Data Analysis of the Differential Pressure of 3-D Printed Porous Materials to Determine Airflow Resistance

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1 Abstract

An important characteristic in determining the acoustic impedance of porous materials is the resistance to airflow in the material. This study will focus on measuring the airflow resistance of 3-D printed material with circular pores. The goal of this study is twofold. First, to design a device that can successfully and accurately measure the volumetric airflow rate through the porous media and the differential pressure across it in order to determine the specific airflow resistance of a porous media. Second, to study the dependence of the flow resistance on porous properties of the material. The device measures the pressure just before and just after a 3-D printed porous plug. The volumetric airflow rate is measured at the output end of the device. Data from plugs with varying lengths will be presented.

2 Introduction

The properties of porous materials are important in acoustical engineering. Porosity (the ratio of pore volume to total volume) and acoustic impedance factor into the sound damping capabilities of materials. NASA has a vested interest in this field. NASA monitors the acoustical environment on every manned spacecraft (i.e. the ISS, Orion Capsule). The Johnson Space Center (JSC) Acoustics and Noise Control Laboratory (ANCL) is tasked with ensuring a "Safe, Healthy, and Habitable Vehicle Acoustic Environment" ([1]). This laboratory uses a number of techniques to measure the acoustic properties of materials used to control noise in a manned spacecraft. This could be the noise from a cooling fan on a piece of equipment or duct noise from air circulation. One of the measurement instruments used at ANCL is an acoustic impedance tube. When designing these materials for noise control, it is important to account for how much airflow a system may need through the sound impeding material. To account for this, the airflow resistance of the materials can be studied. Airflow resistance is defined as the differential pressure over the material divided by the volumetric airflow rate through the material([2]).

$$R = \frac{\Delta p}{q_v} \tag{1}$$

The volumetric airflow rate is determined by the air speed through the material multiplied by the cross sectional area of the output space where speed is being measured.

$$q_v = v\pi r^2 \quad \text{where } r = 0.0330 \text{ m} \tag{2}$$

$$q_v = v(0.00342\text{m}^2) \tag{3}$$

Comparing how material properties affect both sound impedance and airflow resistance will allow for the optimization of acoustic materials. However, this project will solely focus on the airflow resistance of these materials.

3 Data

By running air through a sample, determining the pressure difference of air over the sample, and measuring how fast the air is flowing through the sample, the airflow resistance can be calculated for the sample. A device was designed and 3-D printed to determine these values. Due to limitations of the flow meter being used to determine volumetric airflow rate, only differential pressure data can be automatically collected, and airflow resistance values must be calculated manually. The differential pressure data for materials with varying lengths was collected over the course of an hour for each sample, and is displayed in the following figures.

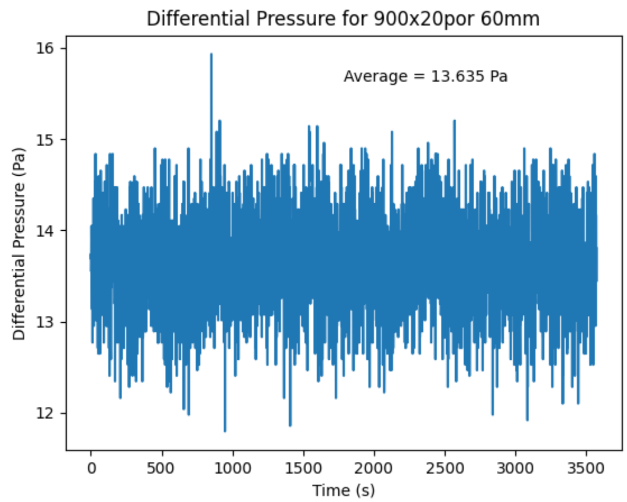

Figure 1: Differential pressure of a 6 cm, 900 pore, and 20 porosity 3-D printed porous material over an hour. The average differential pressure for the hour is displayed.

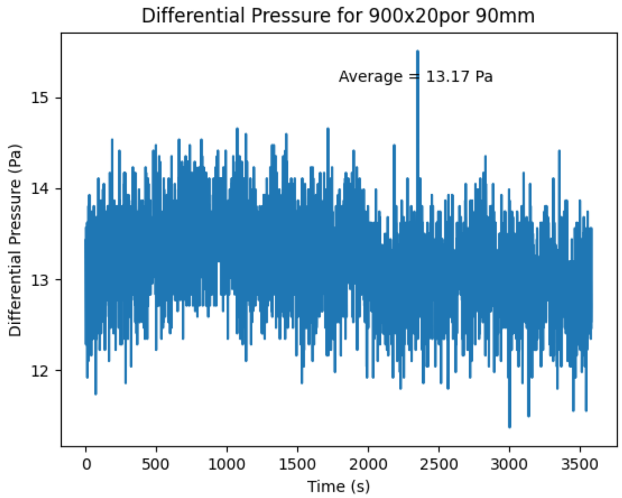

Figure 2: Differential pressure of a 9 cm, 900 pore, and 20 porosity 3-D printed porous material over an hour. The average differential pressure for the hour is displayed.

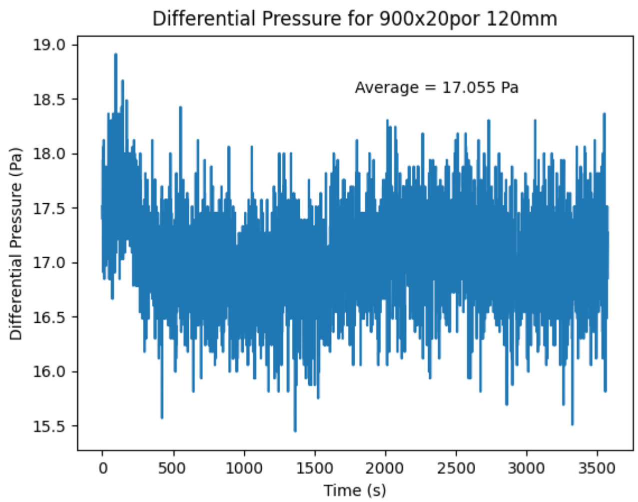

Figure 3: Differential pressure of a 12 cm, 900 pore, and 20 porosity 3-D printed porous material over an hour. The average differential pressure for the hour is displayed.

4 Analysis

Using the average differential pressure for each sample and the readings from the flow meter, the airflow resistance can be calculated. Unfortunately, the speeds at which the device is being run are in the lower limits that the flow meter can detect, so the flow meter cannot stabilize and fluctuates in its flow speed reading. What can be found from this is a range of airflow resistance values. For the 6 cm sample(Figure 1), the average differential pressure was 13.635 Pa and the range of flow speeds was 0.30 to 0.46 m/s. The lower limit of the airflow resistance values was determined using Equation 1.

$$
\begin{aligned}
R &= \frac{13.635 \text{ Pa}}{0.46 \text{ m/s} \times 0.00342} && (4)\\
&= 8.7 \times 10^3 \text{ Pa} \cdot \text{s/m}^3 && (5)
\end{aligned}
$$

And the higher limit:

$$R = \frac{13.635 \text{ Pa}}{0.30 \text{ m/s} \times 0.00342} \tag{6}$$

$$= 1.3 \times 10^4 \text{ Pa} \cdot \text{s/m}^3 \tag{7}$$

This gives an airflow resistance range from 8.7×10^3 to 1.3×10^4 Pa $\cdot$ s/m^3 for the 6 cm sample. The same method was applied to the 9 cm(Figure 2) and 12 cm(Figure 3) samples. The average differential pressure for the 9 cm sample was 13.170 Pa, and 17.055 Pa for the 12 cm sample. The speed range was 0.25 to 0.42 m/s for both the 9 and 12 cm samples. The airflow resistance ranges for the samples were 9.2×10^3 to 1.5×10^4 Pa $\cdot$ s/m^3 and 1.2×10^4 to 2.0×10^4 Pa $\cdot$ s/m^3 respectively.

5 Results

While only a range of airflow resistance values could be produced, the theoretical values of airflow resistance that apply to these samples fit within these ranges for all three samples. This implies that at our current state in our research, we have an accurate method of determining the airflow resistance of 3-D printed porous materials. Additionally verifying our method, as the length of these samples increases, the airflow resistance also increases, as is expected. If the airflow resistance values can be narrowed down through obtaining better equipment, a clearer relationship between airflow resistance and the length of porous materials can be established.

References

[1] NASA Johnson Space Center. Acoustics, 2024. Accessed: 2025-04-27.

[2] Jun Liu, Tianjian Lu, and Peter D. Lee. Numerical study on acoustic performance of microperforated panels made from natural fiber-reinforced composites. *Journal of Engineered Fibers and Fabrics*, 13:1–9, 2018.