Acoustic Properties of NASA Flight Approved Materials and other Testable Samples

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Abstract

In relation to many provided acoustic foams and felts, this project seeks to quantify three frequency dependent quantities; namely, the absorption coefficient, acoustic impedance, and complex wave number values. These are obtained by utilizing an impedance tube in which two microphones simultaneously measure the forward and backward components of generated plane waves within the tube. Data analysis of the complex microphone response measurements is conducted in two ways; one which follows a featured procedure in an ASTM International standard and another which is derived to accommodate for a one inch air gap in the experimental setup. In order to aid in the analysis of these complex quantities, Python code templates are created to read in test data, generate acoustic plots, and also validate prior work with past samples in which the data was evaluated using various formatted equations within Microsoft Excel. Organizing these results can lead into the discussion of how to specifically arrange and utilize the materials to both maximize their acoustic performance based upon a material's density and minimize excess ambient noise on manned space vehicles.

Physical Theory

The testing method uses an impedance tube with a sound source connected to one end and a test sample mounted at the other. Plane waves are generated within the tube by the use of a signal analyzer connected to the sound driver. The wave pattern is decomposed into forward and backward traveling components by simultaneously measuring sound pressures at two fixed locations in the tube's wall.

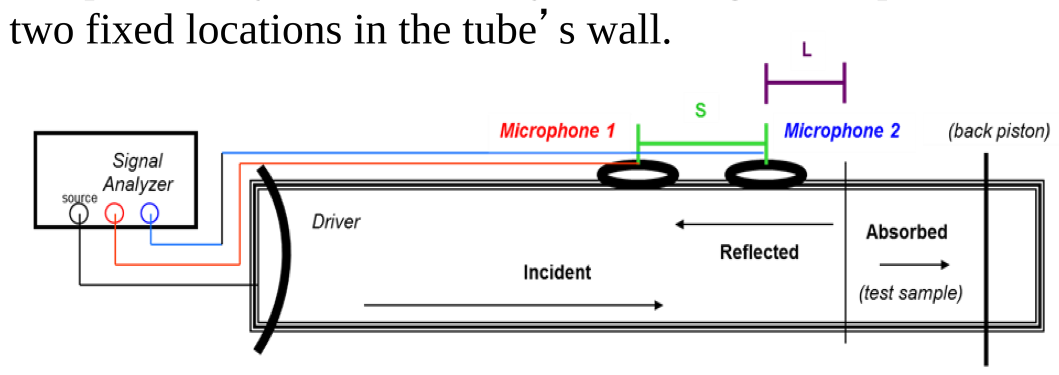

Figure 1: Standard Impedance Tube Representation

Calculating the absorption coefficients under normal incidence is done by analyzing series of complex data from the transfer function between the two microphones. Finding the transfer function of the two microphones corrected for response mismatch, denoted as **H**, and the phase of the complex transfer function, denoted as φ, allows for evaluating the complex acoustic reflection coefficient **R** as,

$$|R|^2 = \left[\frac{1+|H|^2-2|H|\cos(\varphi+ks)}{1+|H|^2-2|H|\cos(\varphi-ks)}\right]$$

where

$$k = \frac{2\pi f}{c},$$

f and c denoting frequency and speed of sound respectively. The absorption coefficient α is directly related to the reflection coefficient R and can be calculated as,

$$\alpha = 1-|R|^2.$$

Experimental Setup

Two ½" Pressure-field 46AO type G.R.A.S. microphones and preamplifiers also with corresponding AB005 power supplies are utilized to measure the raw data from signals which are generated by the connected signal analyzer and driven through the impedance tube. Assuming no wave components reflect off the back piston, calculating the absorption coefficients under normal incidence follows the ASTM International (Designation E1050-08) "Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System."

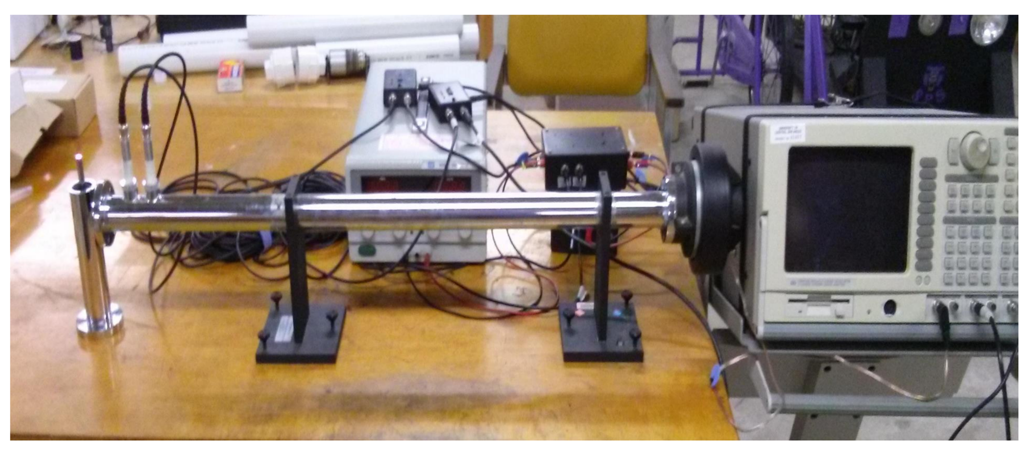

Figure 2: Utilized Equipment consisting of a signal analyzer, impedance tube, and power supplies

Testing Procedure

Each test begins with calibration. A calibration foam is mounted as the tested sample in two tests, the first in the standard configuration as depicted before in Figure 1 and the second in a configuration with the microphones in switched positions, allowing for microphone mismatches to be corrected. Once calibrated, the impedance tube is placed back into standard configuration in testing the various foam samples. Each test records the frequency response measurement between the two microphones in 2000 data points as the driver sweeps through frequencies 200Hz to 5kHz with a 1-volt sound source.

In order to aid in the analysis of these complex quantities, Python code templates have recently been written in order to read in saved test data files and output plots of absorption coefficients with respect to frequency. This recent analysis, simply using the complex expressions, has validated prior work with the past samples in which the data was evaluated using various formatted equations within Microsoft Excel.

Acoustic Results

Initial testing proved successful in calculating absorption coefficients for many foams provided by Johnson Space Center and samples selected locally. Eight additional felts were later obtained and systematically tested by calculating absorption coefficients for various stacks of 1/8" samples up to a 1" sample stack size. Since then, the data has been organized in the context of 1/3 frequency octave bands and sample mass density to help compare properties of the particular samples.

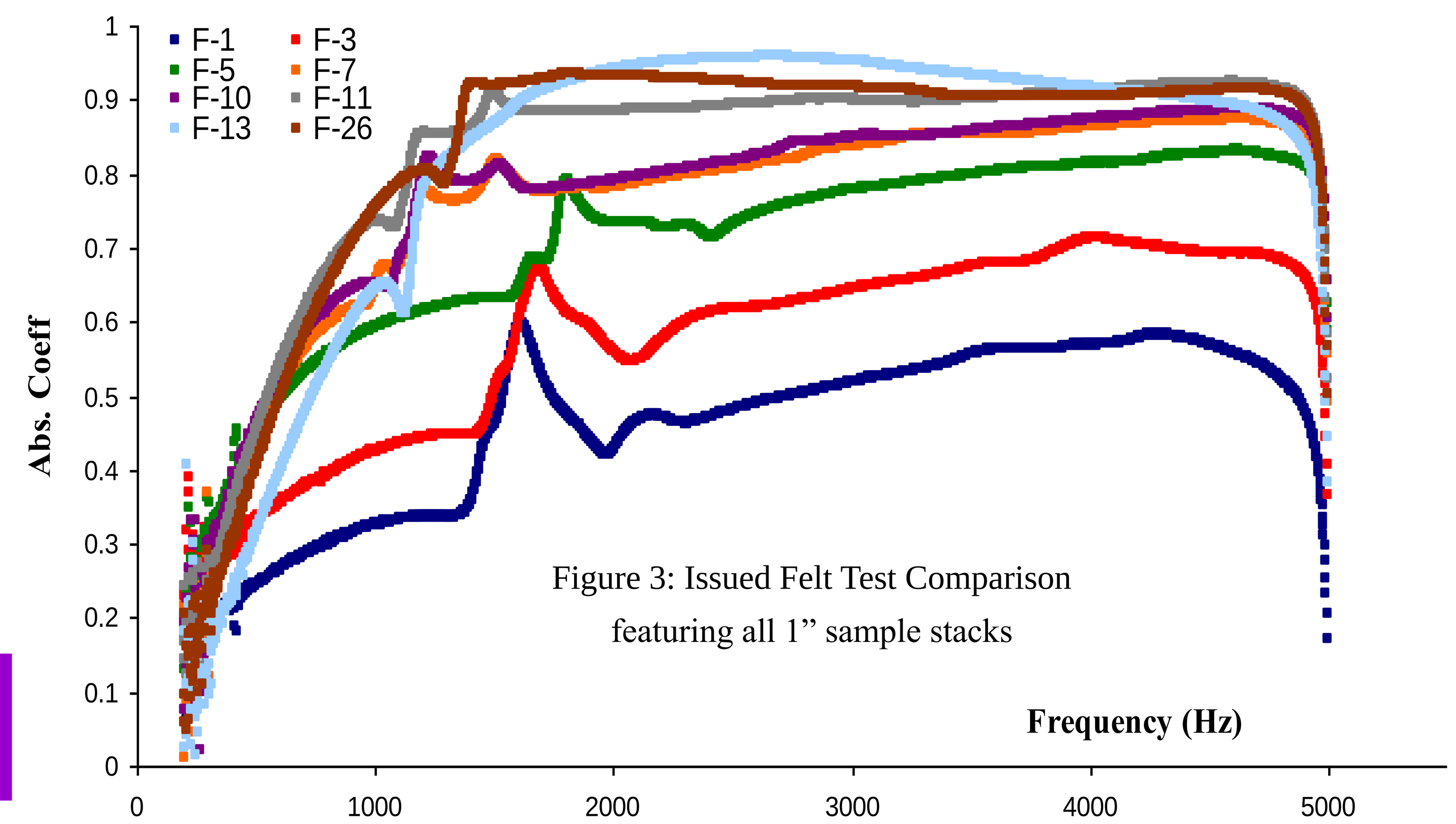

Figure 3: Issued Felt Test Comparison featuring all 1" sample stacks

Felt Sample Name	F-1	F-3	F-5	F-7	F-10	F-11	F-13	F-26
Ave. Mass Density (g/cm^3)	0.384	0.310	0.288	0.210	0.203	0.191	0.146	0.193

Figure 5: Issued Felt Mass Density Comparison

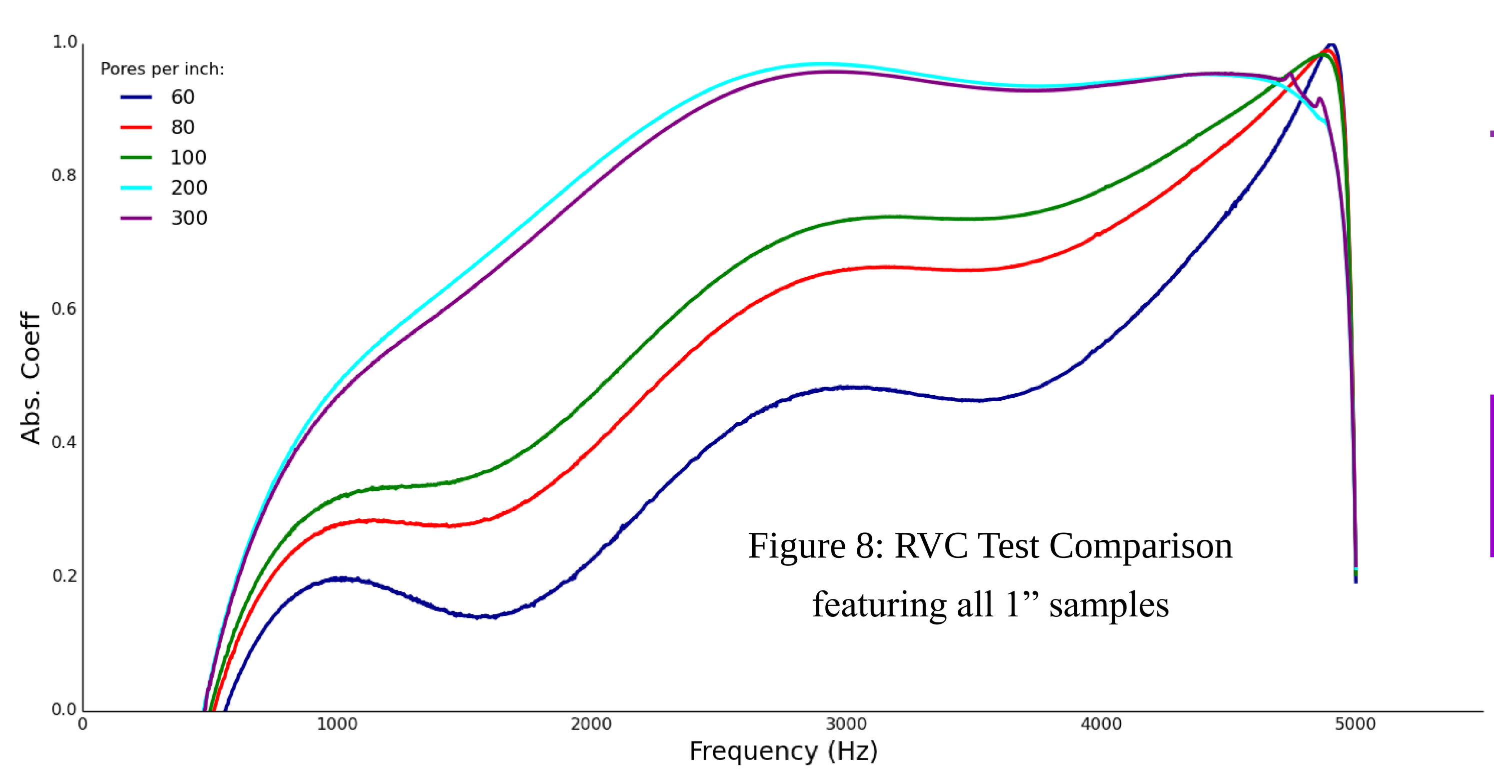

Figure 8: RVC Test Comparison featuring all 1" samples

Future Goals

A more generalized model also has been established in which an air gap is incorporated behind a tested sample and the tube's back plate. By applying the associated boundary conditions at the face of the sample and the air gap, it is possible to calculate the complex impedance and wave number of a given sample based upon the complex data from the transfer function of the microphones as before. An additional program is currently being reviewed to perform these necessary calculations and generate desired plots. Also, there exists a possibility of utilizing the microphones' compatibilities with NI LabView in the attempt to automate a great deal of the testing procedure and data analysis. With this software, an interface could be created which could generate signals, record measurements, and analyze the data for plotting purposes. These benefits may later prove valuable in the testing of any new collections of samples and in the research of future students.

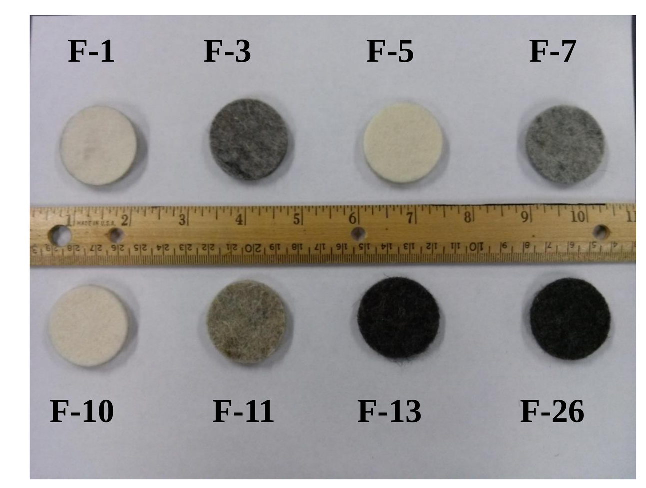

Figure 4: Issued Felt Inventory

Reticulated Vitreous Carbon samples have been recently obtained and tested using a created Python code template which has also been used to recreate the same absorption coefficients plot for the felt samples. These values were calculated using the same theory as described in the ASTM standard.

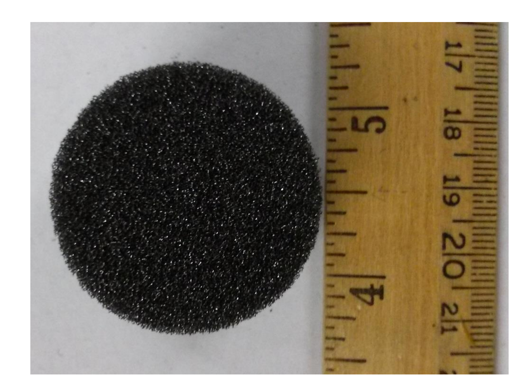

Figure 6: Reticulated Vitreous Carbon

60 pores/ inch sample

Pores Per Inch	60	80	100	200	300
Ave. Mass Density (g/cm^3)	0.050	0.056	0.056	0.133	0.126

Figure 7: RVC Density Comparison

Acknowledgements

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