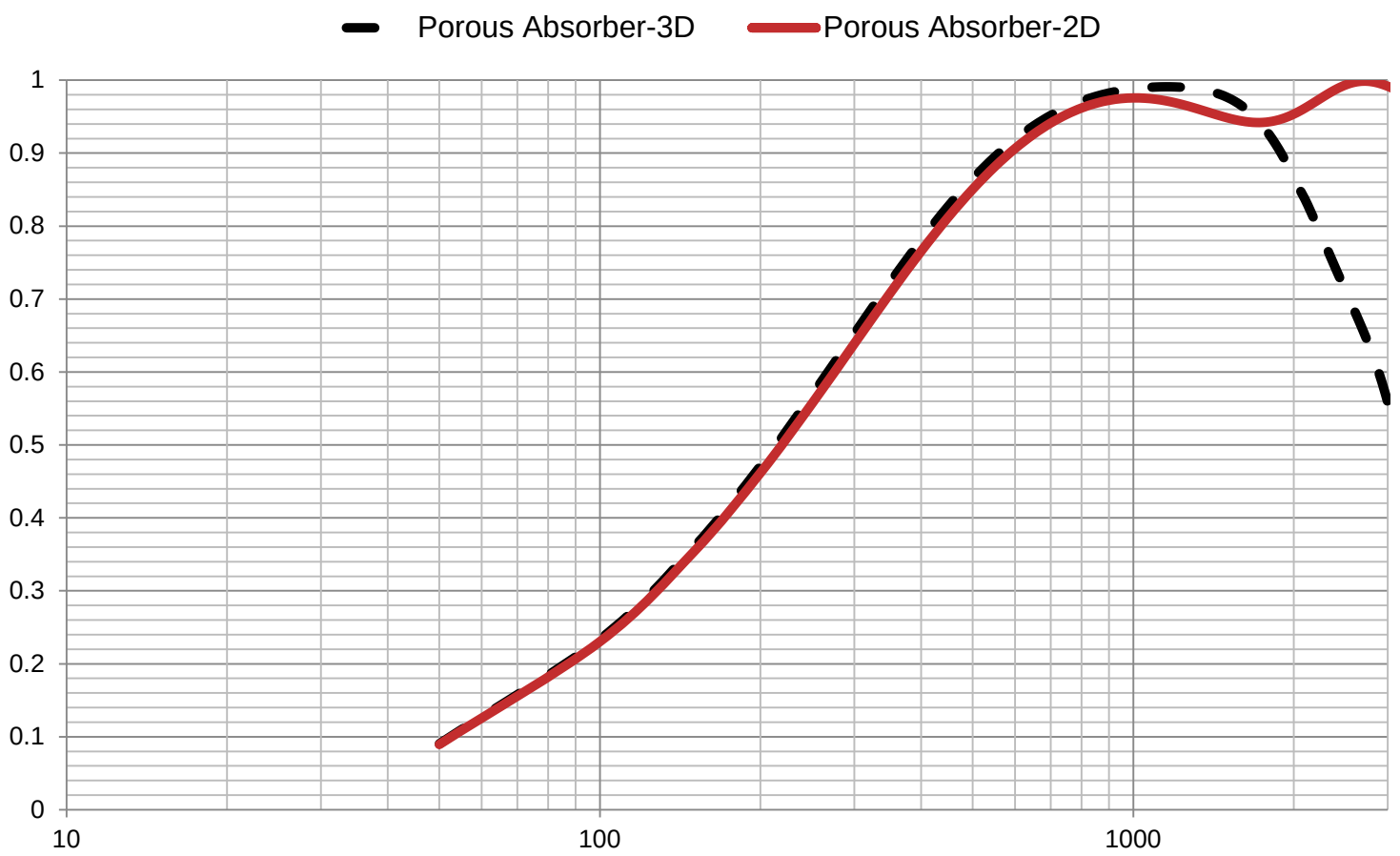
3-D COMSOL Model of Foam Sample





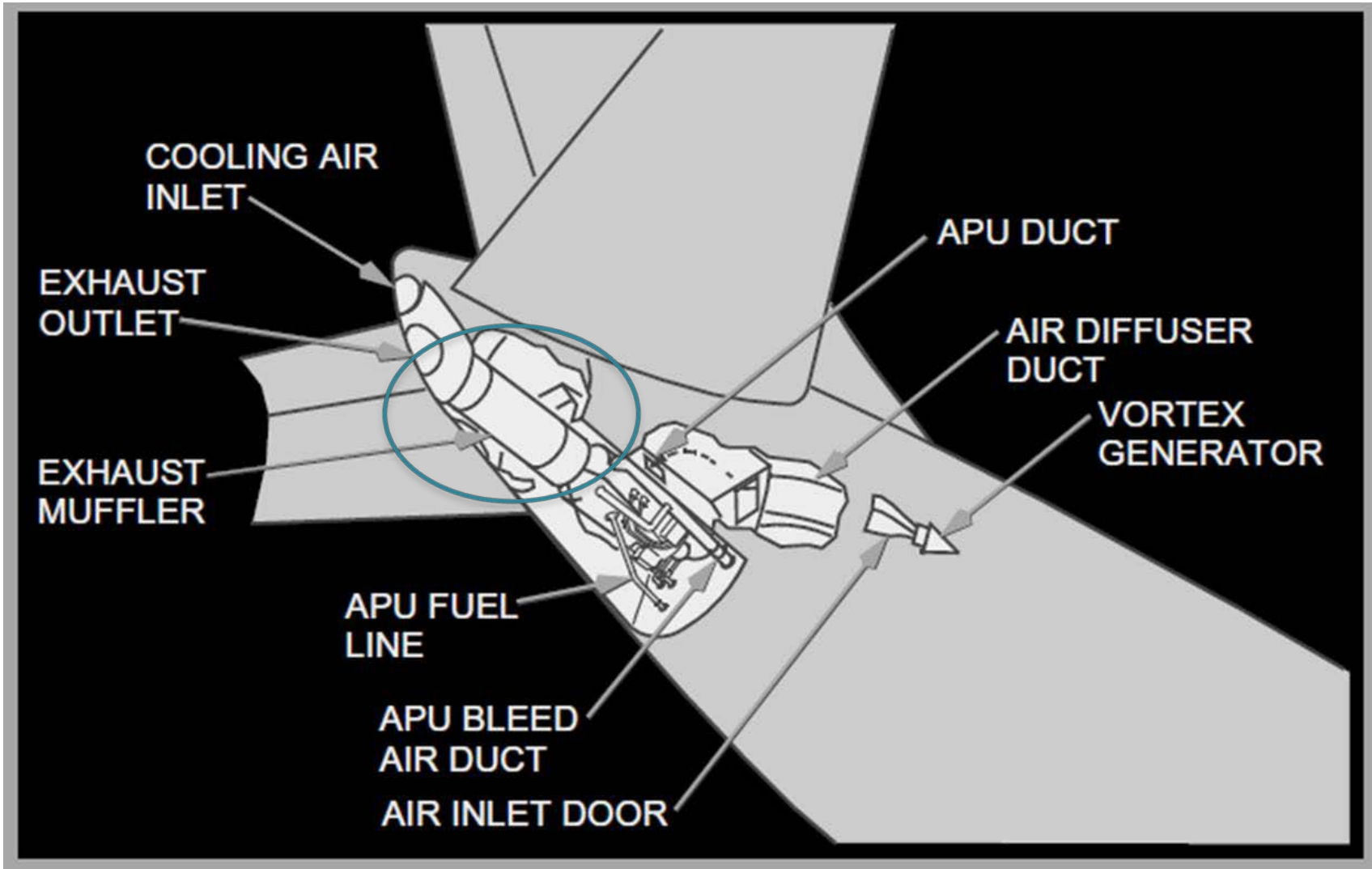


Absorption Coefficient: 3-D vs 2-D Model

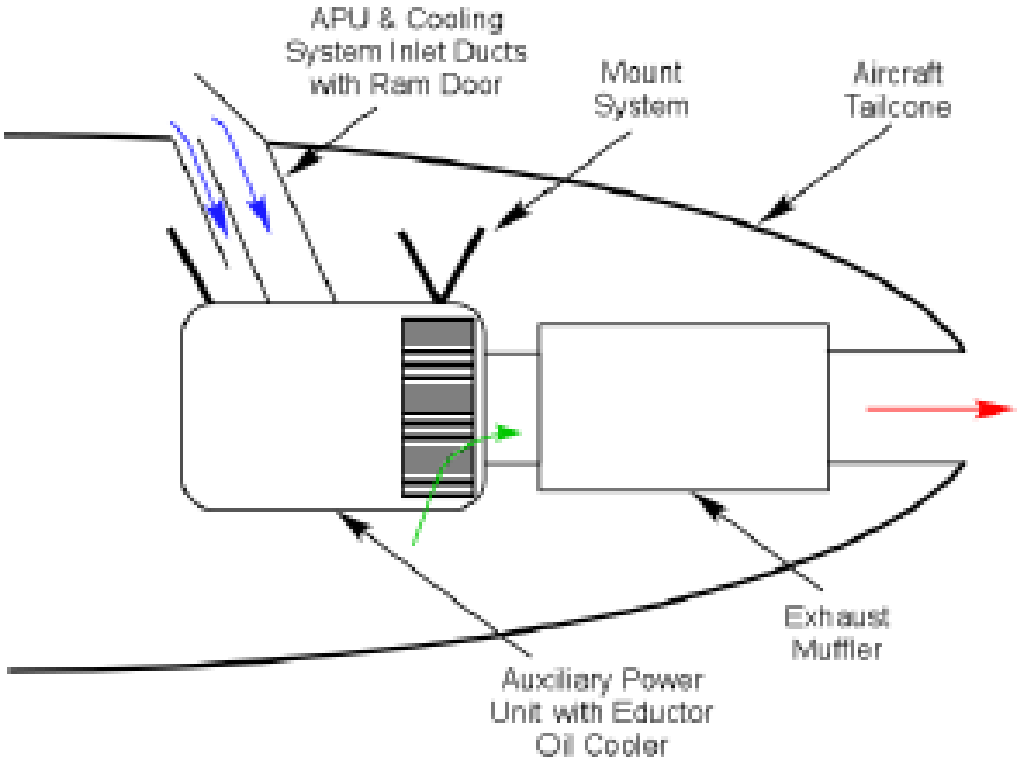


Acoustic Modeling of APU Muffler System

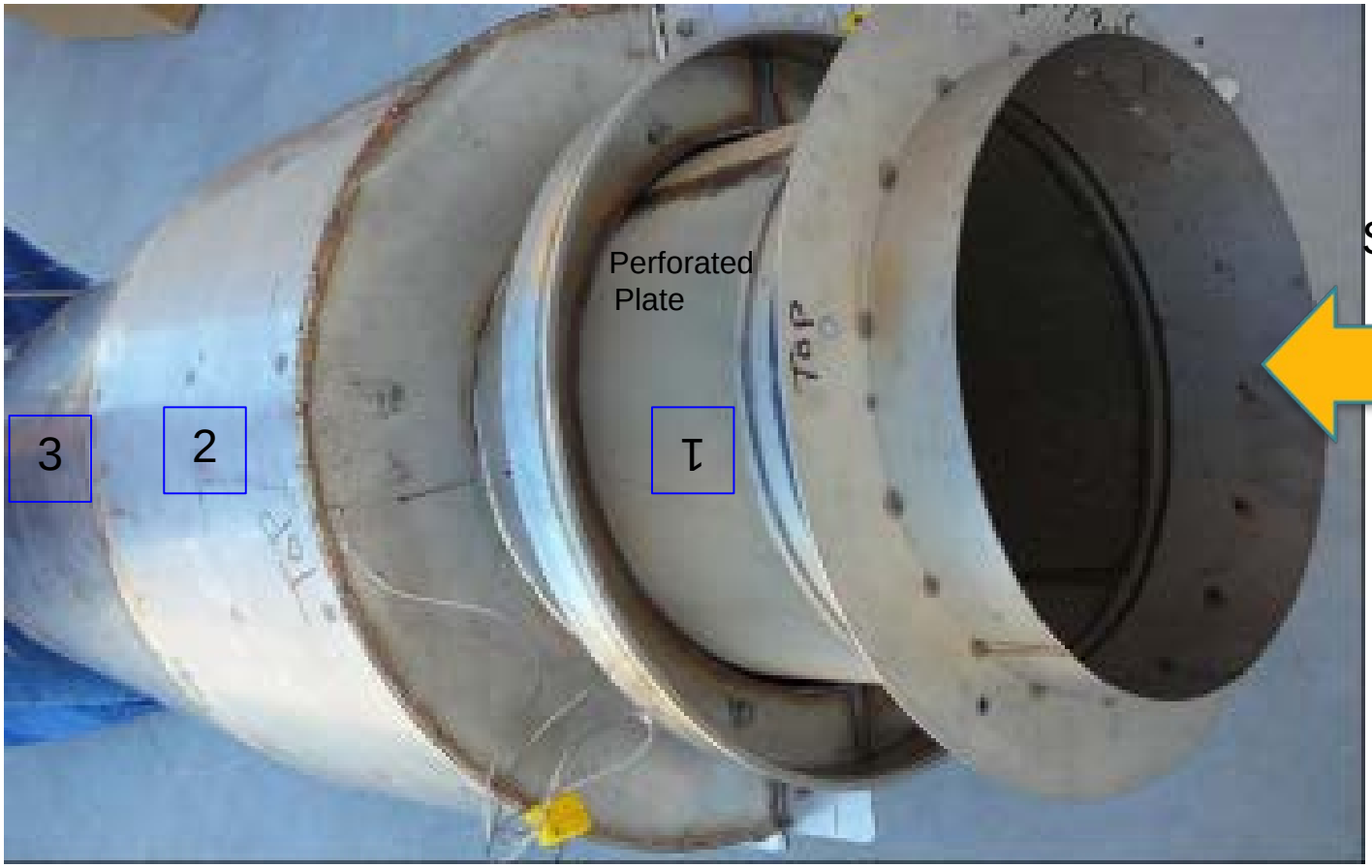
Aircraft APU (Auxiliary Power Unit)



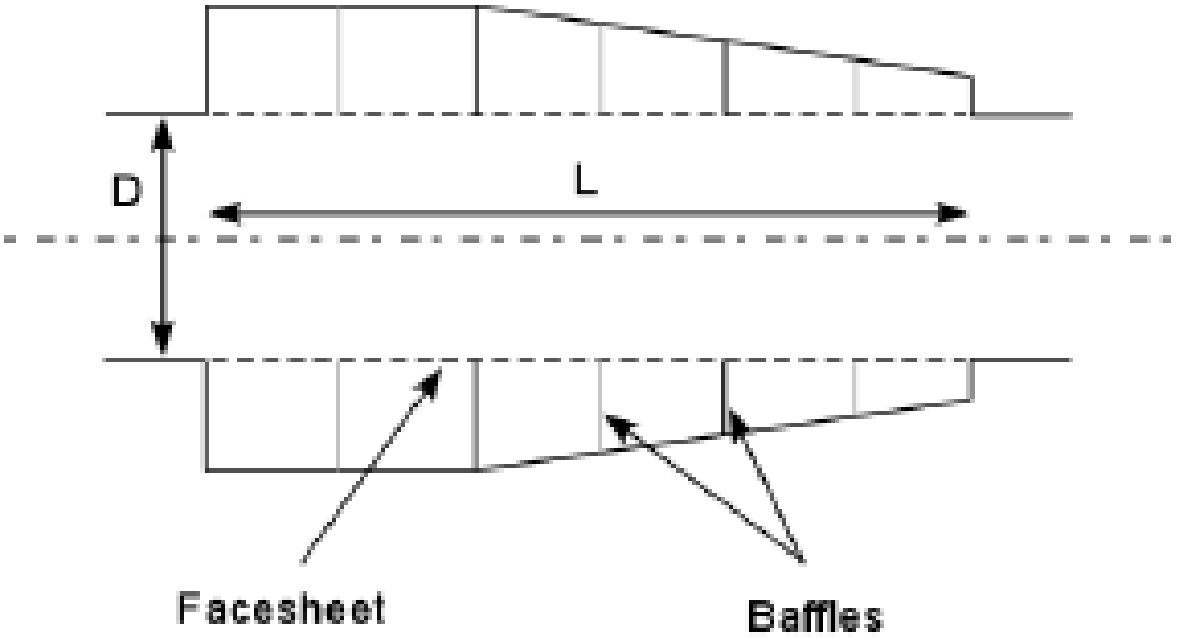
Acoustic Modeling of Aircraft APU (Auxiliary Power Unit)



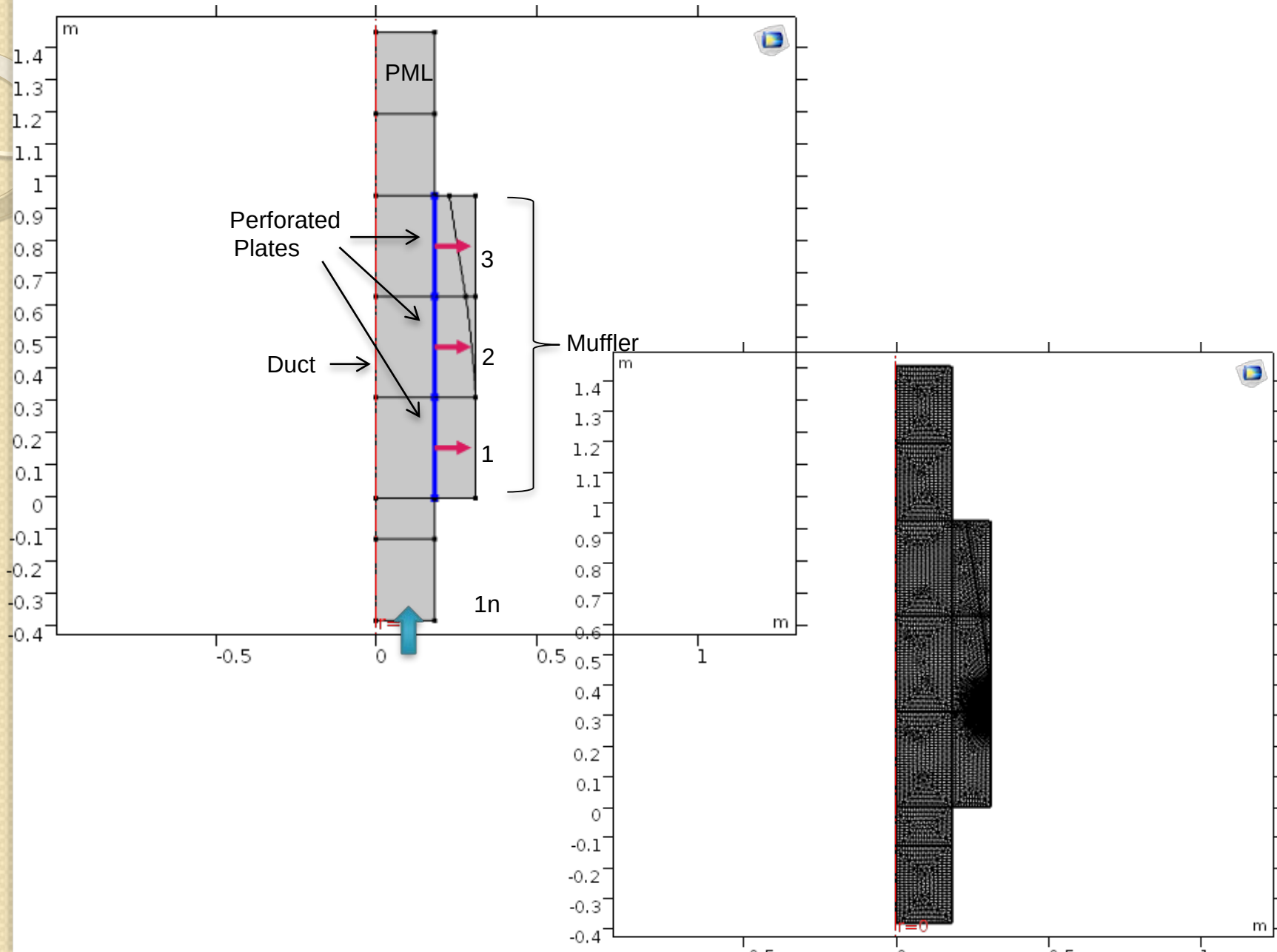
Acoustically Treated APU Exhaust Muffler



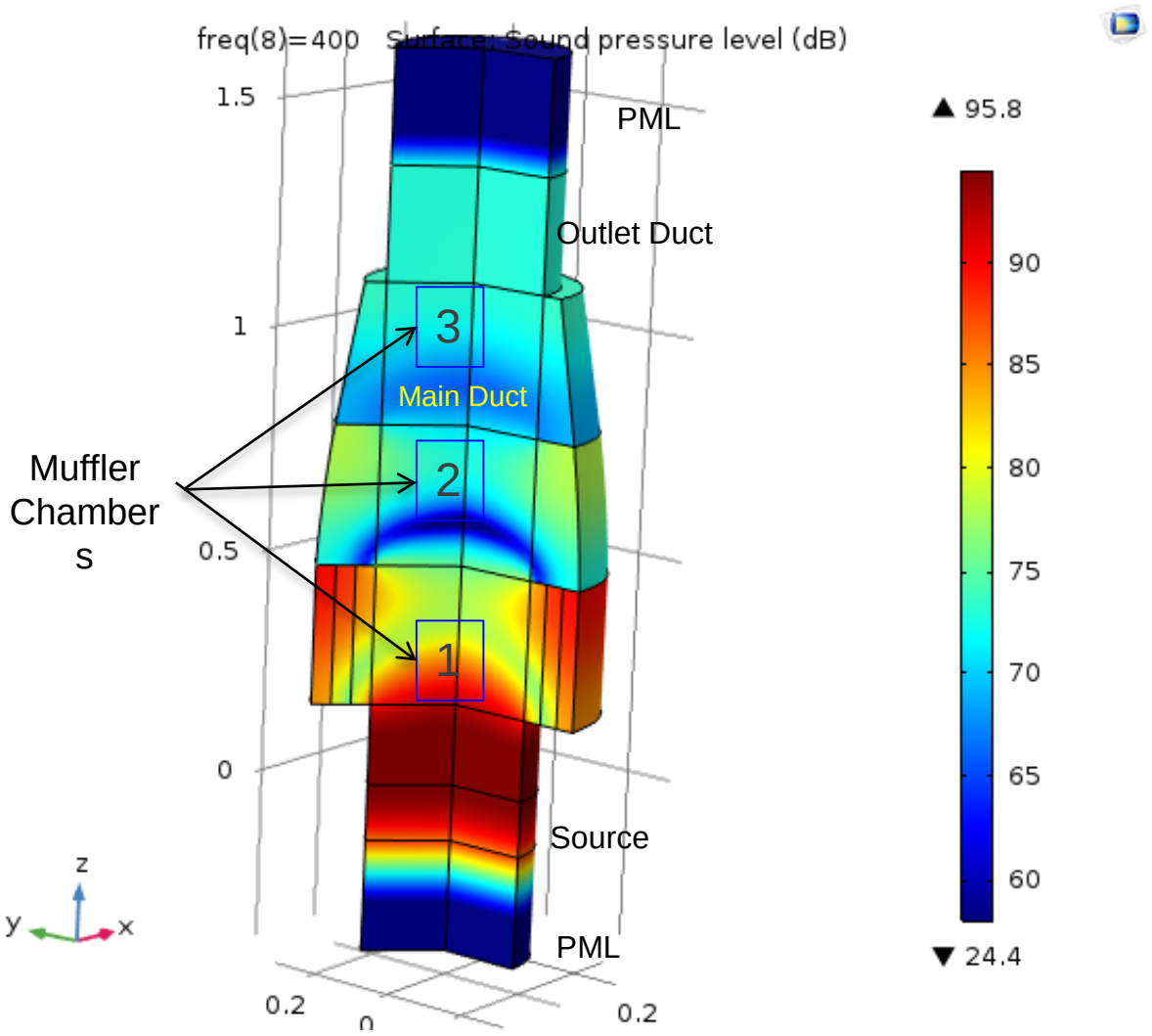
Schematic of Acoustically Treated APU Exhaust Muffler



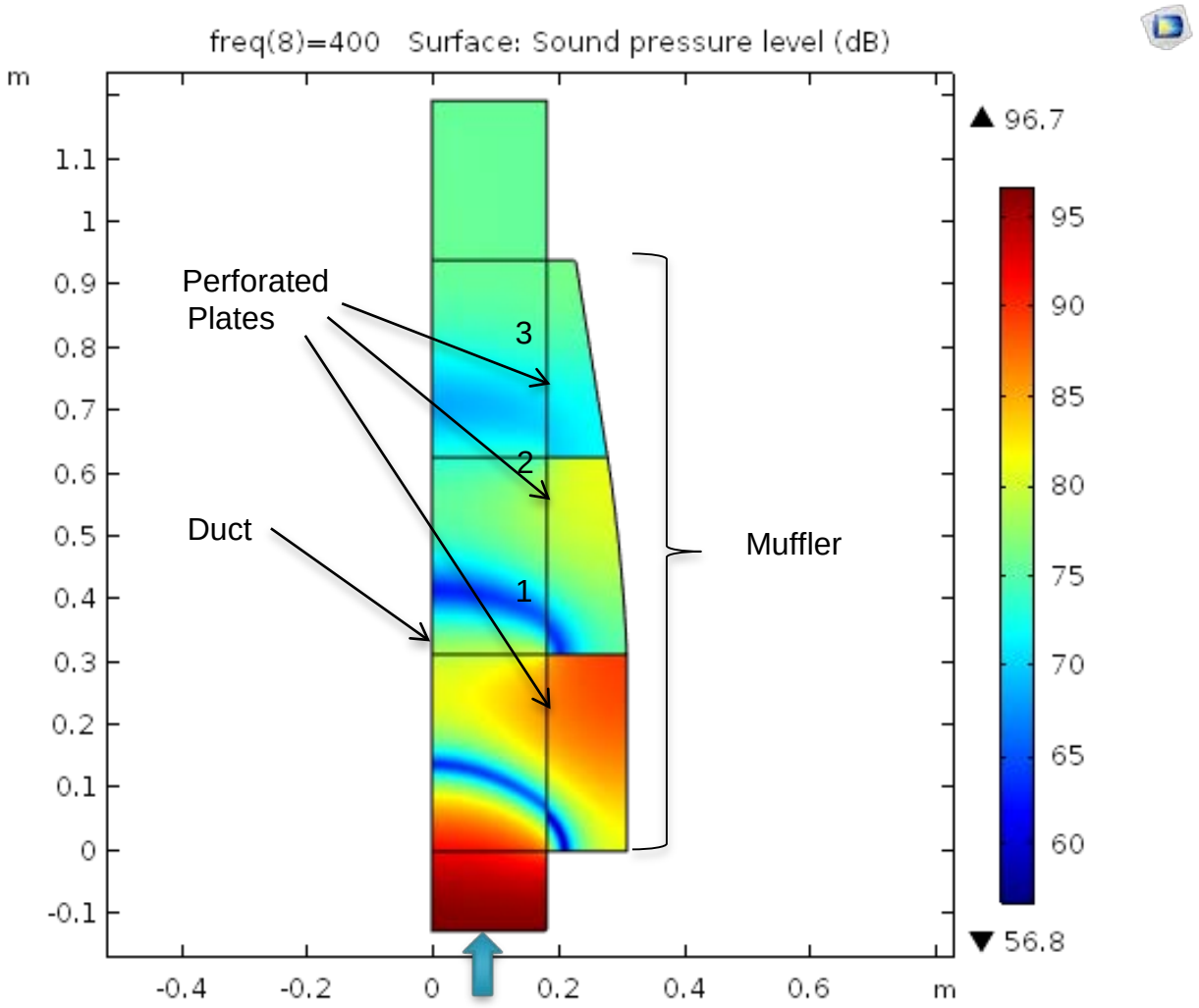
Aircraft APU Muffler – COMSOL Model



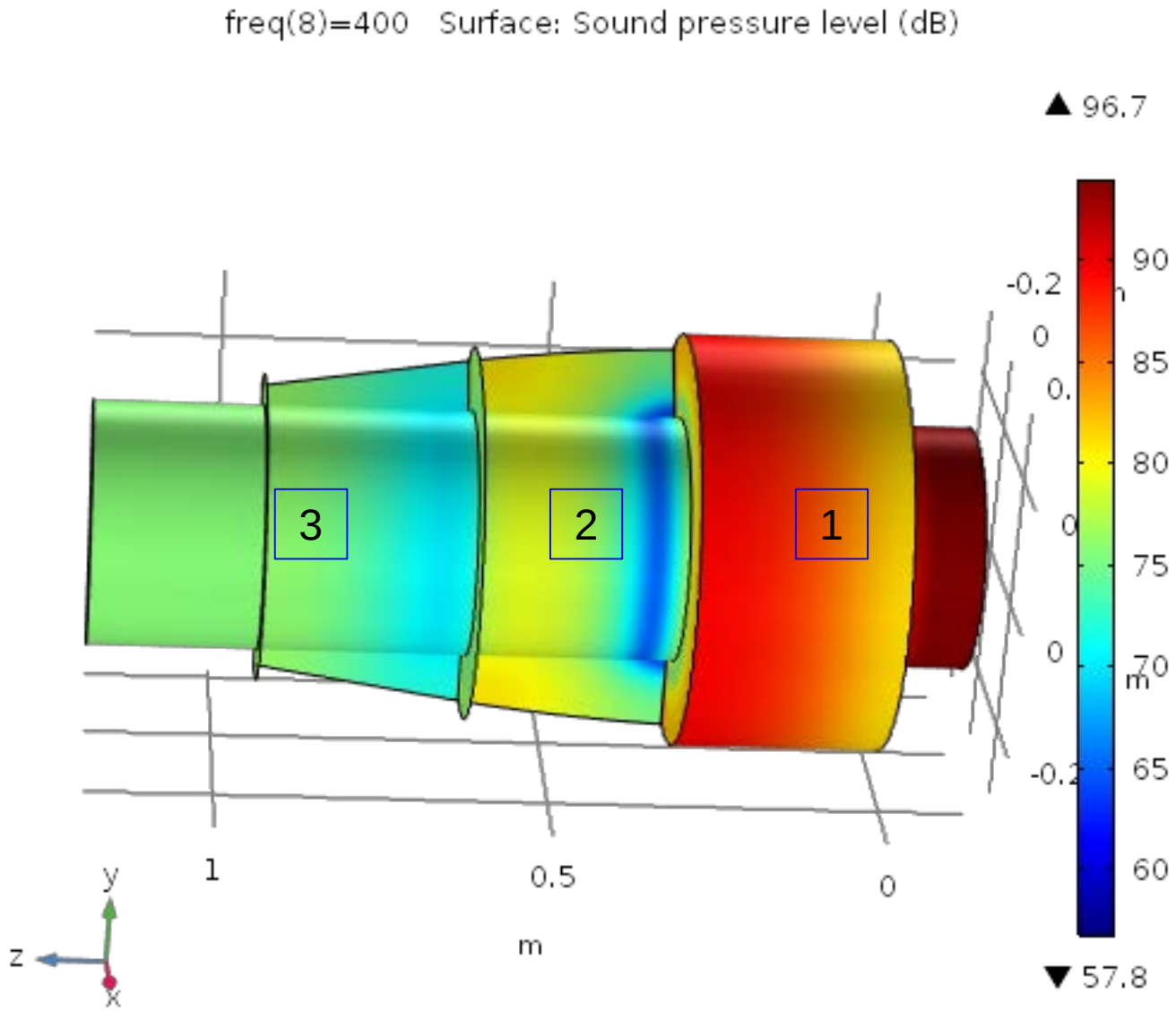
APU Muffler: COMSOL Model



Aircraft APU Muffler – SPL Map



Aircraft APU Exhaust Muffler – SPL Map



Summary

- **COMSOL MultiPhysics – Acoustic Module is a powerful tool for modeling acoustic systems.**
- **2-D and 3-D models of porous absorber were demonstrated showing differences between two approaches.**
- **An acoustic model of an APU exhaust muffler system was also demonstrated.**
- **COMSOL Acoustic module can also be connected with other MutliPhysics modules (e.g., structural mechanics, thermal, etc.)**

- Thanks so much for your attention.

- Q/A