



Acoustic Modeling using COMSOL MultiPhysics

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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:

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

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

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

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

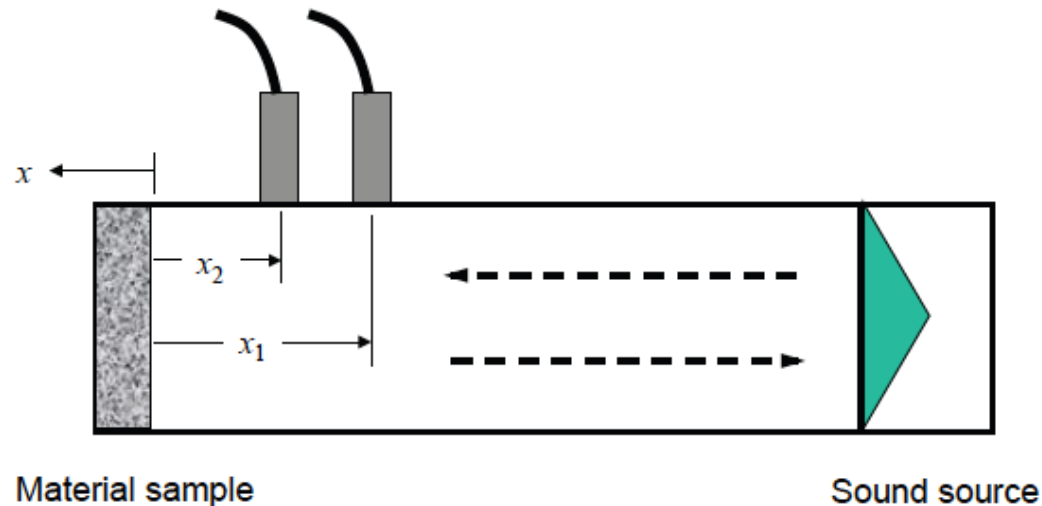
$$SPL(x, y, z) = 20 \log_{10} \left(\frac{p_{rms}(x, y, z)}{p_{ref}} \right)$$

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:

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

\nearrow $+x$ traveling wave \nwarrow $-x$ traveling wave

The transfer function between points 1 and 2:

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

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

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

Model Wizard

Select Space Dimension



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

Help Cancel Done

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

Re

Study

COMSOL – 2D Model

porous_absorber-2.mph

Pressure Acoustics, Frequency Domain | Mesh 1 | Study 1 | Absorption Coefficient

Definitions | Geometry | Materials | Physics | Mesh | Study | Results

Model Builder

- porous_absorber-2 (root)
 - Global Definitions
 - Parameters
 - Materials
 - Component 1 (comp1)
 - Definitions
 - Variables 1
 - Variables 2
 - Integration 1 (intop1)
 - Integration 2 (intop2)
 - Average 1 (aveop1)
 - Destination selection for 'Periodic Coi
 - Destination selection for 'Periodic Coi
 - Destination selection for 'Periodic Coi
 - Boundary System 1 (sys1)
 - Perfectly Matched Layer 1 (pml1)
 - View 1
 - Geometry 1
 - Rectangle 1 (r1)
 - Rectangle 2 (r2)
 - Circle 1 (c1)
 - Form Union (fin)
 - Materials
 - Pressure Acoustics, Frequency Domain (
 - Pressure Acoustics 1
 - Sound Hard Boundary (Wall) 1
 - Initial Values 1
 - Background Pressure Field 1
 - Poroacoustics 1
 - Periodic Condition 1
 - Periodic Condition 2
 - Periodic Condition 3
 - Equation View
 - Mesh 1

Settings

Parameters

Name	Expression	Value	Description
f_max	10[kHz]	10000 Hz	Maximal
lambda_min	343[m/s]/f_max	0.0343 m	Minimal
theta0	0[deg]	0 rad	Incident
W	10[cm]	0.1 m	Domain
H	40[cm]	0.4 m	Air dome
Hp	10[cm]	0.1 m	Porous l
a	2.5[cm]	0.025 m	Inclusion
Hpml	20[cm]	0.2 m	PML Dor
mu0	1.8e-5[Pa*s]	1.8E-5 Pa·s	Dynamic
epsilonP0	0.995	0.995	Melamin
Rf0	10.5e3[Pa*s/m^2]	10500 Pa·s/m²	Flow res
tau0	1.0059	1.0059	Tortuosi
Lv0	240[um]	2.4E-4 m	Viscous
Lth0	470[um]	4.7E-4 m	Thermal

Name:

Expression:

Description:

Graphics

Messages | Progress | Log | Table

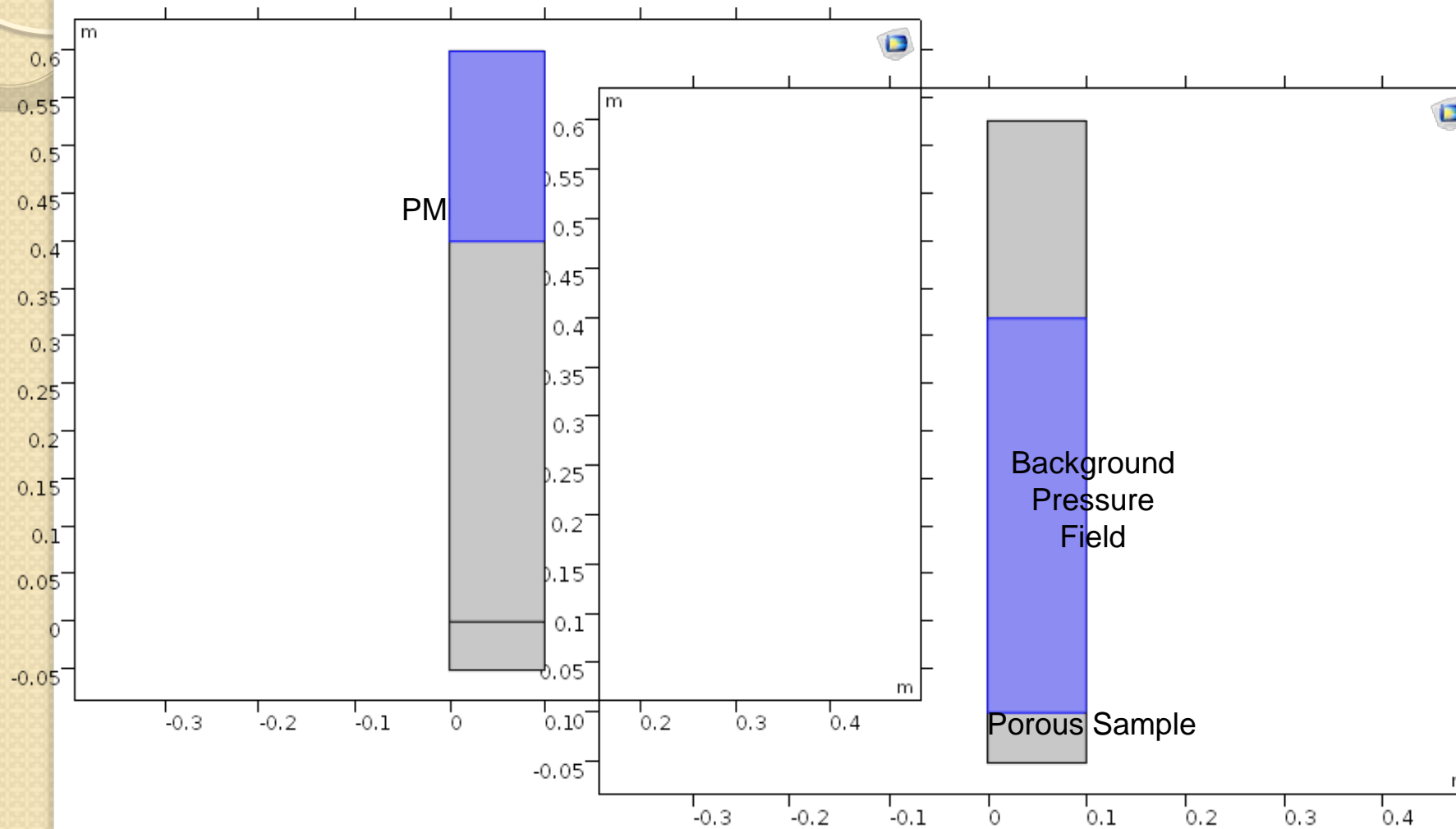
Exported plot data: /Users/apple65/Desktop/ComsolDay-Porosabsorber-2D-10cm.txt
 Number of degrees of freedom solved for: 10688.
 Solution time (Study 1): 25 s.
 Exported plot data: /Users/apple65/Desktop/ComsolDay-Porosabsorber-2D-10cm.txt
 Exported plot data: /Users/apple65/Desktop/ComsolDay-Porosabsorber-2D-10cm.txt

Material Parameters

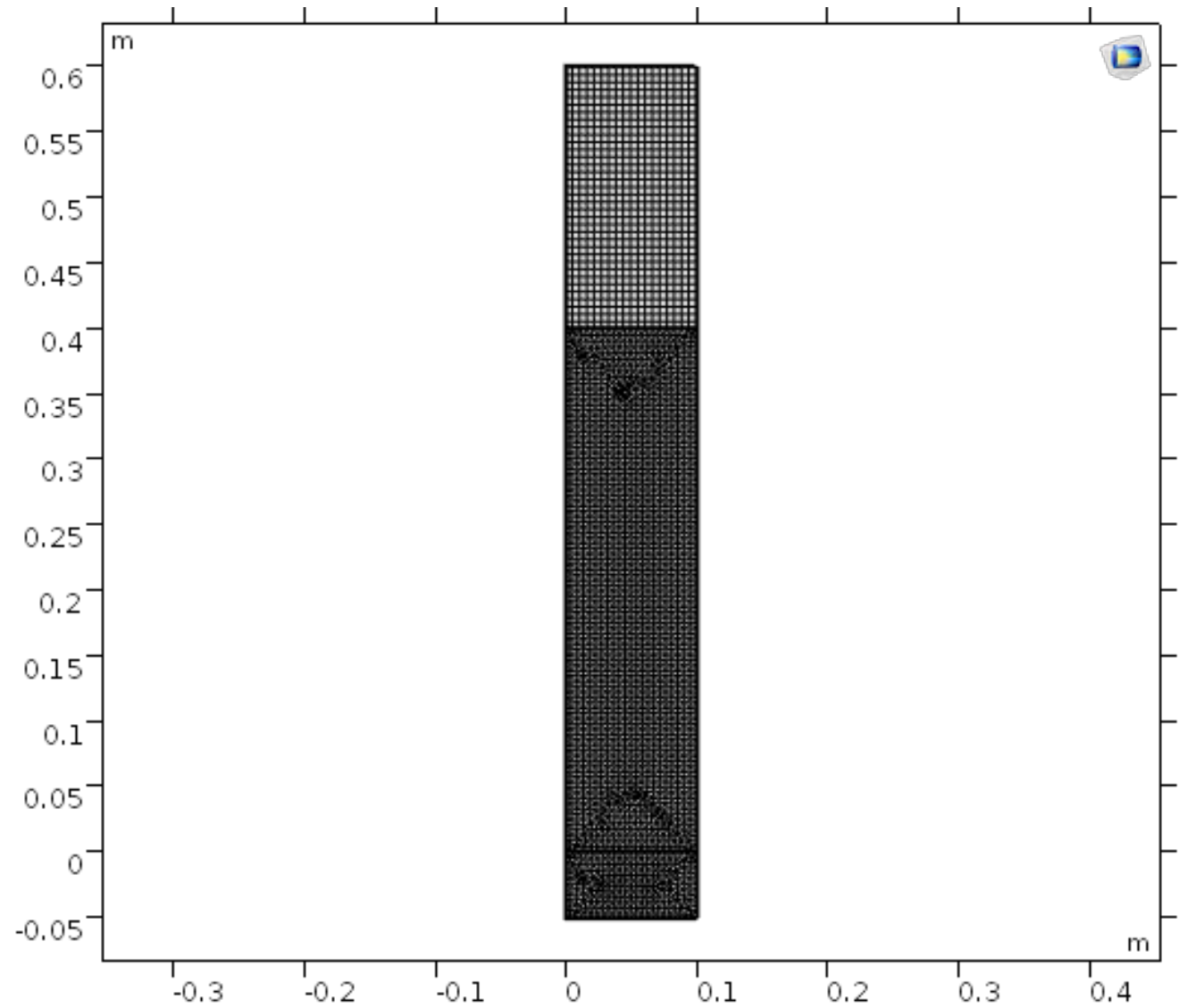
TABLE I: MELAMINE FOAM MATERIAL PARAMETERS

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 μ m	Thermal characteristic length
L_v	240 μ m	Viscous characteristic length
τ	1.0059	Tortuosity factor

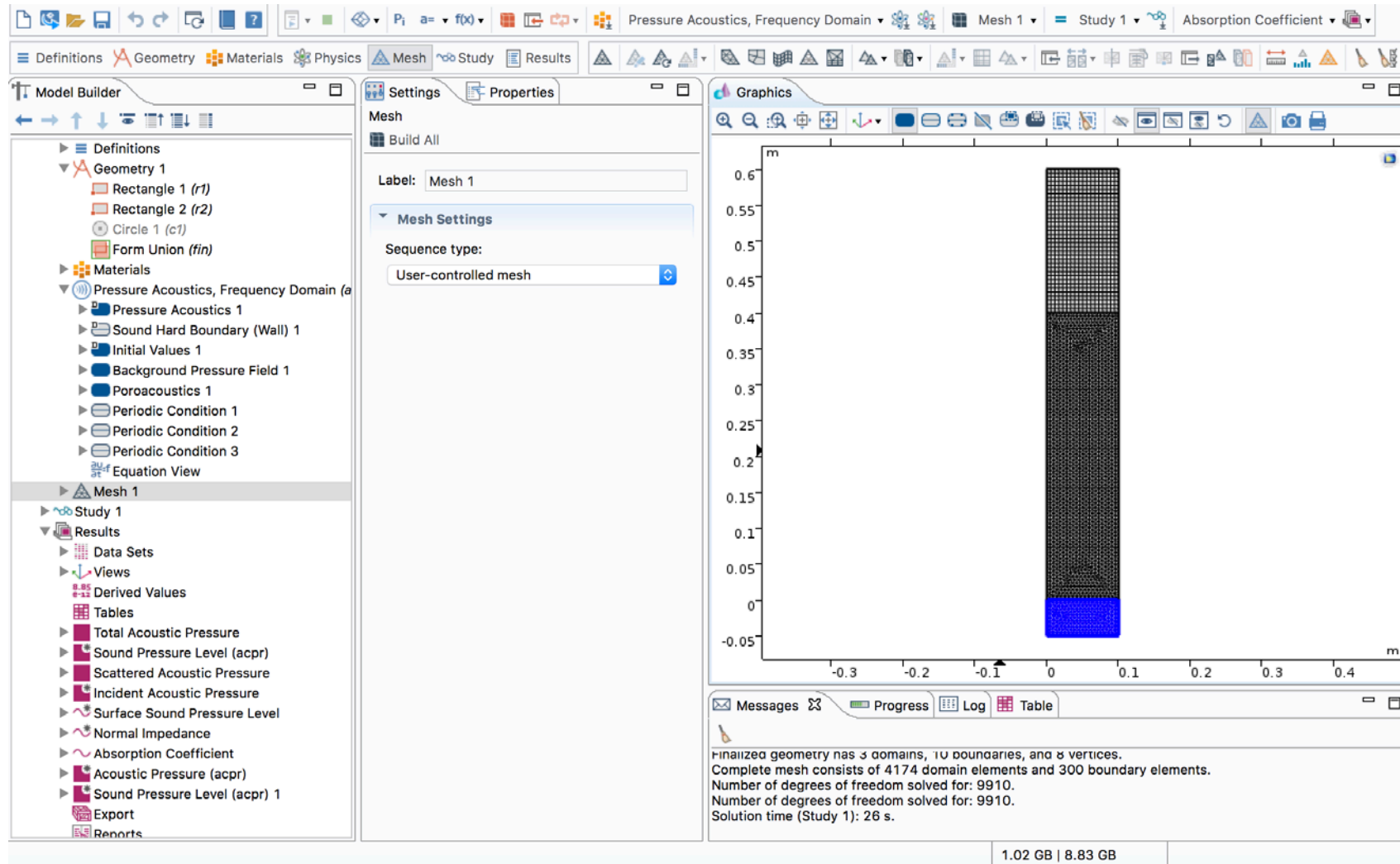
Comsol Model: PML and Excitation Field



FE MESH



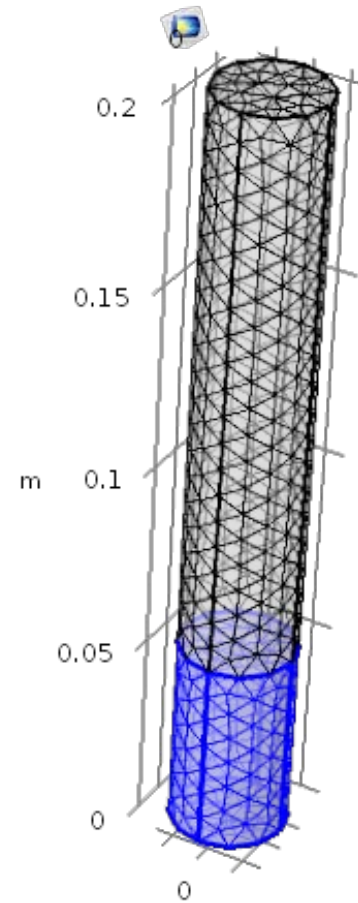
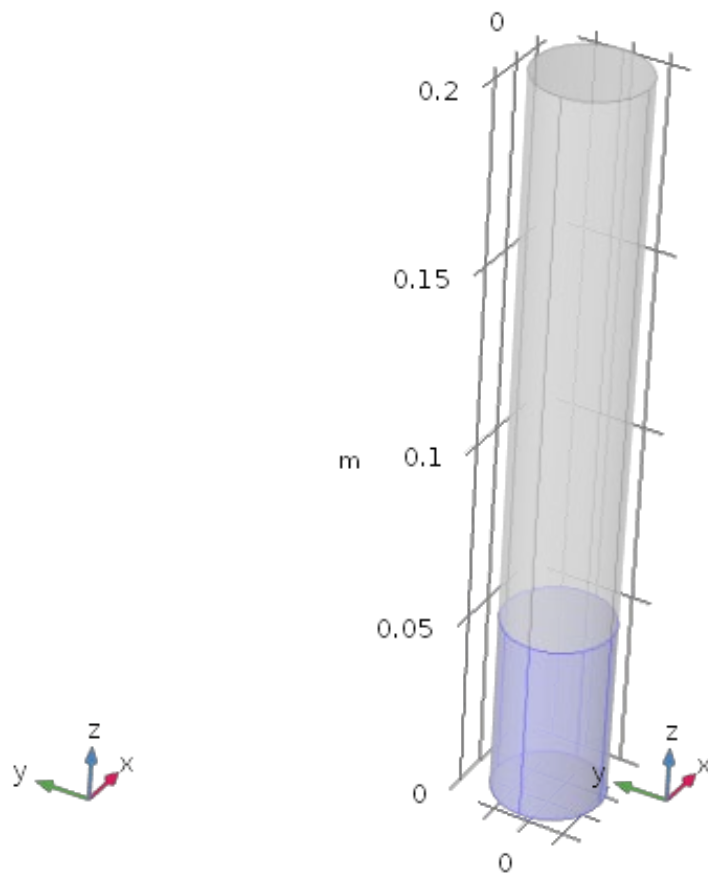
COMSOL – 2D Model





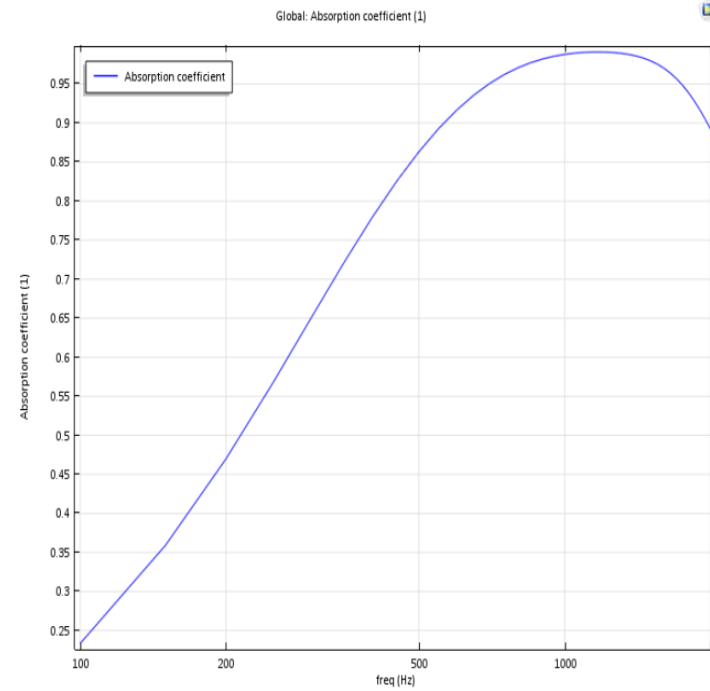
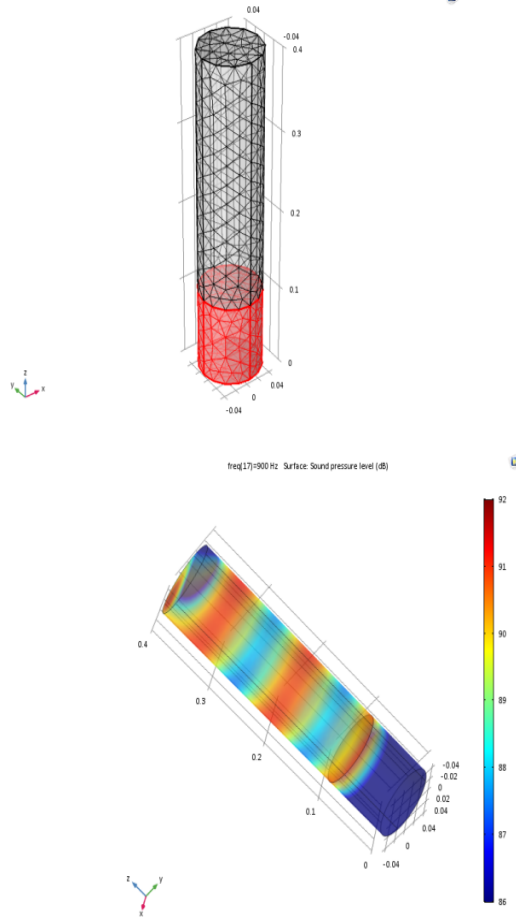
Porous Absorber – 3D Model

Porous Absorber – 3D Model

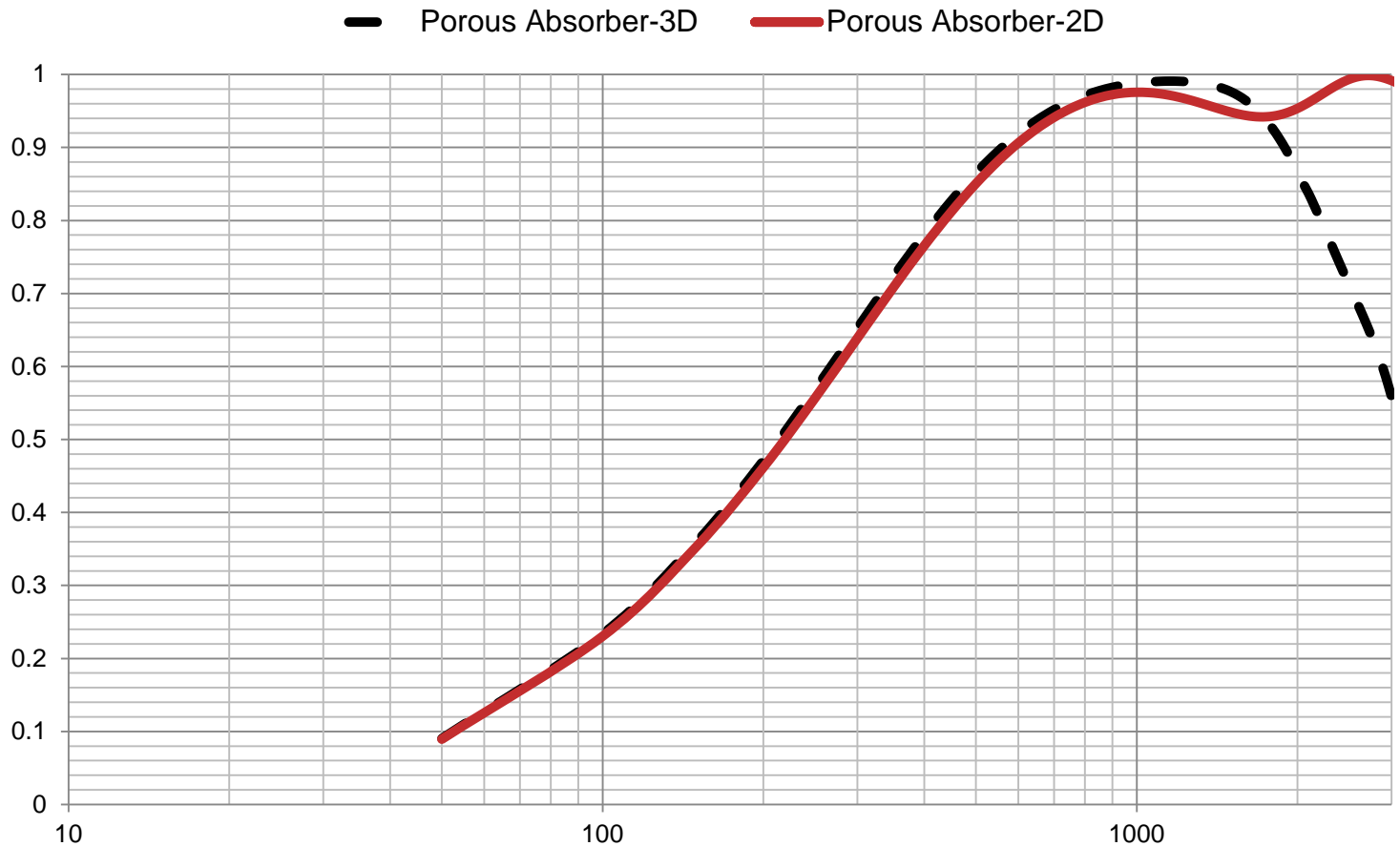


Porous Absorber – 3D Model

3-D COMSOL Model of Foam Sample



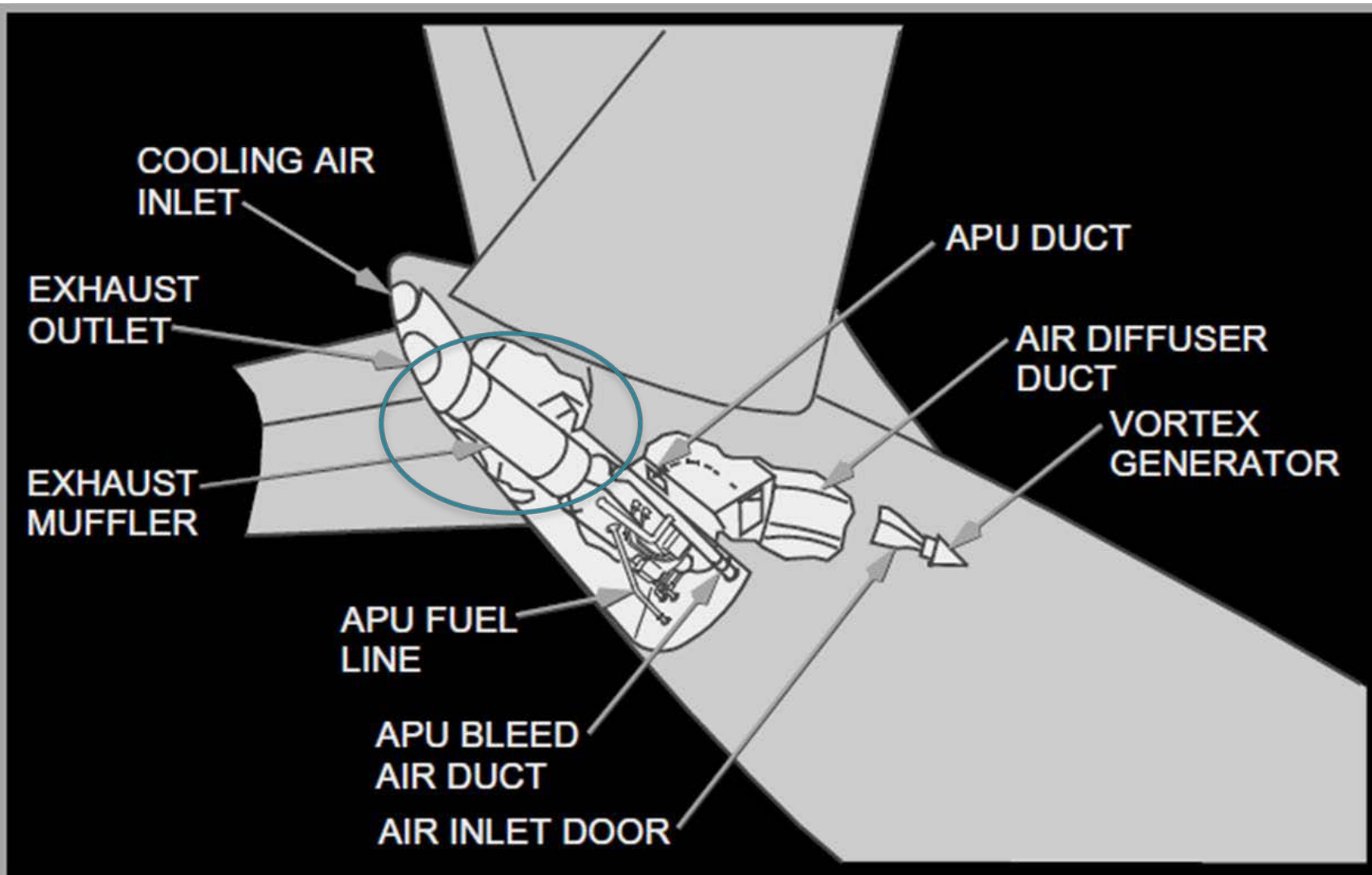
Absorption Coefficient: 3-D vs 2-D Model



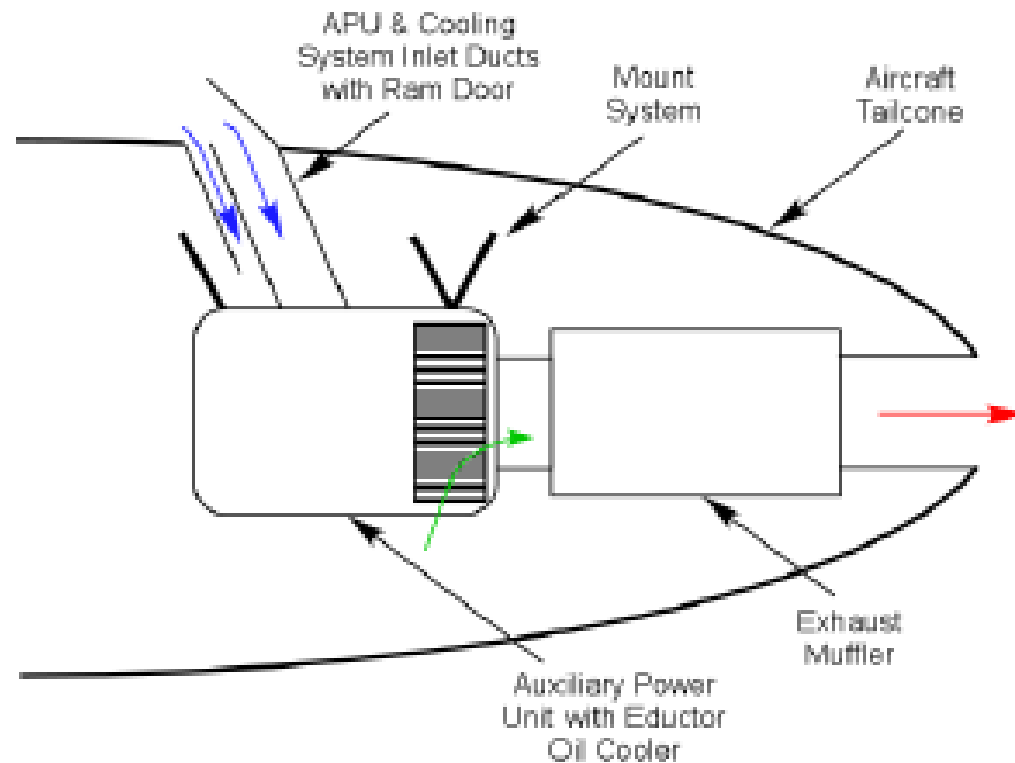


Acoustic Modeling of APU Muffler System

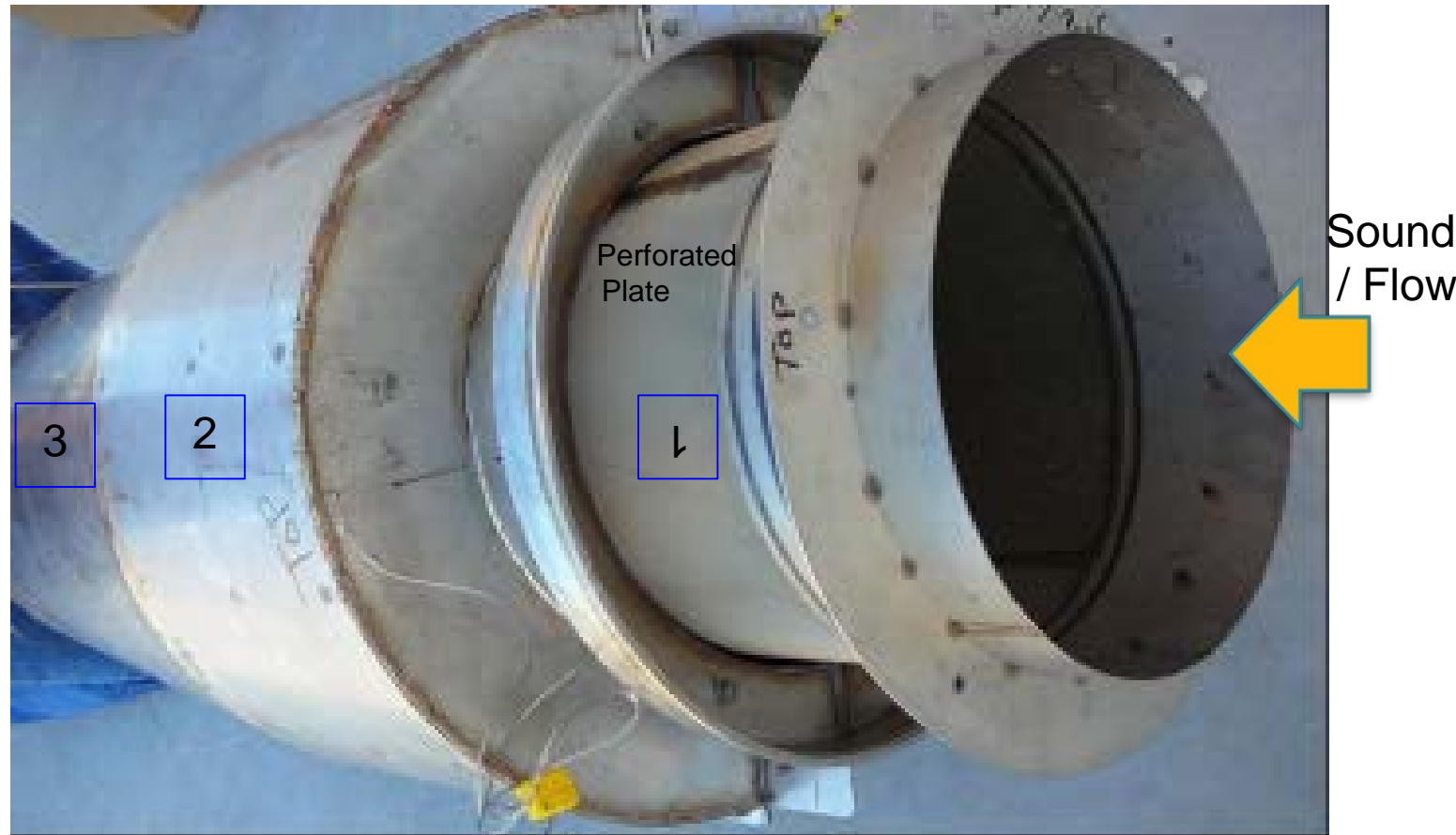
Aircraft APU (Auxiliary Power Unit)



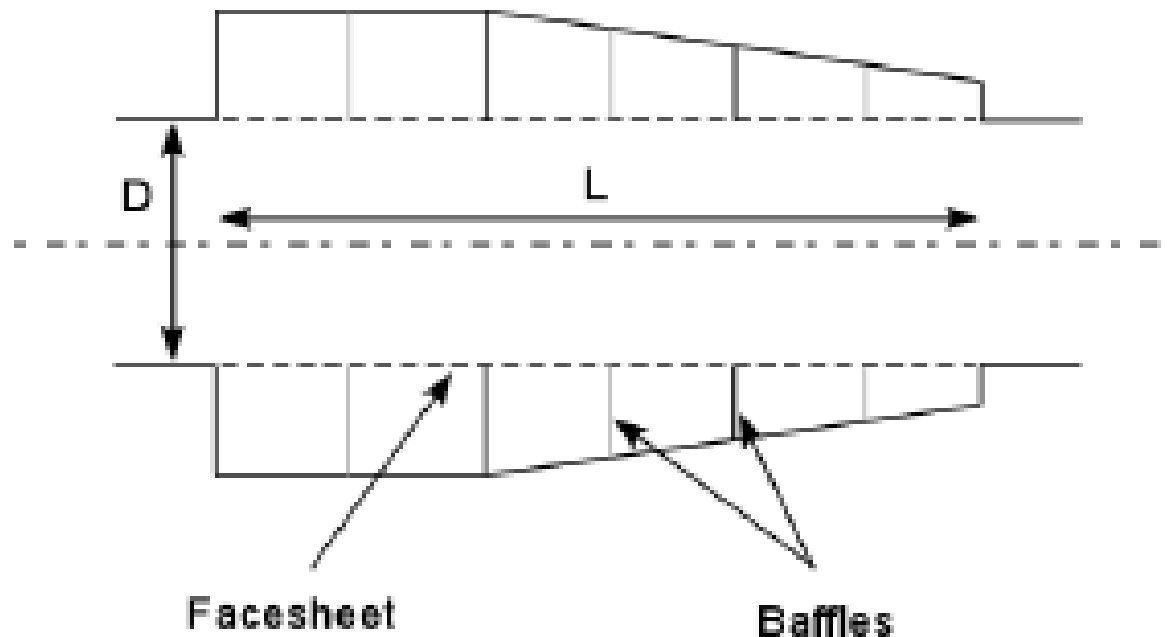
Acoustic Modeling of Aircraft APU (Auxiliary Power Unit)



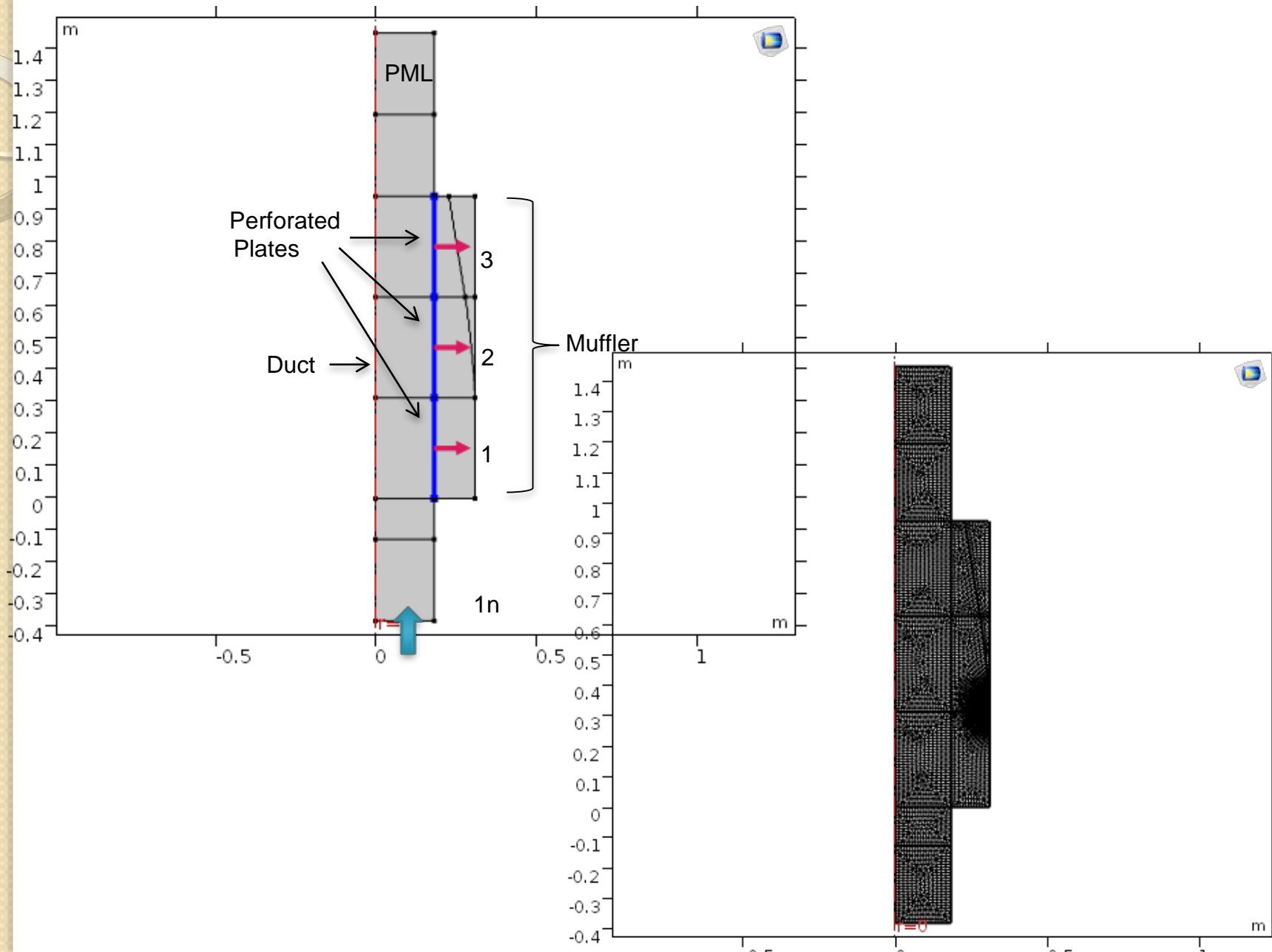
Acoustically Treated APU Exhaust Muffler



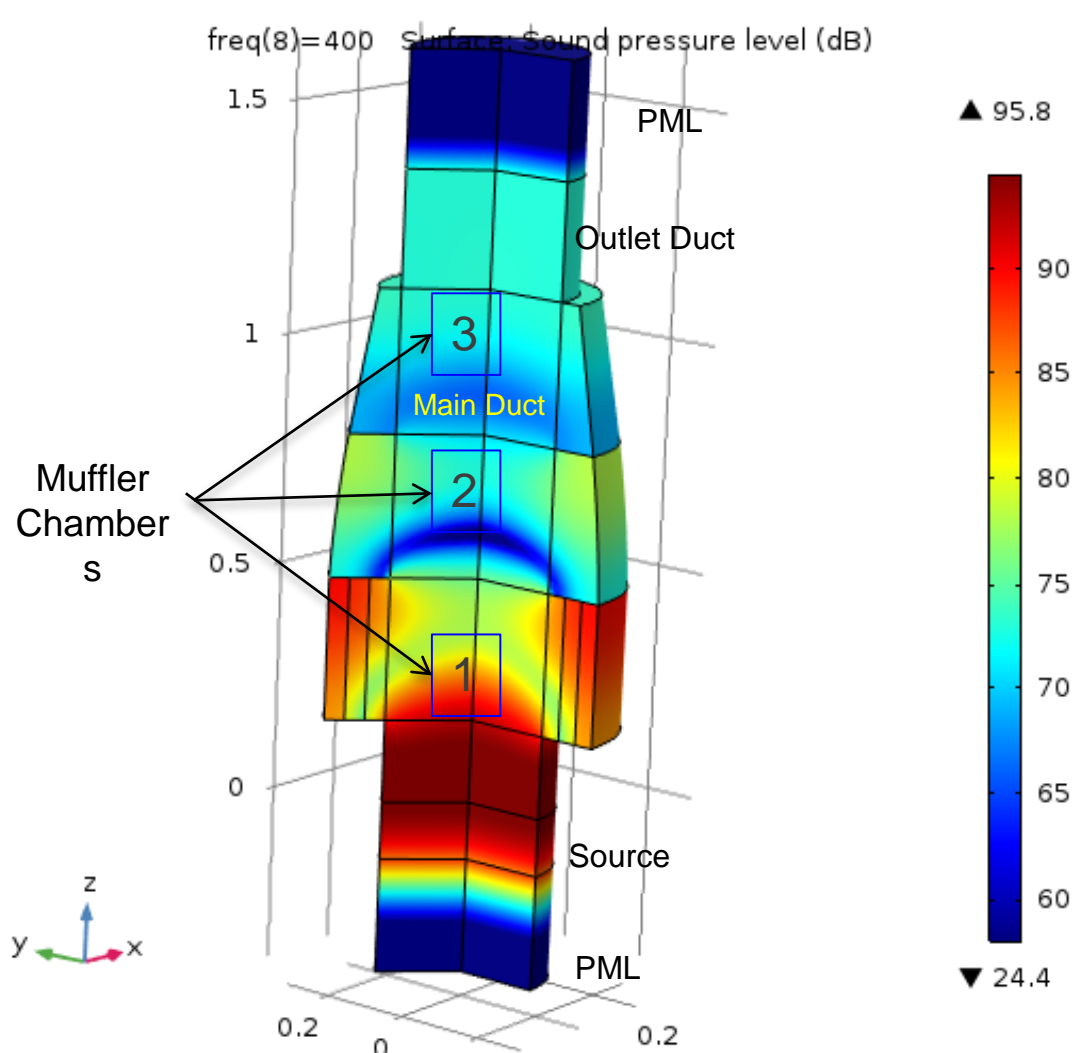
Schematic of Acoustically Treated APU Exhaust Muffler



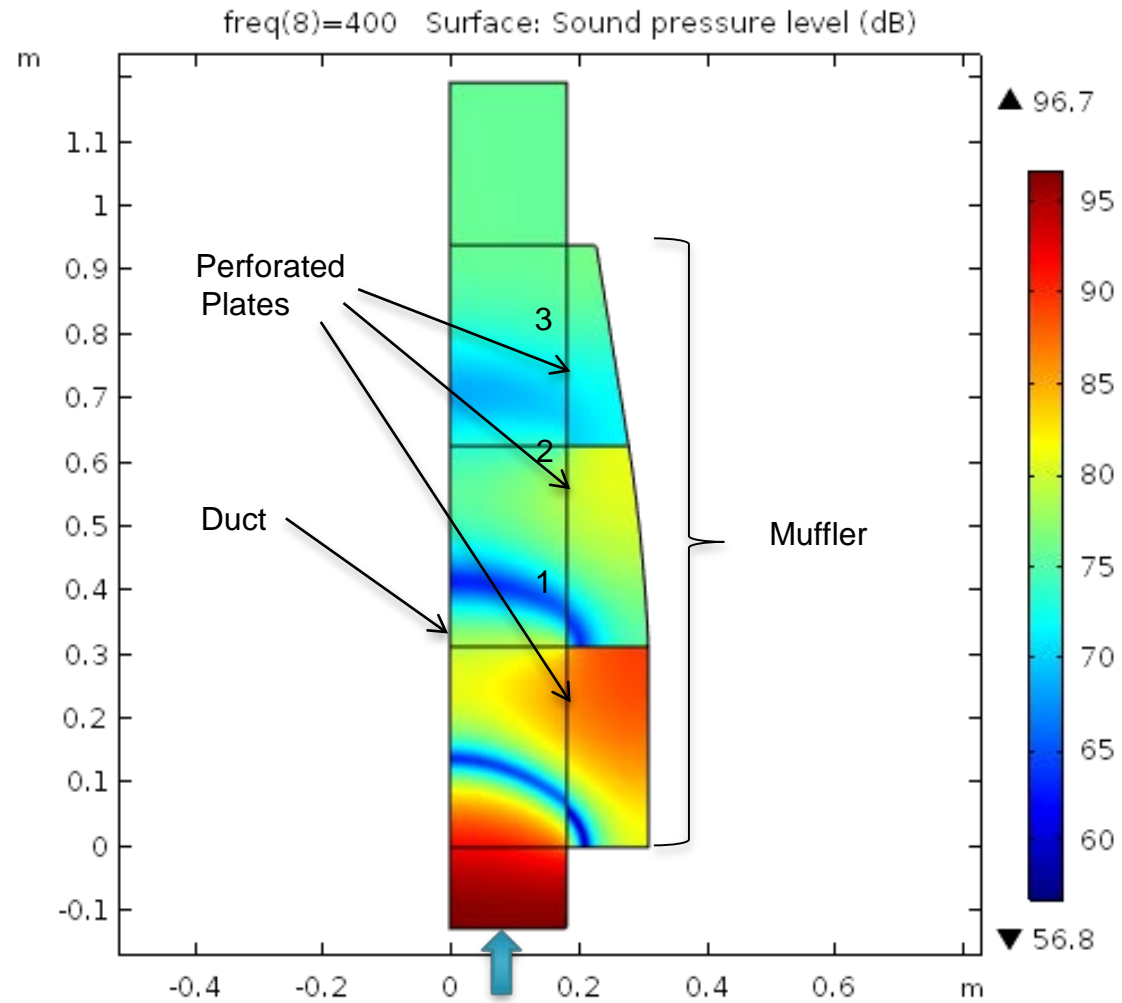
Aircraft APU Muffler – COMSOL Model



APU Muffler: COMSOL Model

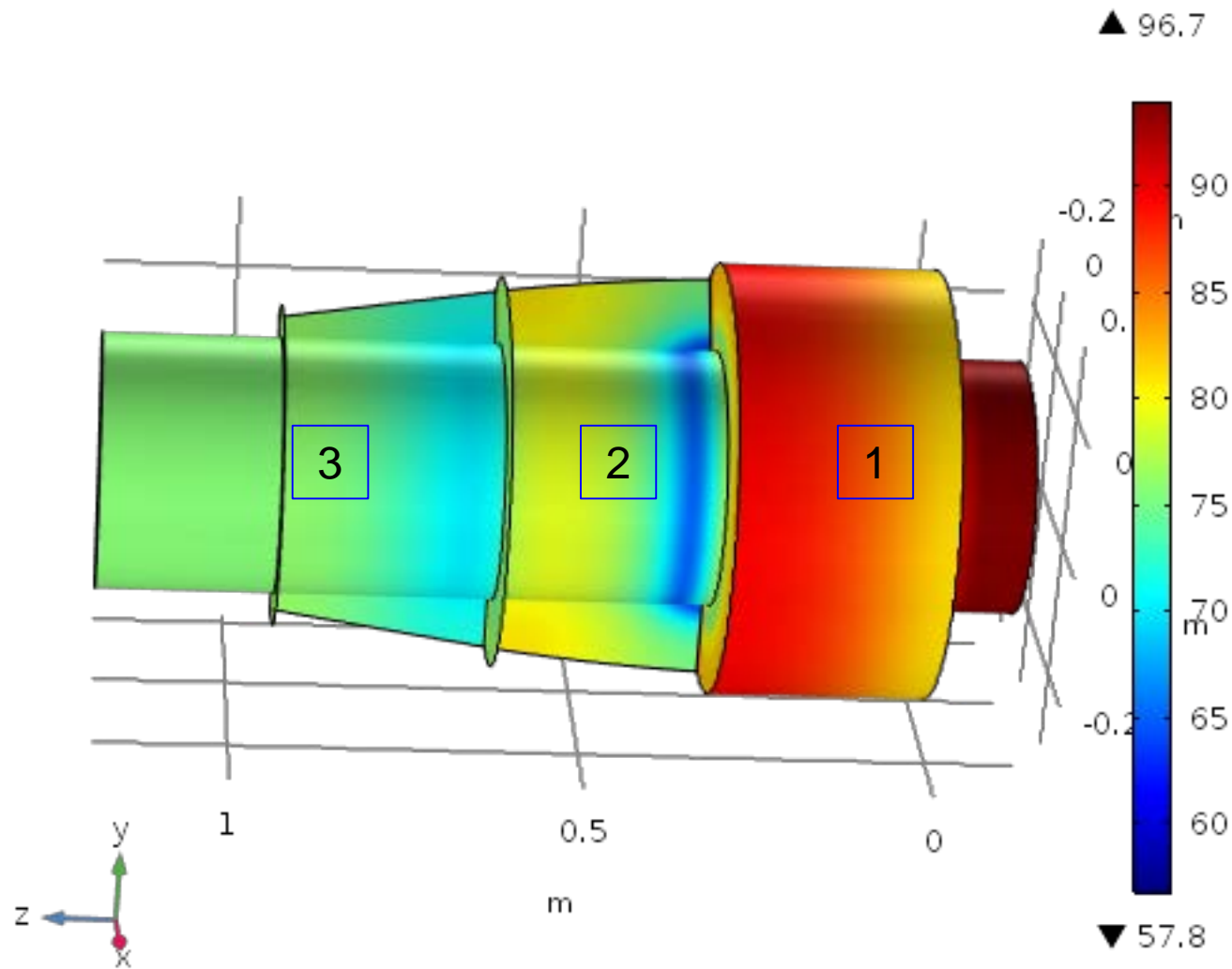


Aircraft APU Muffler – SPL Map



Aircraft APU Exhaust Muffler – SPL Map

freq(8)=400 Surface: Sound pressure level (dB)



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