The Design and Construction of the Texas Christian University Impedance Tube

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This project focuses on the design, construction, and validation of a two microphone impedance tube. The two-microphone impedance tube test method is a well-established and widely used technique for determining the acoustic absorption coefficient and impedance ratio of materials. This method uses two closely spaced microphones to simultaneously measure the incident and reflected sound waves. A two-microphone impedance tube measurement system made of 6061-T6 Aluminum with a diameter of 3 inches, a 0.5 inch wall thickness, and microphones spaced 2.7 inches apart has been constructed for undergraduate research at Texas Christian University (TCU).

Abstract

The two-microphone impedance tube test method is a well-established and widely used technique for determining the acoustic absorption coefficient and impedance ratio of materials. This method uses two closely spaced microphones to simultaneously measure the incident and reflected sound waves. A two-microphone impedance tube measurement system made of 6061-T6 Aluminum with a diameter of 3 inches, a 0.5 inch wall thickness, and microphones spaced 2.7 inches apart has been constructed for undergraduate research at Texas Christian University (TCU). These geometrical values suggest a usable frequency range of 50 Hz to 2637.77 Hz as referenced in ASTM Standard E1050-19. Validation of the system was achieved by taking measurements on Owen Corning Type 705 pressed fiberglass board with a 1-inch thickness and comparing them to absorption data provided by the manufacturer. Additional validation measurements were taken without a test sample in place. All validation tests suggest that the TCU impedance tube is an accurate measurement system.

Key Design Parameters

As described in the ASTM E1050-19 Standard Test Method, the geometric properties of the impedance tube determine its usable frequency range. To be more specific, the microphone spacing and the tube diameter limit the frequency. Since the tube diameter is 3 inches, a microphone spacing of 2.7 inches was chosen.

$$0.05\frac{c}{s} < f < 0.45\frac{c}{s} \qquad f < 0.586\frac{c}{d}$$

Where:

c = speed of sound in m/s

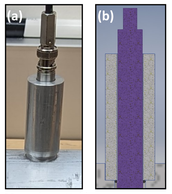
s = microphone spacing in m

d = diameter of tube in m

Another specification put forth by ASTM E1050-19 is that a minimum of three tube diameters should be allowed between the sound source and first microphone and a minimum of two times the diameter between the second microphone and the test material. This allows for any nonplane waves generated to dissipate before they reach the microphones.

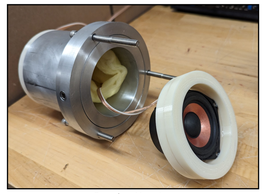
The Design

Once the key design parameters were found, the tube was modeled in Autodesk Inventor, a 3D CAD software, and detail drawings were created. The impedance tube was constructed out of a 6061-T6 Aluminum tube with a 3 inch diameter and a 0.5 inch wall thickness. The key sections of the impedance tube include the speaker housing, tube body, microphone holders, and the material housing.

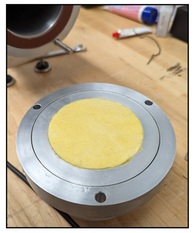


(a) Microphone Holder

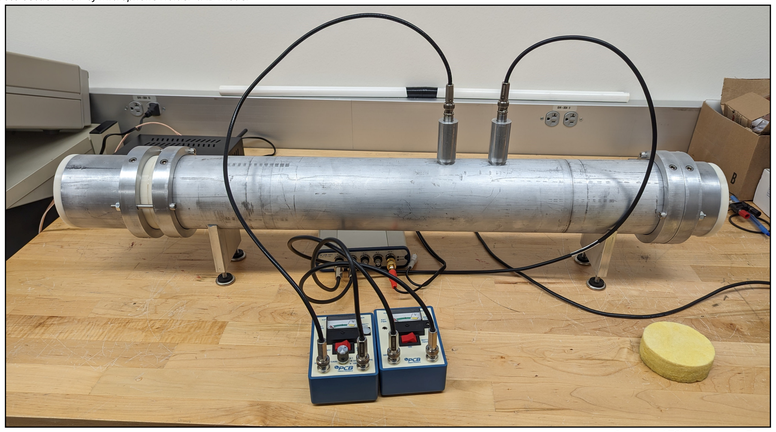
(b) Cross-Section View of Microphone Holder CAD Model



Speaker Housing



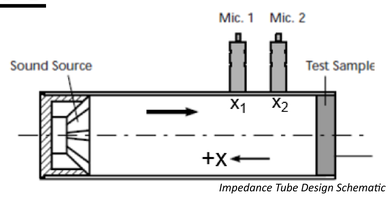
Material Housing



Completed TCU Impedance Tube

TCU Impedance Tube

- Tube Diameter = 3”
  - High Frequency Limit = 2637.77 Hz
- 6061-T6 Aluminum Construction
  - Wall thickness = 0.5”
- Microphone Spacing = 2.7”
  - Low Frequency Limit = 50 Hz
- X2 = 9” - 3 diameters for Asymmetrical Surfaces
- 2.5” Douk Audio Speaker (LB020)
- 0.5” PCB Microphones (378B02 & Y378A13)



Impedance Tube Design Schematic

TCU Impedance Tube Cross-Section

Testing and Validation

The validation of the TCU Impedance Tube began by calibrating the two PCB microphones. This process used a G.R.A.S Type 51AB acoustic calibrator to calibrate the phase of both microphones. Once the microphones were calibrated, the tube was set up to test. Once the microphones were calibrated, the impedance tube can be set up to test.

The validation test for the system was achieved by taking measurements on Owen Corning Type 705 pressed fiberglass board with a 1-inch thickness and comparing them to absorption data provided by the manufacturer as well as an impedance tube Dr. Hall created from 2016.

Microphone Calibration

OC 705 3” Diameter Test Sample

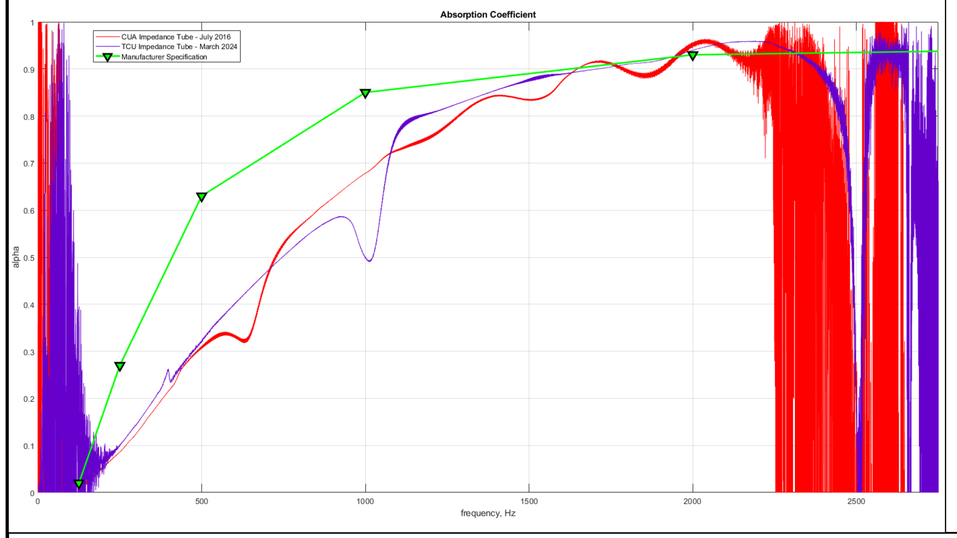
$$\hat{H}_{12}(f) = \frac{p_2}{p_1} = \frac{e^{-i\hat{k}x_2} + \hat{R}e^{i\hat{k}x_2}}{e^{-i\hat{k}x_1} + \hat{R}e^{i\hat{k}x_1}}$$

$$\hat{R} = \frac{\widehat{H_{12}} - e^{-jk(x_1-x_2)}}{e^{jk(x_1-x_2)} - \widehat{H_{12}}} e^{j2kx_1}$$

$$\alpha = 1 - \left|\hat{R}\right|^2$$

Transfer Function and Key Equations Applied

The data was acquired using a LabView program that was then run through a Matlab program that extracted the necessary data and applied the proper transfer functions and equations. The output of the program is the absorption coefficient (α) for the Owen Coring at the frequency range tested.



References

[1] A. F. Seybert and D. F. Ross. Experimental determination of acoustic properties using a two-microphone random-excitation technique. The Journal of the Acoustical Society of America, 61(5):1362–1370, 1977.

[2] ASTM E1050-19, Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System, 2019.