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Investigation and Development of Multiphysics Modeling Software Applications for Building Noise Control

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Investigation and Development of Multiphysics Modeling Software Applications for Building Noise Control

University Honors Program Thesis

University of Nebraska at Omaha

Submitted by

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April 2019

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April 19, 2019

UNIVERSITY OF NEBRASKA AT OMAHA

HONORS THESIS/PROJECT/CREATIVE ACTIVITY ABSTRACT

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PROGRAM SIZE:	450+
THESIS:	REQUIRED
THESIS ISSUED:	PROGRAM

ABSTRACT OF THESIS

COMSOL Multiphysics is a simulation software for modeling engineering processes and designs. The software can be used to create applications that allow users to change variables in a model and see the effect on the physics phenomenon under investigation. COMSOL applications can provide an interactive learning experience and help students visualize engineering concepts. This project examines the use of COMSOL to develop applications related to noise control in buildings, focusing on making them useful for education. Two applications were developed based on existing COMSOL models. One simulates sound absorption by a porous foam, and the other simulates sound propagation through a duct with a right-angled bend. The applications were used to calculate the absorption coefficient across frequency for a melamine foam sound absorber and the insertion loss across frequency for a duct. To test the applications' accuracy, these results were compared with data from other software and from product data sheets. The results from the porous absorber application were reasonably accurate when compared to published data for a foam absorber. For the duct application, the calculated insertion loss values were close to the results from other software without an absorptive liner, although there was a larger discrepancy with a liner.

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A. Introduction

1. Purpose

Noise control is important in many types of buildings and has a significant impact on people's lives. In classrooms, for example, students need to hear the teachers without being distracted by noise. In offices, reducing noise leads to better concentration and productivity. In housing, noise control allows for better communication and relaxation that improves residents' quality of life. The purpose of this project was to develop new educational applications in COMSOL Multiphysics software to help architectural engineering students learn how to design buildings where people can communicate, concentrate, and relax without interference from background noise.

B. Background

1. COMSOL Multiphysics

COMSOL Multiphysics is a physics simulation software program that is utilized in engineering. A particularly useful aspect of COMSOL is that models created in the software can be turned into applications, allowing the models to be employed in a web browser. COMSOL is often used in research, but COMSOL applications can also be excellent educational tools. They provide a way for students to visualize engineering concepts, and the web browser interface allows students to run simulations without needing specialized software. Students can use the applications to change variables in a model and observe the effect on the physics of the model. The software includes several existing acoustics models that are applicable to noise control in buildings. However, many of these models do not have corresponding web-browser applications, including the two used in this project.

Although it is mainly used for research, COMSOL has also begun to be used in engineering education, and studies have shown that it is an effective educational tool. For example, students in a thermodynamics course who participated in a collaborative project using COMSOL scored 3% higher on final exam questions than students who did a similar project without COMSOL (Wright, 2018). Another study showed that students who used COMSOL felt that the software enhanced their learning experience and increased their interest in the course (Ngabonziza & Delcham, 2014).

2. Definitions of Acoustical Metrics

In this project, the following metrics were used to characterize the acoustical properties of the models.

a. Sound pressure level: A logarithmic representation of the ratio of a given sound pressure to a reference sound pressure. Related to human perception of loudness.

b. Absorption coefficient: The proportion of incident sound absorbed by a material.

c. Insertion loss: Reduction in sound level due to the insertion of a noise control device in the sound path.

d. Noise reduction coefficient (NRC): The proportion of incident sound absorbed by a material, averaged across the octave bands from 250 to 2000 Hz.

C. Methods

1. Existing COMSOL Models

Two applications were developed based on existing COMSOL models:

a. Porous Absorber: Simulates sound absorption by a porous foam material (COMSOL Inc., 2019). The model is shown in **Figure *1***.

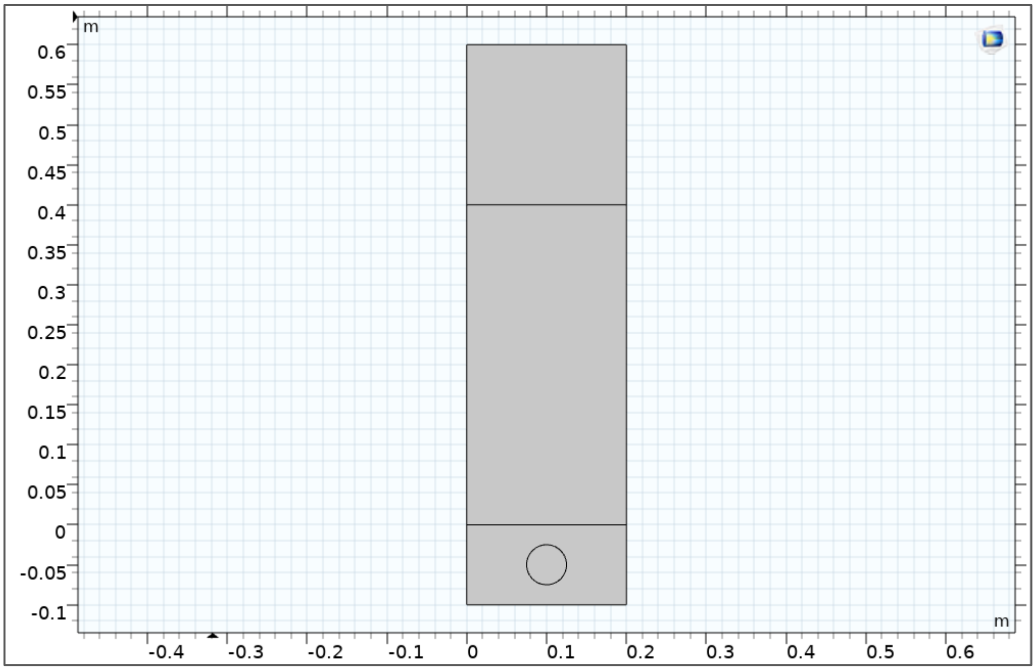

Figure 1. The original Porous Absorber model.

b. Duct with Right-Angled Bend: Simulates the propagation of sound through a rectangular duct segment with a right-angled elbow (COMSOL Inc., 2019). The original model is shown in Figure 2.

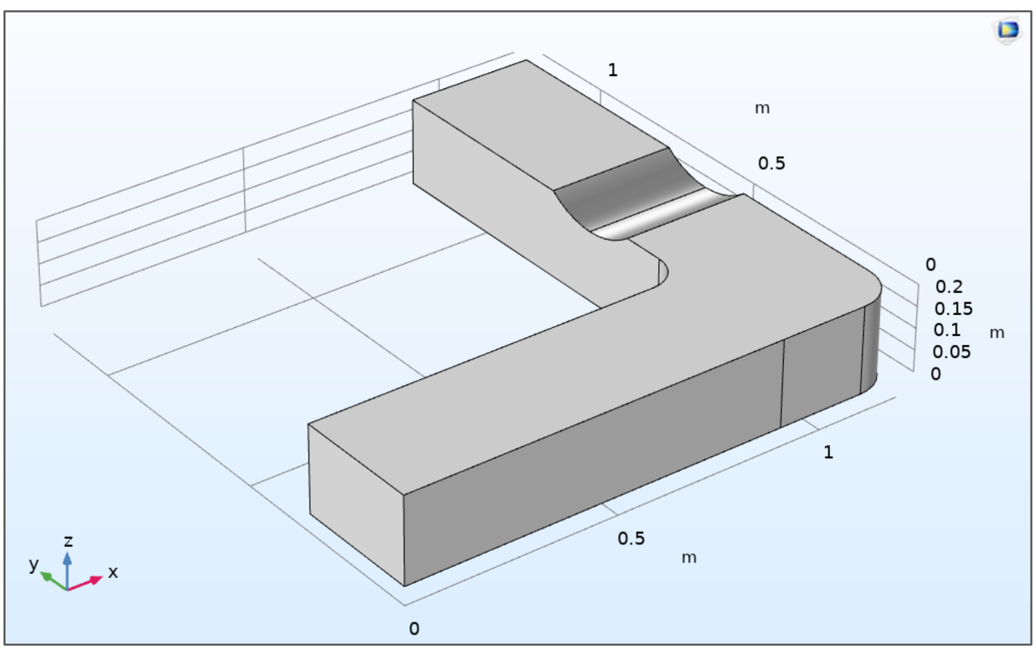

Figure 2. The original Duct with Right-Angled Bend model.

2. Application Development

Applications were developed based on the two models using the COMSOL Application Builder. The applications were parameterized to allow users to change variables and see the resulting acoustical effects. Input fields were created for each variable, and graphics were inserted into the application to display the results. Buttons were also added for plotting geometry, computing and plotting results, resetting inputs, creating a report, and opening documentation. In the Duct with Right-Angled Bend application, an absorptive liner was added to the model using the Poroacoustics feature, and an additional study was created to analyze the duct with the liner. The application includes options to run the study with or without the liner. The dent in the top of the duct shown in Figure 2 was also removed.

3. Data Collection

To test the accuracy of the applications, acoustical metrics were calculated using the newly developed applications, and the results were compared with data from other software and product data sheets.

a. Porous Absorber: To find material properties to use in the application, data was obtained from a study of melamine foam sound absorbers (Kino & Ueno, 2008). The values used in the application were averaged from three samples of foam. These values are shown in Table 1.

Porosity	**Flow resistivity ($Pa*s/m^2$)**	**Tortuosity**	**Viscous characteristic length (μm)**	**Thermal characteristic length (μm)**
0.993	13700	1.0056	200	430

Table 1. Material properties of melamine foam (Kino & Ueno, 2008).

The application was used to compute absorption coefficients across frequency for a 20 cm wide and 5 cm thick absorber with the material properties displayed in Table 1. The results were compared with product data for a melamine foam absorber of the same thickness (Sound Service, 2011). The NRC was also calculated for each data set based on the absorption coefficients, using Equation 1:

$$NRC = \frac{1}{4}(\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}) \quad (1)$$

where α_{250}, α_{500}, α_{1000}, and α_{2000} are the absorption coefficients at 250, 500, 1000, and 2000 Hz.

b. Duct with Right-Angled Bend: A duct was analyzed in the application with the dimensions shown in Table 2, with and without a 1" liner. An identical duct was analyzed in Pottorff AIM software to compare with the COMSOL results.

Length of straight runs (ft)	**Width (in)**	**Height (in)**	**Bend curvature radius (in)**	**Liner thickness (in)**
4	10	8	10	1

Table 2. Dimensions of the analyzed duct.

D. Applications

1. Porous Absorber

As shown in Figure 3, a user can enter the dimensions and material properties of the absorber. The resulting plots display the acoustic pressure (Figure 4) and sound pressure level (Figure 5) throughout the absorber, and it plots absorption coefficients across frequency (Figure 6). The user can select the frequency to display in the acoustic pressure and sound pressure level plots. Figures 4 and 5 show that the acoustic pressure and sound pressure level decrease as the sound travels through the absorber. As shown in Figure 6, the absorber is more effective at high frequencies.

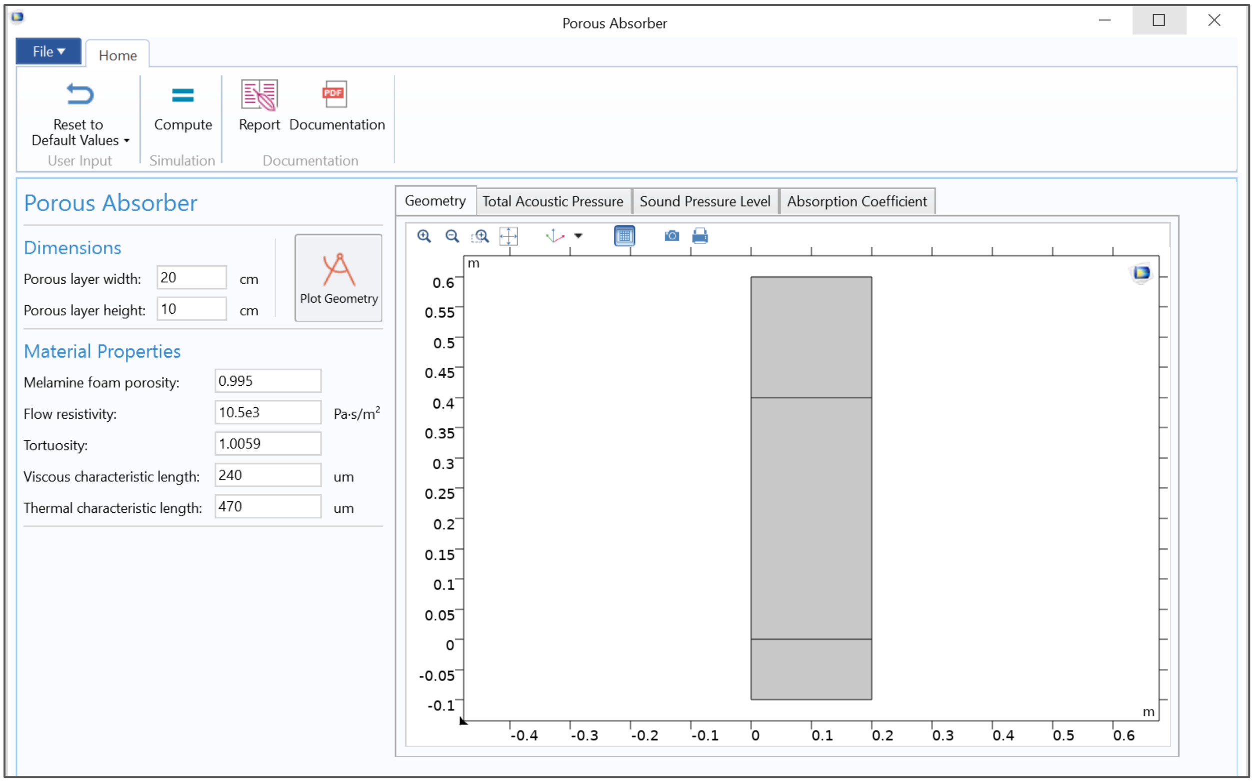

Figure 3. Porous Absorber application.

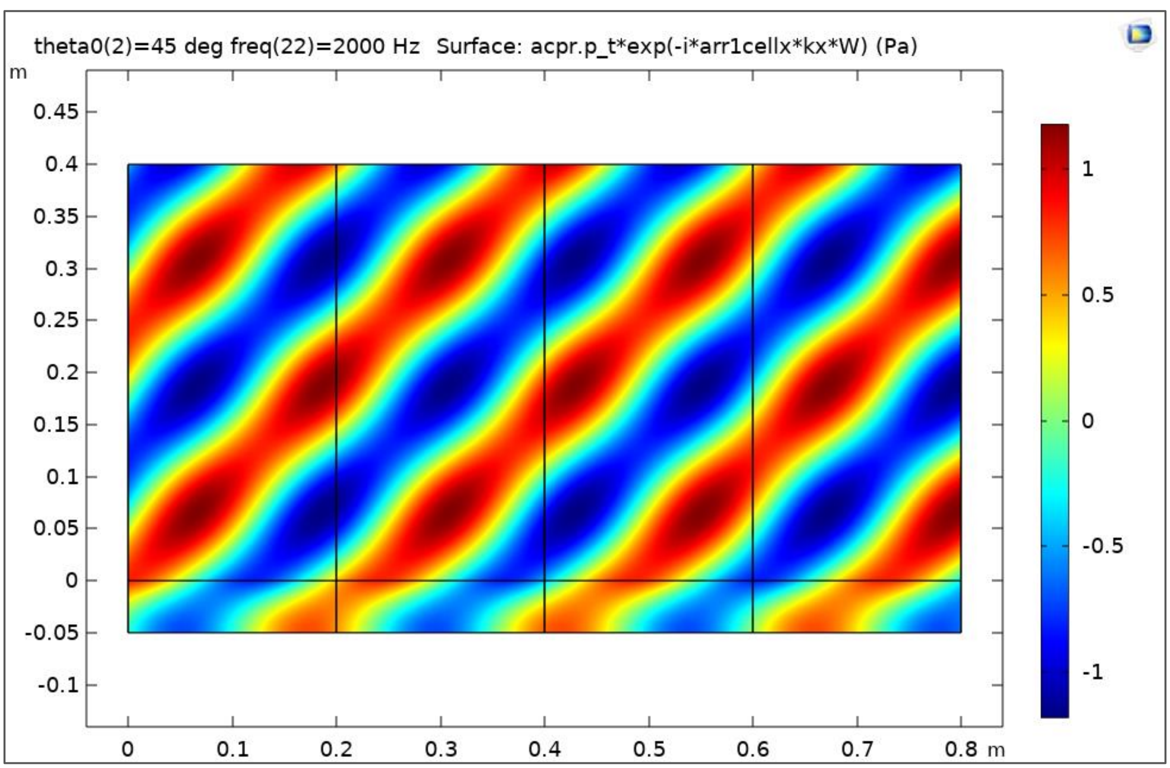

Figure 4. Acoustic pressure plot at 2000 Hz from Porous Absorber.

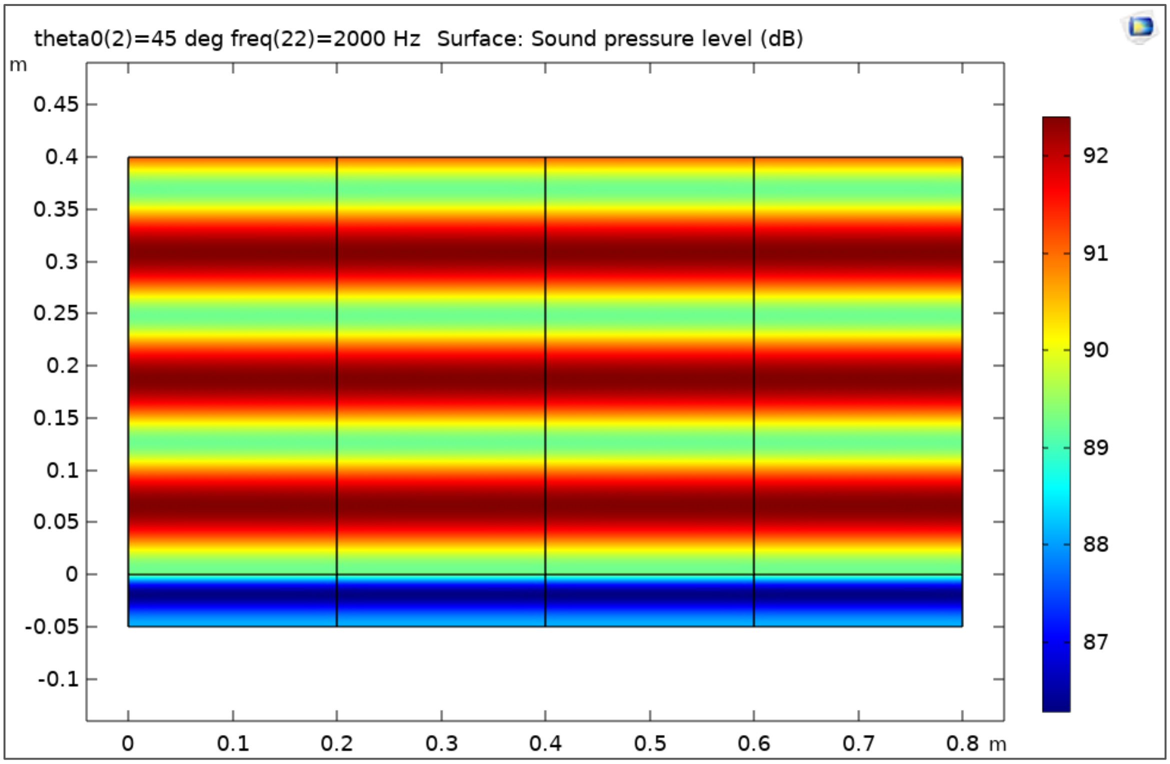

Figure 5. Sound pressure level plot at 2000 Hz from Porous Absorber.

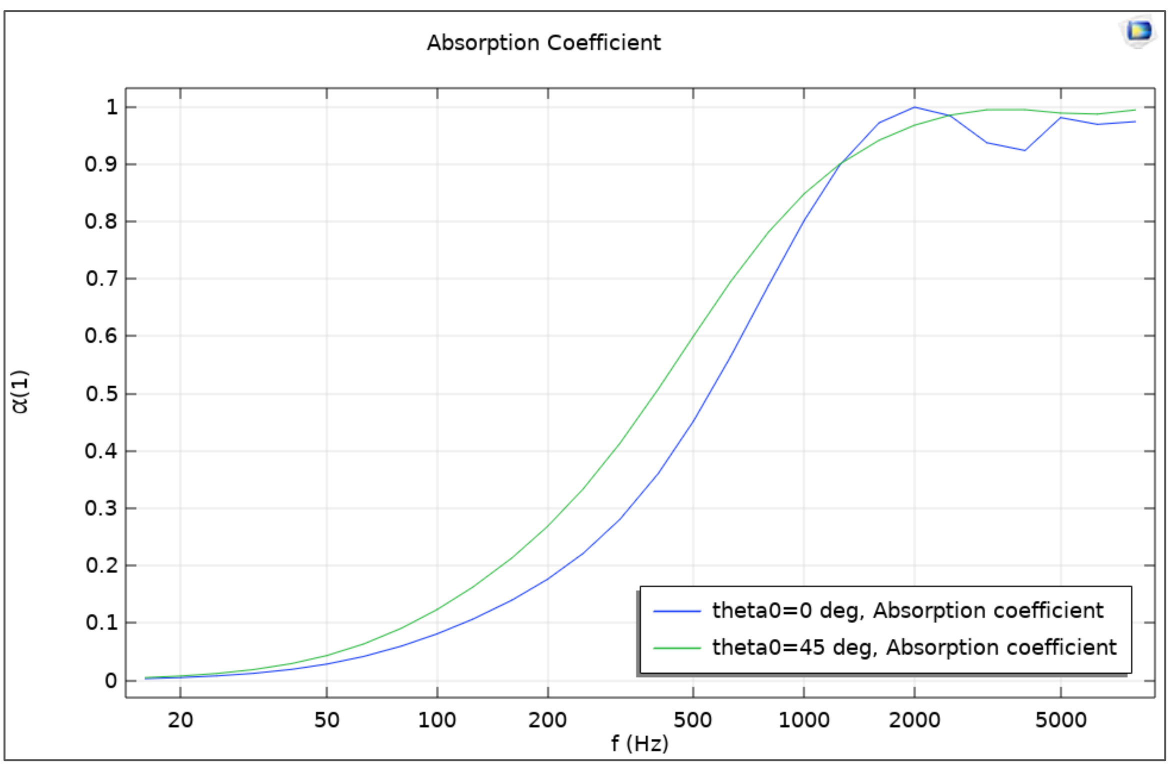

Figure 6. Absorption coefficient plot from Porous Absorber.

2. Duct with Right-Angled Bend

As displayed in Figure 7, in the Duct with Right-Angled Bend application, the user can enter duct dimensions, liner properties, and frequency range. The application plots the acoustic pressure (Figure 8) and sound pressure level (Figure 9) on the surfaces of the duct, as well as isosurfaces of the acoustic pressure (Figure 10). The user can select the frequency to show in these three plots. The application also plots insertion loss across frequency (Figure 11). As shown in these figures, the sound level decreases slightly from the inlet to the outlet of the duct without the liner, while it decreases much more with the liner. Figure 11 also shows that there is more sound attenuation at higher frequencies.

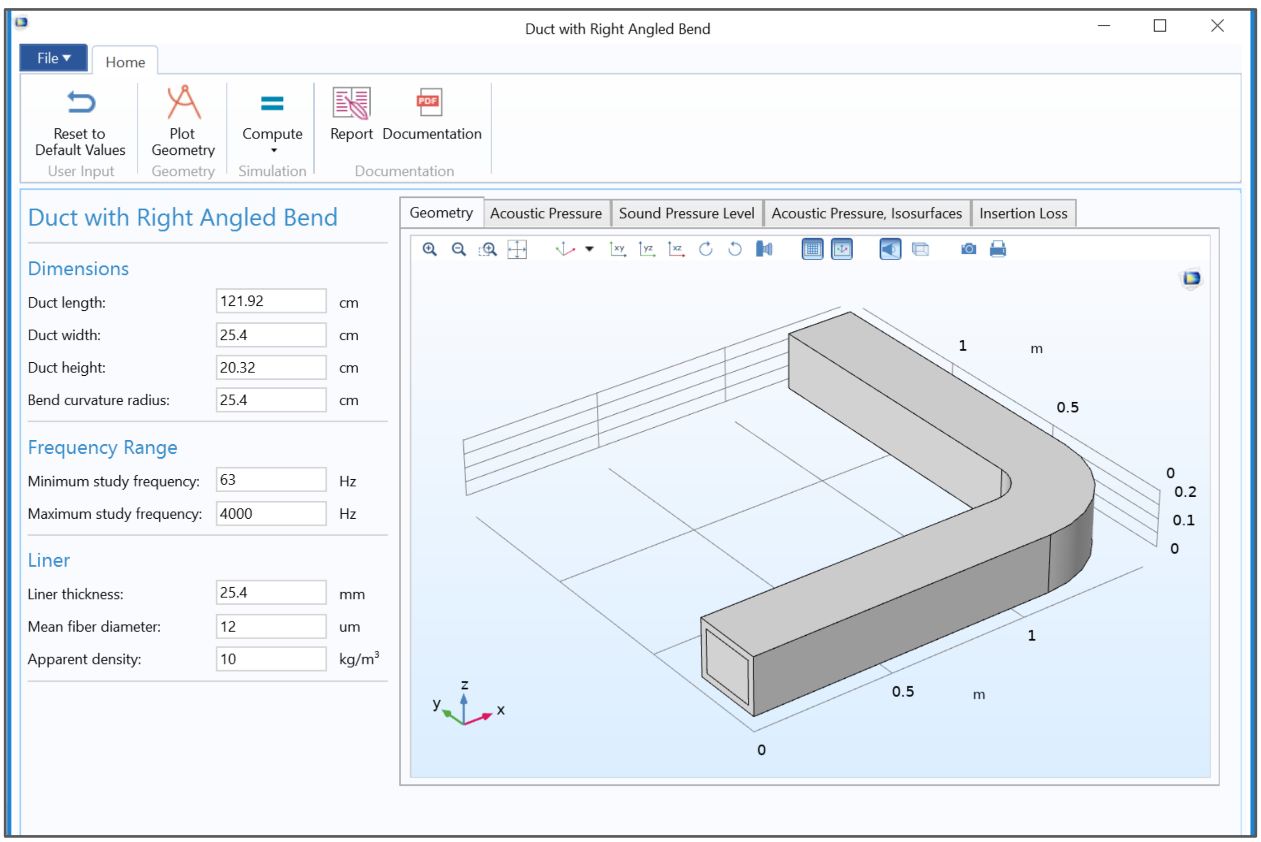

Figure 7. Duct with Right-Angled Bend application.

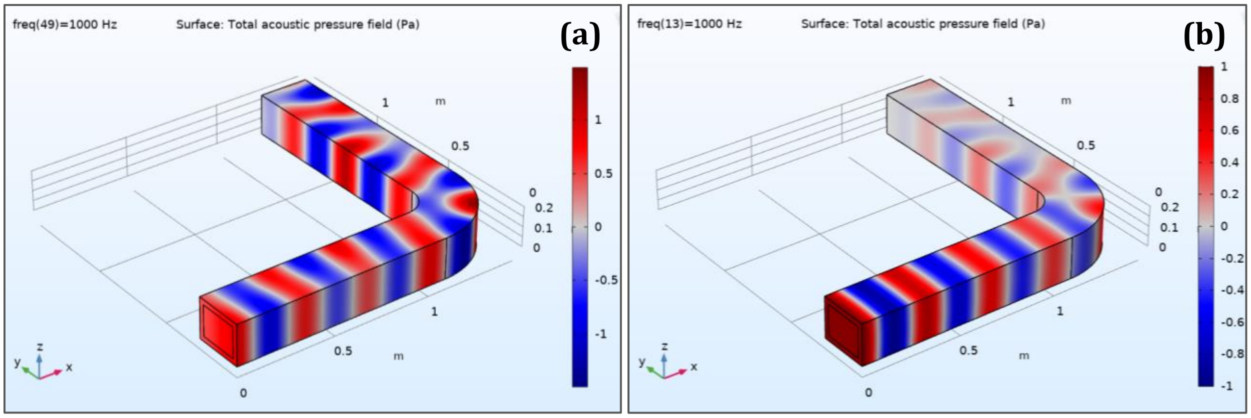

Figure 8. Acoustic pressure plots at 1000 Hz from Duct with Right-Angled Bend, (a) without a liner and (b) with a liner.

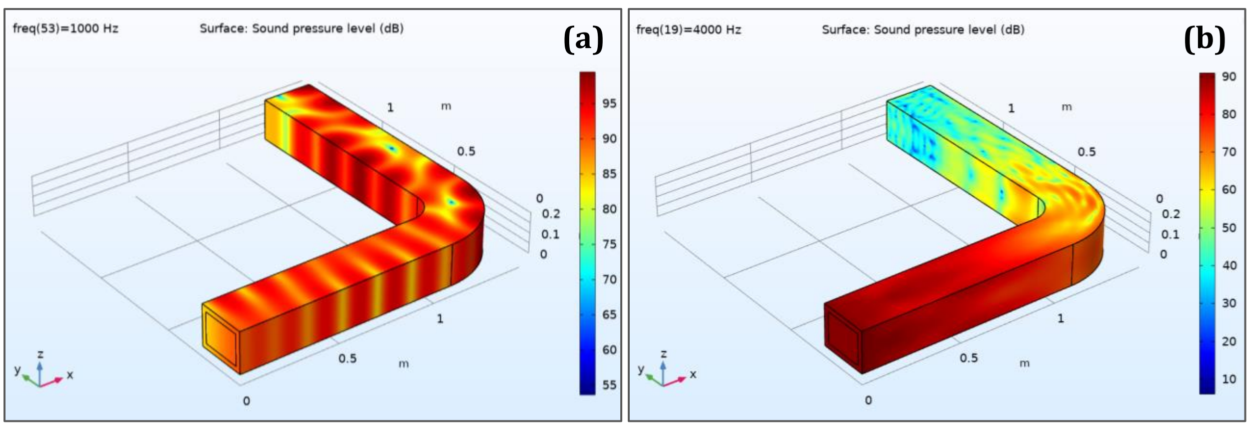

Figure 9. Sound pressure level plots at 1000 Hz from Duct with Right-Angled Bend, (a) without liner and (b) with liner.

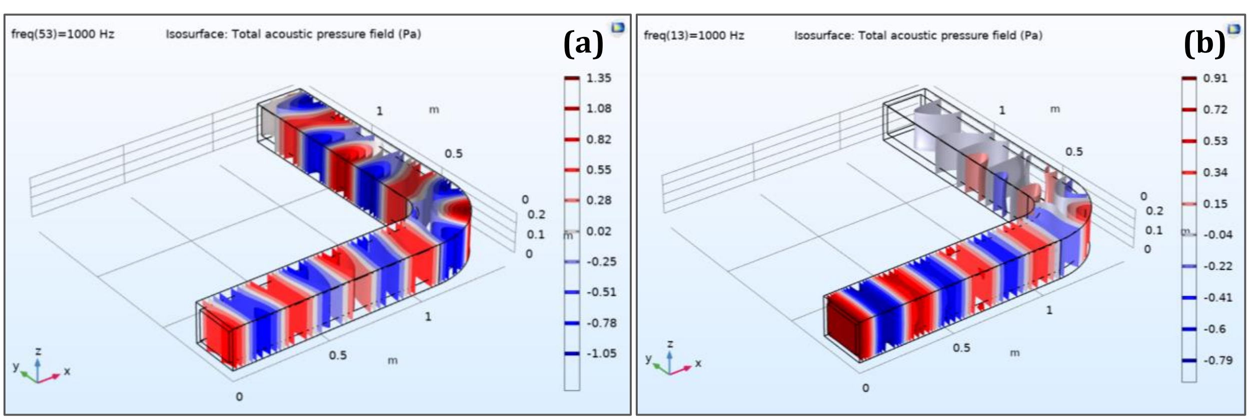

Figure 10. Acoustic pressure isosurfaces at 1000 Hz from Duct with Right-Angled Bend, (a) without liner and (b) with liner.

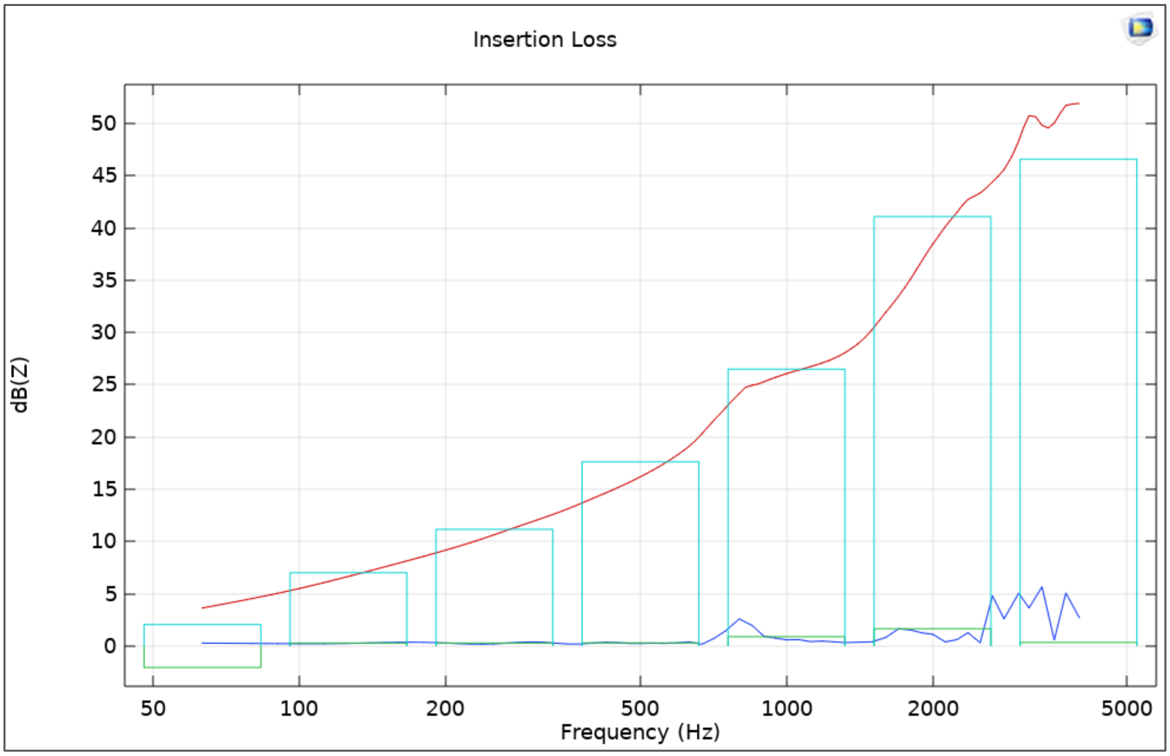

Figure 11. Insertion loss plot from Duct with Right-Angled Bend application.

E. Results

1. Porous Absorber

As shown in Figure 12, absorption coefficients from the COMSOL porous absorber application were fairly close to the absorption coefficients from the data sheet at most frequencies. However, the application results tended to be greater than the values from the data sheet at low frequencies and less than the data sheet values at high frequencies. The percent error between the NRC from COMSOL and AIM was 3.8%. The absorption coefficients from COMSOL and the data sheet are shown in Table 3.

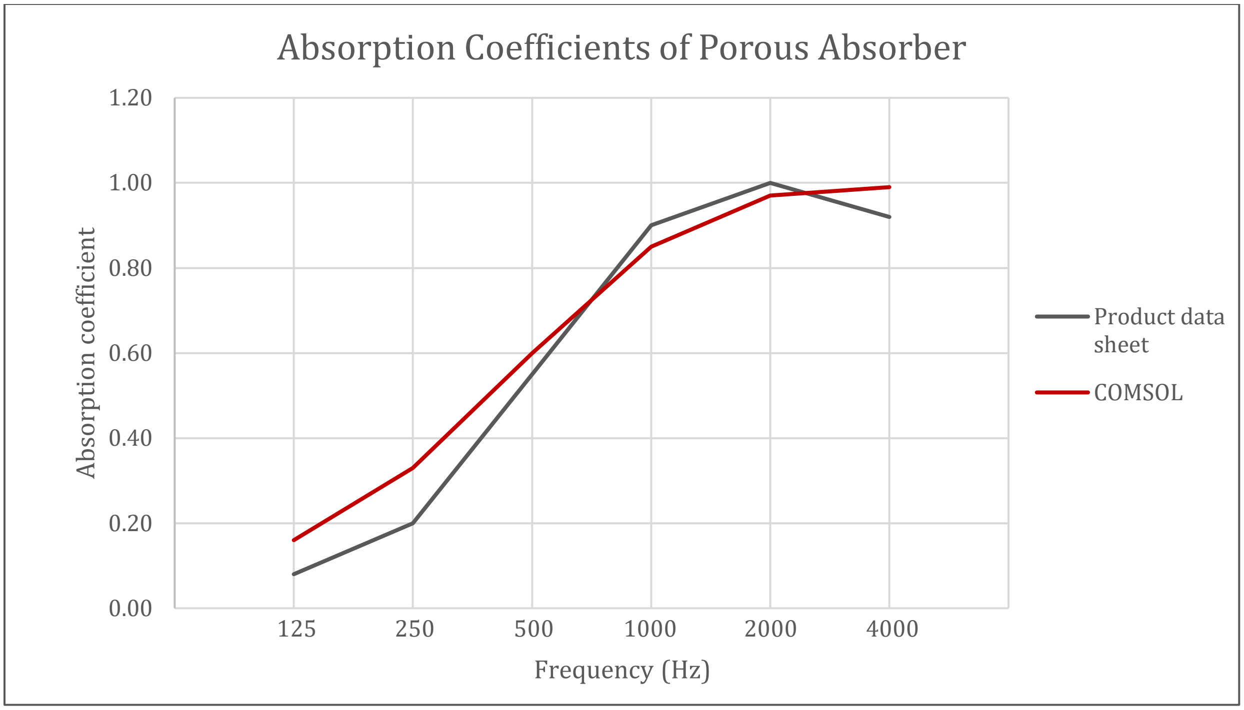

Figure 12. Absorption coefficients of a melamine foam sound absorber from COMSOL and product data sheet.

Frequency	125	250	500	1000	2000	4000	NRC (250 – 2000 Hz)
Absorption coefficient from data sheet	0.08	0.20	0.55	0.90	1.00	0.92	0.66
Absorption coefficient from COMSOL	0.16	0.33	0.60	0.85	0.97	0.99	0.69
Error	0.08	0.13	0.05	0.05	0.03	0.07	0.03
% error	100.0	65.0	9.1	5.6	3.0	7.6	3.8

Table 3. Absorption coefficients from COMSOL and product data sheet.

2. Duct with Right-Angled Bend

Figure 13 shows that the results from the COMSOL duct application were relatively similar to the AIM results without the liner, but less similar with the liner, especially at high frequencies. As shown in Table 4, the difference between the average COMSOL and AIM insertion loss was 2.1 dB without a liner. This is less than the minimum perceptible difference in sound level, which is 3 dB. However, the error with a liner was 8.5 dB, which is a perceptible difference.

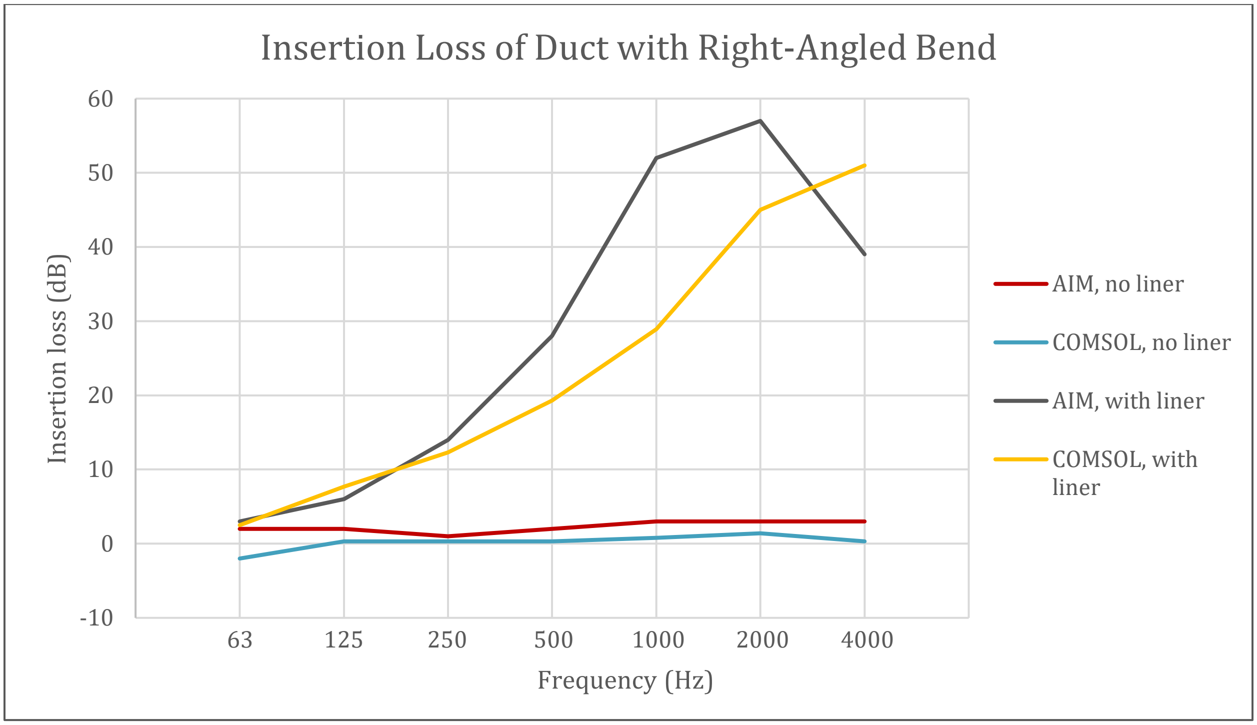

Figure 13. Insertion loss of a duct with a right-angled bend from COMSOL and AIM.

	Frequency (Hz)	63	125	250	500	1000	2000	4000	Average
No liner	Insertion loss from AIM (dB)	2	2	1	2	3	3	3	2.3
	Insertion loss from COMSOL (dB)	-2	0.3	0.3	0.3	0.8	1.4	0.3	0.2
	Error (dB)	4	1.7	0.7	1.7	2.2	1.6	2.7	2.1
Liner	Insertion loss from AIM (dB)	3	6	14	28	52	57	39	28.4
	Insertion loss from COMSOL (dB)	2.5	7.7	12.3	19.3	28.9	45.0	51.0	23.8
	Error (dB)	0.5	1.7	1.7	8.7	23.1	12.0	12.0	8.5

Table 4. Insertion loss from COMSOL and AIM.

F. Discussion

1. Porous Absorber

The COMSOL Porous Absorber application showed reasonably good agreement with the published absorption coefficients of a foam sound absorber. This application could be a useful tool for teaching about the sound absorption properties of porous materials. Students could use it to visualize the reduction in sound level as sound travels through a porous material and to observe how effective a porous absorber is at different frequencies.

2. Duct with Right-Angled Bend

The Duct with Right-Angled Bend application results were fairly close to results from AIM without an absorptive liner. The application could provide students with a useful demonstration of the behavior of sound in a duct, and it could be used to interactively teach students how they can design ducts to minimize noise. However, it did not agree with AIM at higher frequencies when analyzed with a liner. The application could still serve as a general illustration of the effect of a duct liner, but these results suggest that it should not be used to obtain precise data for insertion loss of a duct with a liner. Based on these results, the application will be modified to include only the option without the liner.

3. Future Directions

Future research could be done to investigate possible sources of error and look for ways to improve accuracy, especially for the liner option in the Duct with Right-Angled Bend application. One possible source of error is user error, such as inputting data into the applications incorrectly. The experiment could be repeated to reduce the chance of user error. Another potential source of error that could be examined is inaccuracy in the material properties of the liner and the porous absorber. These values were obtained from a different source than the data with which the applications were compared, so the material properties may not have been exactly the same. To address this issue, the absorption coefficients or insertion loss could be measured for real absorbers or duct liners with known properties, and the COMSOL results could be compared with these measurements.

Another possibility for future research is to test the accuracy of the applications with absorbers and ducts of different sizes, shapes, and materials. This would ensure that the applications are consistently accurate in a variety of cases, not just for one specific type of absorber or duct.

Research could also be done to study the effect of the applications on learning. The grades of students who use the applications in a class could be compared with those of students who have taken the same class without the applications. The students could also be asked whether they felt that the applications were helpful, and they could provide suggestions for ways to improve the applications.

G. References

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