NASA/TM–2014-218154

Adaptive Back Sheet Material for Acoustic Liner Applications—ARMD Seedling Fund Phase I Final Report

Carl H. Gerhold and Michael G. Jones
Langley Research Center, Hampton, Virginia

Dawnielle Farrar
John Hopkins University Applied Physics Laboratory, LLC, Laurel, Maryland

January 2014

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question to help@sti.nasa.gov

- Fax your question to the NASA STI Information Desk at 443-757-5803

- Phone the NASA STI Information Desk at 443-757-5802

- Write to:
  STI Information Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TM–2014-218154

Adaptive Back Sheet Material for Acoustics Liner Applications—ARMD Seedling Fund Phase I Final Report

Carl H. Gerhold and Michael G. Jones
Langley Research Center, Hampton, Virginia

Dawnielle Farrar
John Hopkins University Applied Physics Laboratory, LLC, Laurel, Maryland

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

January 2014

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

Abstract

A recently developed piezo-electric composite film is evaluated for its usefulness in application in acoustic liners. Researchers at the NASA Langley Research Center Liner Technology Facility developed experiments to measure the electrical response of the material to acoustic excitation and the vibrational response of the material to electrical excitation. The robustness of the piezo-electric film was also assessed. The material's electrical response to acoustic excitation is found to be comparable to a commercial microphone in the range of frequencies from 500 to 3000 Hz. However, the vibrational response to electrical excitation in the frequency range of interest is an order of magnitude less than may be necessary for application to acoustic liners. Nevertheless, experimental results indicate that the potential exists for the material to produce a measurable change in the impedance spectrum of a liner. Work continues to improve the authority of the piezo-electric film.

Nomenclature

A	= amplitude of the incident wave in the duct
B	= amplitude of the reflected wave in the duct
p_t	= total sound pressure in the duct
v_t	= total acoustic particle velocity in the duct
f	= frequency
c	= sound speed in air
t	= perforate thickness
d	= perforate hole diameter
h	= honeycomb chamber depth
M	= Mach number of flow in the duct
k	= wavenumber (=2*π*f/c)
L	= distance from the piezo-electric film sample to the rigid termination
Z	= acoustic impedance = R +i*I
R	= Resistance, real part of the acoustic impedance
I	= Reactance, imaginary part of the acoustic impedance
ρ	= density of the air
ζ	= acoustic impedance, Z, normalized by the characteristic impedance, ρc
θ	= phase angle
C_α	= absorption coefficient
i	= $\sqrt{-1}$

Subscripts

1	= location of microphone 1 for impedance evaluation
2	= location of microphone 2 for impedance evaluation
s	= indicates a piezo-electric film
l	= indicates an SDOF perforate-over-honeycomb liner
m	= mass reactance term of impedance
tl	= transmission line term of impedance

I. Introduction

The purpose of this research project is to demonstrate the applicability of a newly discovered smart composite material to serve as a compliant back wall for an acoustic liner. A compliant back wall allows the liner to respond to changes in the aircraft engine shaft speed related tone noise by actively modifying the liner impedance. The material being investigated consists of an α-Helical Polypeptide, which has been developed by researchers at the Johns Hopkins University Applied Physics Laboratory[1], and has shown promise as an actuator capable of being excited at frequencies in the audible range. This project is the first phase of an Aeronautics Research Mission Directorate (ARMD) Seedling Fund project.

The basic parameter used to describe the acoustic properties of the piezo-electric composite is the impedance. The impedance is defined as the ratio of the sound pressure to the acoustic particle velocity normal to the surface. The impedance consists of a real term that describes the resistance to sound propagation and an imaginary term that describes the frequency-dependent reactance. The impedance quantifies the boundary condition presented by the wall of a duct and is used to complete mathematical models of sound propagation in waveguides. Derivation of the expression for impedance will be presented in the next section.

II. Results

The two key deliverables of this Phase I include: 1) Built-up liner samples with piezo-electric actuators bonded as a back wall, and 2) Mathematical model of the impedance of the liner incorporating the active back wall. The test coupons that were fabricated and evaluated consist of the piezo-electric film sample bonded to a sleeve with a small air gap behind. The evaluation of the samples identifies the impedance of the piezo-electric film plus air gap and the impedance is then incorporated into a mathematical model of the built-up honeycomb liner with compliant back wall.

1. Description of Samples Tested

The researchers at Johns Hopkins University Applied Physics Laboratory have fabricated five test coupons mounted on plastic sleeves for testing. An example coupon is shown in Figure 1. The piezo-electric sample is clear. A metal electrode is attached to the sample in order to deliver voltage to the piezo-electric (actuator mode) or to sense voltage from the sample (sensor mode). Three such samples with electrodes of various metals and design (1.0 in x 1.0 in Cr-Au, 1.75 in x 1.75 in in Cr-Au, Conductive adhesive) were evaluated in the test. Two other samples were fabricated and mounted on the plexiglass sleeves. These samples do not have electrodes bonded to them, but rather are encapsulated in a plastic sheathing for improved durability.

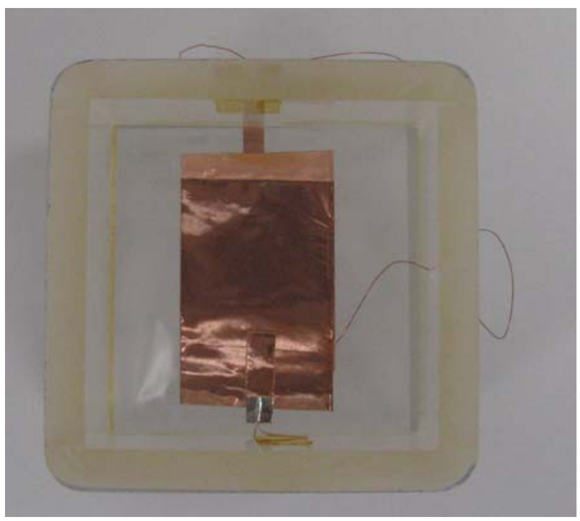

Figure 1. Photograph of piezo-electric sample mounted on plexiglass sleeve sample holder.

It became necessary to encapsulate the samples when it was discovered that the original piezo- electric samples are too fragile to be subjected to sound pressure levels in excess of 120 dB. Table 1 briefly describes the characteristics and summarizes the current condition of the five mounted samples. In addition to the mounted samples, two unmounted samples of the encapsulated piezo-electric composite have also been fabricated.

2. Characterization Of The Composite Samples

The normal incidence impedance is evaluated based on measurements performed in the Normal Incidence Tube in the Liner Technology Facility at NASA Langley Research Center.

An example set up is shown in Figure 2. The piezo-electric film sample, which is affixed to the plexiglass sleeve, is located approximately 1.25 inch above the rigid plate, shown at the bottom of the photograph. An empty sleeve approximately 3.0 inch length is attached above the sample and connects to the Normal Incidence Tube. Sound is generated by four loudspeakers whose output is adjusted to achieve a specified sound pressure level at the reference microphone, which is indicated at the top of the photograph. The sound pressure level is measured at two microphones z_1 and z_2 that are located 5.50 and 6.75 inch, respectively, above the sample. These microphones are not visible in the photograph.

Table 1. Piezo-electric sample configurations evaluated to date

Sample	Description	Electrode	Electrode size	Status
JHS1	Composite film, no encapsulate	Cr-Au, evaporated	1.00"x1.00"	Functional
JHS2	Composite film, no encapsulate	Cr-Au, evaporated	1.75"x1.75"	Destroyed
JHS3	Composite film, encapsulated	No electrode	N/A	Functional
JHS4	Composite film, no encapsulate	Conductive adhesive	1.75"x1.00"	Destroyed
JHS5	Composite film, encapsulted	No electrode	N/A	Functional

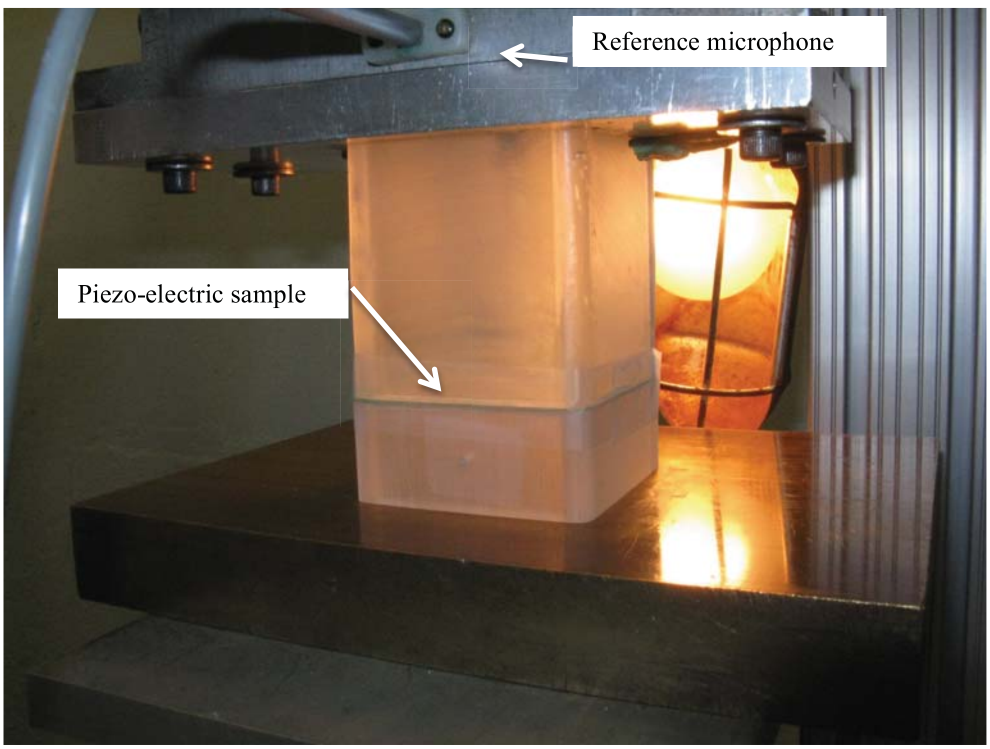

Figure 2. Photograph of impedance test set up.

The total sound pressure, p_t in the hard wall duct at any location x above the sample is given by:

$$p_t(x) = Ae^{-ikx} + Be^{ikx} \tag{1.1}$$

The ratio of sound pressure at microphone locations x_1 and x_2 is:

$$\frac{p_t(x_2)}{p_t(x_1)} = \left|\frac{p_2}{p_1}\right| e^{i\theta} = \frac{Ae^{-ikx_2} + Be^{ikx_2}}{Ae^{-ikx_1} + Be^{ikx_1}} \tag{1.2}$$

where:

$\left|\frac{p_2}{p_1}\right|$ is the ratio of the magnitudes of the sound pressures

θ is the phase of signal 2 relative to signal 1

The ratio of amplitudes, B/A is determined by rearranging:

$$\frac{B}{A} = \frac{e^{-ikx_2} - \left|\frac{p_2}{p_1}\right| e^{i\theta} e^{-ikx_1}}{\left|\frac{p_2}{p_1}\right| e^{i\theta} e^{ikx_1} - e^{ikx_2}} \tag{1.3}$$

The location of the piezo-electric film sample is defined as x = 0. The sound pressure at this location is:

$$p_t(0) = A + B \tag{1.4}$$

and the particle velocity is:

$$v_t(0) = \frac{1}{\rho c}(A - B) \tag{1.5}$$

The impedance, Z at location x = 0 is the ratio of the total sound pressure in the duct to the total particle velocity. The impedance is often expressed in a form in which it has been normalized by the characteristic impedance:

$$\zeta = \frac{Z}{\rho c} = \frac{R}{\rho c} + i\frac{I}{\rho c} = \frac{p_t(0)}{v_t(0)} = \frac{1 + \frac{B}{A}}{1 - \frac{B}{A}} \tag{1.6}$$

The impedance that is evaluated in the set up of Fig. 2 combines the impedance of the piezo-electric film and the impedance of the air gap beyond it:

$$\zeta = \zeta_s - i\cot(kL) \tag{1.7}$$

The sample is subjected to broadband noise from 400 to 3000 Hz with overall sound level at the reference microphone set at 110, 120, 130, or 140 dB. Single tones are also generated from 400 to 3000 Hz in 200 Hz increments. Figure 3 shows a typical impedance spectrum evaluated from the measured data for the sample JHS3 with broadband noise input. This sample is described as an encapsulated, mounted composite. The test set up includes the sample backed by a cavity that terminates in a rigid wall. The figure shows that the sample has a resonant frequency at approximately 525 Hz, which is indicated when the reactance goes from negative to positive. This is the lowest order resonant frequency of the membrane consisting of the encapsulated piezo-electric film backed by an air gap. The impedance becomes quite large from 2000 to 3000 Hz, indicating the sample acts as a rigid surface at these higher frequencies.

The effect of the piezo-electric film with the air gap is to change the overall impedance of a liner. This is shown in the following example, in which the rigid back wall of a standard, single degree of freedom perforate-over-honeycomb liner is replaced with a back wall consisting of the composite backed by a cavity. Jones, et al.[2] use a Two Parameter Impedance Prediction model to define the impedance parameters, the resistance and reactance, of a single-degree-of-freedom perforate over honeycomb core liner. The expression for impedance, normalized by the characteristic impedance is given as:

$$\frac{Z_l}{\rho c} = \frac{R_l}{\rho c}(d,t,M) + \frac{i}{\rho c}\left(I_m(f,t,d) + I_{tl}(k,h)\right) \tag{1.8}$$

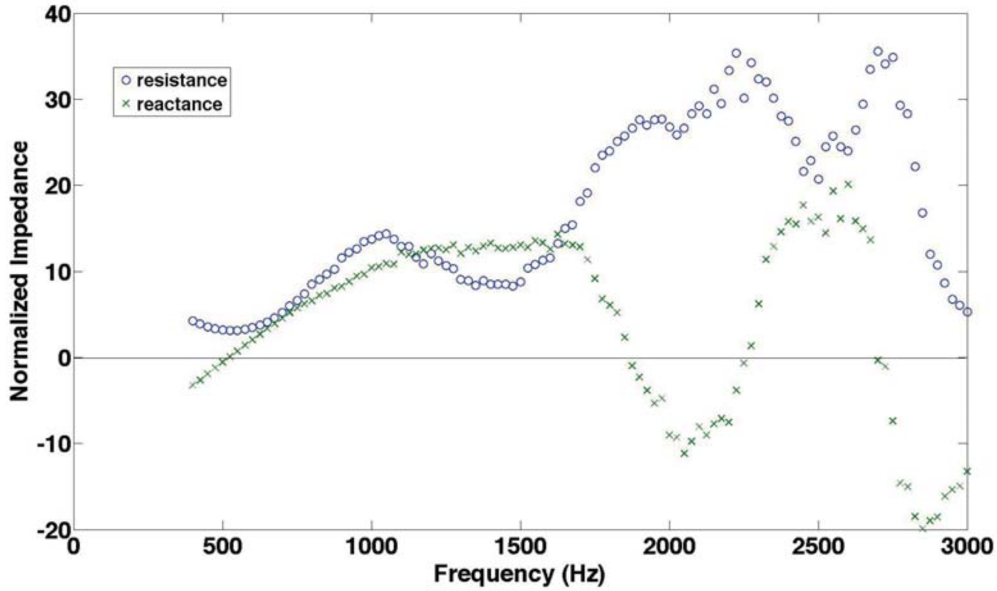

Figure 3. Impedance of test set up with sample JHS3 evaluated with two-microphone method using broadband noise at 130 dB overall sound level.

The resistance term, $\frac{R_l}{\rho c}$, is defined by the thickness of the perforated facesheet, the hole diameter, and the Mach number of the grazing flow in the duct. The Mach number is 0 in the Normal Incidence Tube experiment. The reactance, $\frac{1}{\rho c} * (I_m + I_{tl})$, depends on the perforate thickness and hole diameter, the core depth of the honeycomb, and the frequency. The reactance component of the impedance consists of a mass reactance, I_m, which varies linearly with frequency and a transmission line, I_{tl}. The transmission line term is evaluated as follows.

Figure 4a shows a typical liner cross-section with perforate face sheet, honeycomb core, and rigid back wall. The depth of the honeycomb core is h. For the purposes of this discussion, the location of back wall is designated x = 0. In this case then, the face sheet is located at x = -h.

The sound transmission through the honeycomb core characterizes the impedance seen at the face sheet:

$$\frac{I_{tl}}{\rho c}(-h) = \frac{Ae^{ikh} + Be^{-ikh}}{Ae^{ikh} - Be^{-ikh}} \tag{1.9}$$

The expression for the impedance at the termination of the honeycomb is:

$$\frac{Z}{\rho c}(0) = \frac{A + B}{A - B} \tag{1.10}$$

If the honeycomb is terminated by a rigid wall, $Z = \infty$ or, A=B, and the impedance seen at the face sheet is:

$$\frac{I_{tl}}{\rho c}(-h) = -i\cot(kh) \tag{1.11}$$

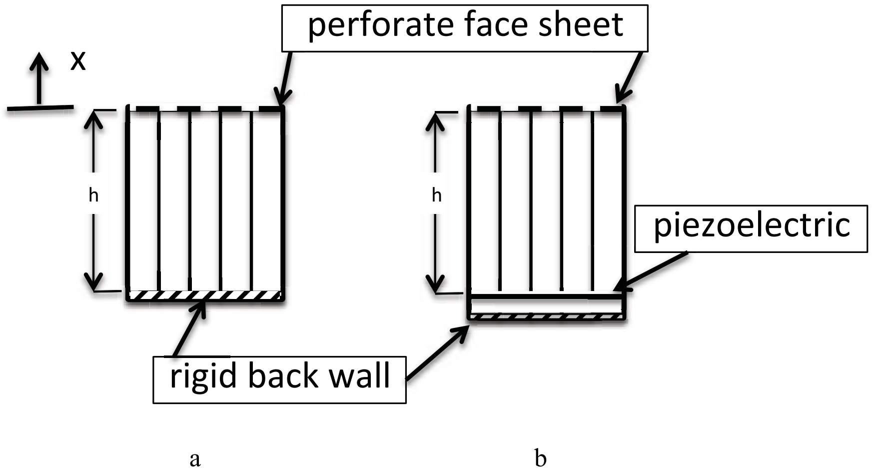

Figure 4. Schematic representation of a standard perforate-over-honeycomb liner with honeycomb of depth h terminating; (a) at a rigid wall, and (b) with compliant back wall at h.

The transmission term of equation 1.11 is incorporated into the impedance equation (1.8) in order to estimate the sound absorption.

When the rigid back wall is replaced by the piezo-electric film with the air gap, as shown in Figure 4b, the impedance at x = 0 is finite and is evaluated from:

$$\frac{I_{tl}}{\rho c}(0) = \frac{A+B}{A-B} = \zeta \tag{1.12}$$

from which:

$$B = \frac{\zeta - 1}{\zeta + 1} A \tag{1.13}$$

The transmission term, equation 1.9 is written:

$$\frac{I_{tl}}{\rho c}(-h) = \frac{\zeta\cos(kh) + i\sin(kh)}{i\zeta\sin(kh) + \cos(kh)} \tag{1.14}$$

It is assumed that a small gap exists between the honeycomb cells and the piezo-electric film such that the motion of the film is not constrained by contact with the edges of the honeycomb cells. The impedance in equation 1.8 incorporating the transmission term of equation 1.14 is used to estimate the sound absorption, C_{α}:

$$C_{\alpha} = 1 - \left(\frac{\frac{Z_l}{\rho c} - 1}{\frac{Z_l}{\rho c} + 1} \right) conj \left(\frac{\frac{Z_l}{\rho c} - 1}{\frac{Z_l}{\rho c} + 1} \right) \tag{1.15}$$

Figure 5 shows the absorption calculated for the liner with the rigid back wall, configuration a in Figure 4, compared with the absorption for compliant back wall, configuration b in Figure 4. In this case, the honeycomb core is 1.5 in deep, the perforate is 0.040 in thick with 0.040 in diameter holes. The perforate open area is 8.7%. The figure shows that the hard wall backed liner has maximum absorption of ~80% at

2200 Hz. This is the resonance of the rigid wall backed liner, where cot(kh) ~ 0. The compliant back wall adds another absorption peak near 500 Hz. This was noted as the resonant response of the encapsulated piezo-electric film backed by an air gap in the normal impedance curve, Figure 3. So replacing the rigid back wall with a compliant back wall gives rise to an increase in absorption when the back wall goes into resonance. It was also noted that the piezoelectric impedance is very high in the range from 2000 to 3000 Hz. This means that the piezoelectric appears as a hard wall from 2000 to 3000 Hz and thus the liner behaves as the rigid back wall liner, with the high absorption in the vicinity of 2200 Hz.

The analysis indicates that the frequency range for high liner absorption can be extended with the passive compliant back wall.

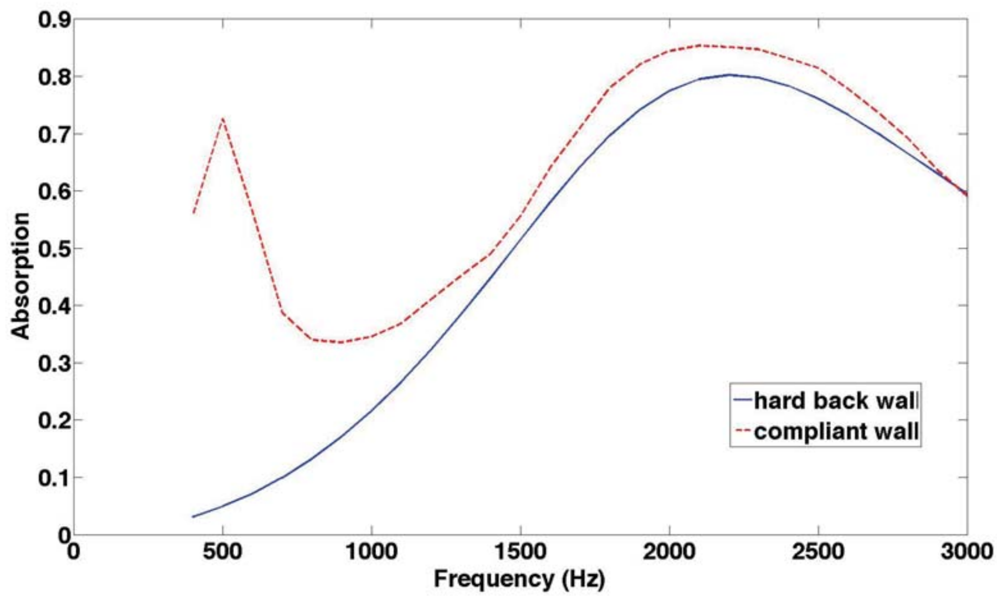

Figure 5. Calculated absorption of a perforate-over-honeycomb liner comparing rigid back wall to compliant back wall, JHS3.

3. Further Characterization Of The Piezo-Electric Composites

The impedance of the passive sample can be measured and the resulting impedance incorporated into the analytical model for the overall impedance of a liner with compliant back wall, as was shown above. Refinement of the analytical model requires that the response of the sample to acoustic excitation and the response of the sample to electrical excitation be known. Experimental procedures were developed in order to obtain these relationships. The experimental techniques were developed using the film sample JHS1, which has electrodes for electrical excitation.

A. Piezo-electric sample as sensor.

While the primary purpose of this project is to assess the piezo-electric material as an active device, it may be useful as a sensor. This is particularly the case in a feedback control loop where one piezo-electric film is used as a sensor whose signal drives an actuator piezo-electric film. In order to evaluate the piezo-electric film as a sensor, it is subjected to a known acoustic signal and the voltage generated at the electrode is measured. Figure 6 shows a typical plot of voltage out vs. sound pressure in, where the pressure is expressed in Pascals. The sample shows good linearity between the voltage generated by the piezo-electric film and the pressure input. The sound pressure level at the sensor was 97 < SPL < 124 dB.

Table 2 shows the sensitivity of the sensor at different frequencies. The sensitivity is higher at 1500 Hz than at other frequencies. This indicates that the sensor resonance is in the vicinity of 1500 Hz. The sample JHS4 was also evaluated before it failed. The sensitivity of that sample at 1000 Hz was found to be 0.00070 v/Pa, which is comparable to the sensitivity determined for sample JHS1. The sensitivity of these piezo-electric devices, which is on the order of 1 mV/Pa, is comparable to the sensitivity of a 1/8 in diameter condenser microphone, although the variation of sensitivity with frequency is higher than is expected in a precision microphone. Thus, this piezo-electric device could be suitable in sensor mode if it is calibrated.

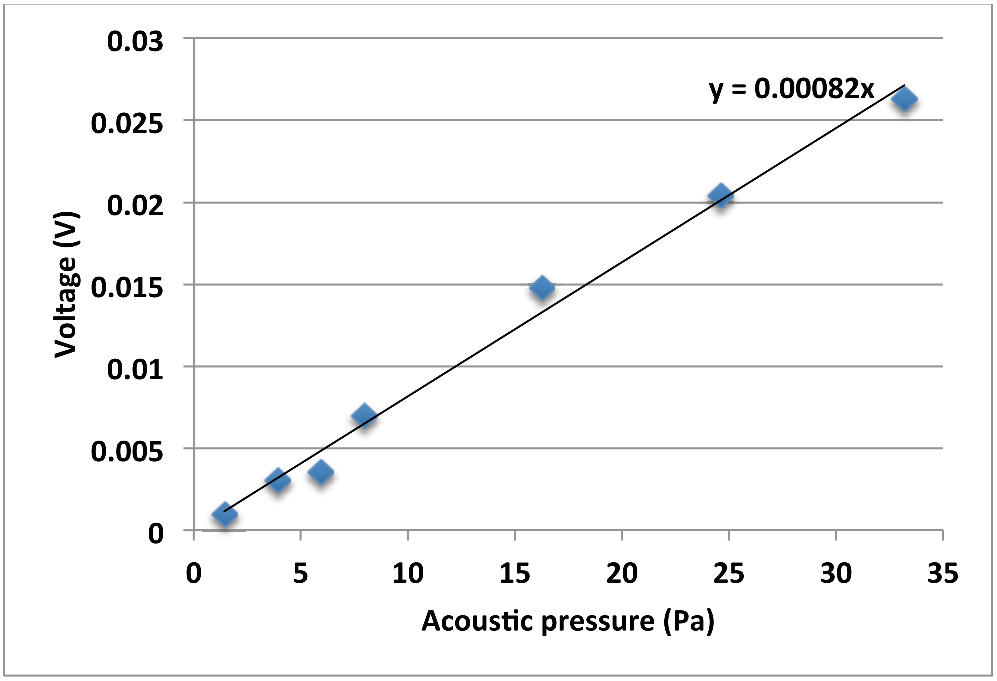

Figure 6. Voltage generated at the electrode of sample JHS1 when subjected to sound at 1000 Hz.

Table 2. Measured sensitivity of sensor JHS1, voltage output for acoustic signal input

Frequency (Hz)	Input sensitivity (v/Pa)
500	0.00101
1000	0.00082
1500	0.00266
2000	0.00082
2500	0.00122
3000	0.00107

B. Piezo-electric as an actuator.

The primary purpose of this project is to evaluate the piezo-electric sample as an acoustic actuator. For this reason, an experiment was devised in which the out-of-plane velocity at the center of the sensor is measured as a function of voltage excitation to the electrode. The test set-up is shown in Figure 7. The velocity was measured using a Polytec PDV 100 portable digital laser vibrometer, on loan from the Systems Integration and Test Branch at NASA Langley Research Center. The sample was excited by a tone from an HP model 3325A function generator, amplified using a PiezoSystems, Inc, model EPA-104-115 piezo-electric amplifier. The amplifier is on loan from the Advanced Sensing and Optical Measurement Branch at NASA Langley Research Center. The amplifier generates a dynamic signal of up to +/- 200 volt to the electrode.

Figure 8 shows the rms velocity response of the sample JHS1, measured at the center of the sample, for excitation at 1500 Hz. The curve is linear over the range of excitation voltage $40 < v < 140$ volt. It was noted throughout the data acquisition that the velocity response at the first harmonic of the excitation frequency was quite strong. It was the same order of magnitude as the response at the excitation frequency and, in some cases, was even higher.

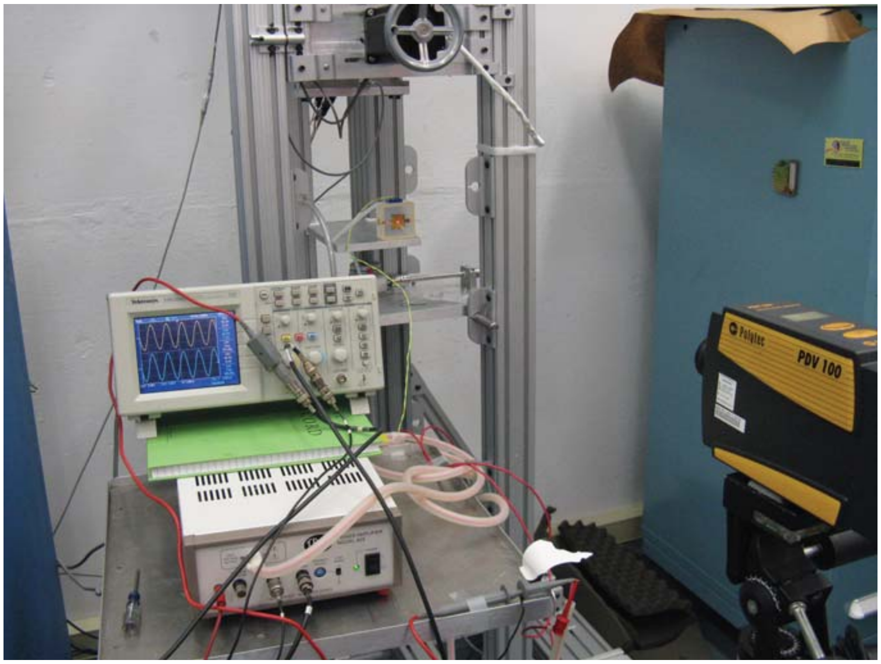

Figure 7. Test set up for measurement of piezo-electric sample velocity response to AC voltage excitation.

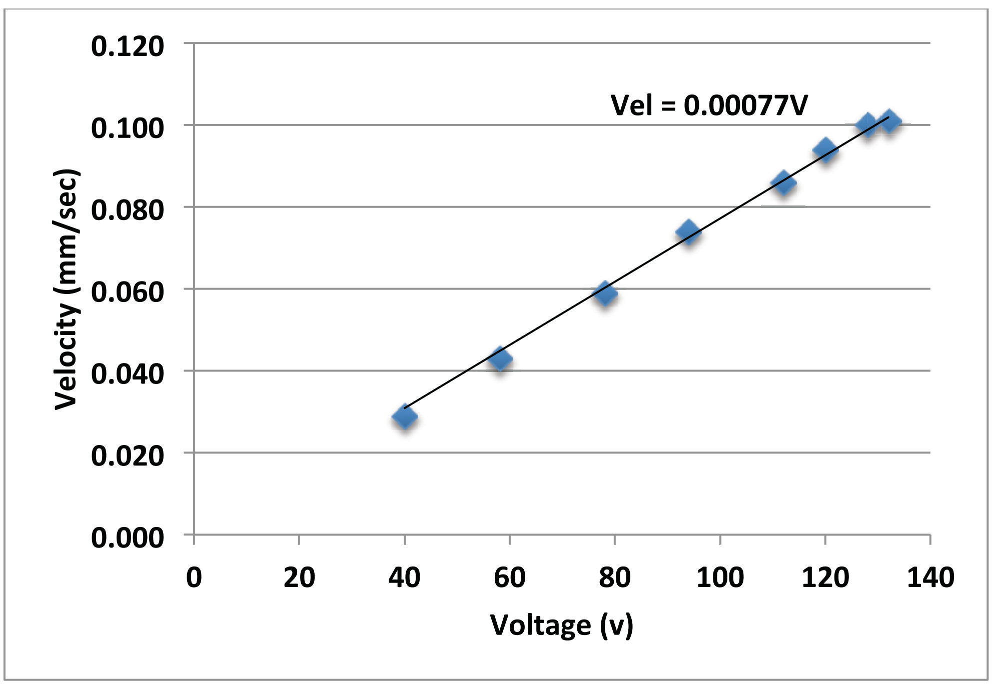

Figure 8. Velocity response of sample JHS1 to dynamic signal excitation at 1500 Hz.

Table 3 summarizes the measured response of the piezo-electric sample JHS1 to voltage excitation over the range of frequencies from 500 to 3000 Hz. The sensitivity of the piezo-electric sample to voltage excitation is higher at 1500 and 2000 Hz than it is at the other frequencies. This behavior is consistent with higher response at 1500 Hz noted with acoustic excitation.

Table 3. Measured sensitivity of piezo-electric sample JHS1 to dynamic voltage input.

Frequency (Hz)	Output sensitivity (mm/s/volt)
500	.00027
1000	.00040
1500	.00077
2000	.00087
2500	.00032
3000	.00034

The velocity response is less than what is expected to be required as an actuator. For example, the acoustic particle velocity at 130 dB sound level is approximately 150 mm/sec. The velocity of the piezo-electric film, when actuated at 150 volt at 1500 Hz, is approximately 0.12 mm/sec, or 0.1% of the particle velocity. However, since the velocity of the rigid back wall of the liner is zero, even a small motion of the back wall may be sufficient to change the liner response near the resonant frequency of the liner.

4. Measured Actuator Performance Under Acoustic Load

In order to assess the change in performance with voltage excitation of the piezo-electric sample JHS1 under acoustic load, the impedance is measured first without and then with power to the sample. The sample, with no power to the electrode, is subjected to sound at 110 dB in tones from 400 to 3000 Hz in 200 Hz increments, and the impedance determined. The experiment is repeated with the electrode powered by a signal at the same frequency as the acoustic excitation and amplified to approximately 150 V (0-peak). No attempt is made to control the phase of the excitation in this experiment. The impedance is determined under this condition. The absorption of the piezo-electric film with the air gap is determined from the resulting impedance measurements and plotted in Figure 9. The most significant effect of the excitation of the piezo-electric occurs near the resonance, where the absorption is greatest. The peak absorption of the unpowered piezo-electric sample occurs at 1600 Hz, which is the unforced resonance frequency. Energizing the sample shifts the peak absorption from 1600 to 1400 Hz. Replacing the 0 velocity at the back wall with a finite velocity makes the chamber appear to be deeper and thus lowers the resonant frequency.

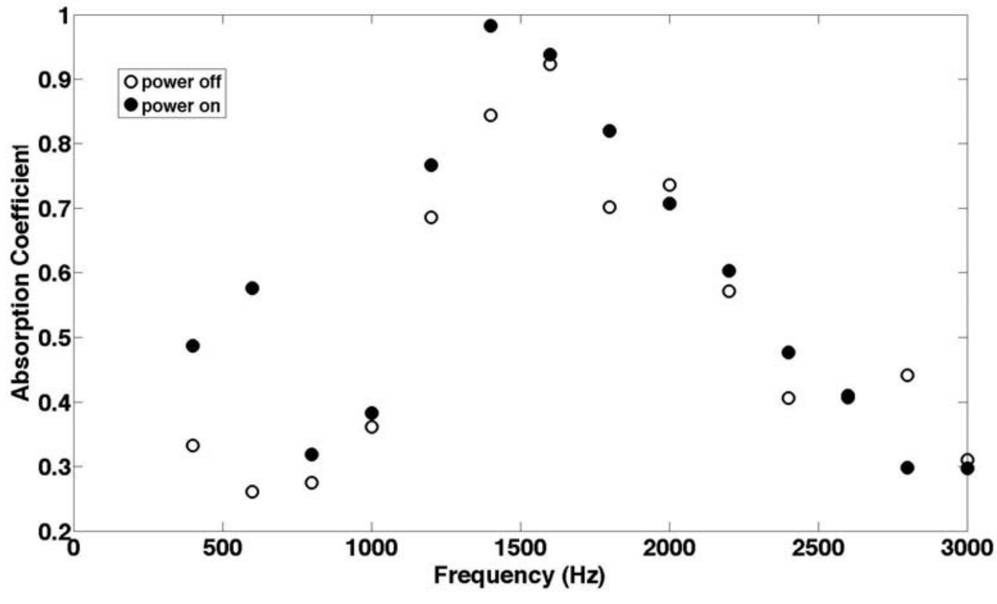

Figure 9. Calculated absorption coefficient for sample JHS1, compares power off to power on.

5. Predicted Performance Of Active Back Wall In A Liner

The effect of installing the piezo-electric film in a liner configuration and energizing it is estimated. The impedance of the piezo-electric film without excitation is used to determine the transmission term of the impedance, equation 1.14 and the overall impedance is estimated using equation 1.8. The energized impedance is then used to determine the transmission term and the overall liner impedance is determined. This overall impedance is used to estimate the sound absorption for the two conditions. Figure 10 shows the calculated absorption of the liner with a passive compliant back wall (power off) and an energized compliant back wall (power on). When the power to the piezo-electric film is off, the absorption curve shows two broad peaks, at 900 Hz and at 2200 Hz. This is two degree of freedom behavior typical of a liner with a buried septum, where the passive piezo-electric film acts as a septum. When the piezo-electric is energized, the absorption increases at frequencies between the two peaks. If the velocity response of the piezo-electric film were greater, it is expected that the gap between the two peaks would be filled in even more, such that the liner would be a broadband liner, absorbing sound over the frequency range from 900 to 2200 Hz.

The current design of the electrodes lacks authority to affect the absorption to a greater extent than 200 Hz from the resonance, as seen in Figure 9. Despite this lack of authority, it is seen in Figure 10 that a measurable improvement in the absorption is possible in a liner configuration. Modifications to the electrode design have started in order to increase the control authority by at least 1 order of magnitude.

Table 4 shows the material properties of the two encapsulated samples as supplied by Applied Physics Laboratory researchers. The process of encapsulation greatly improves the durability of the composite sample and it is expected that all future samples will be encapsulated.

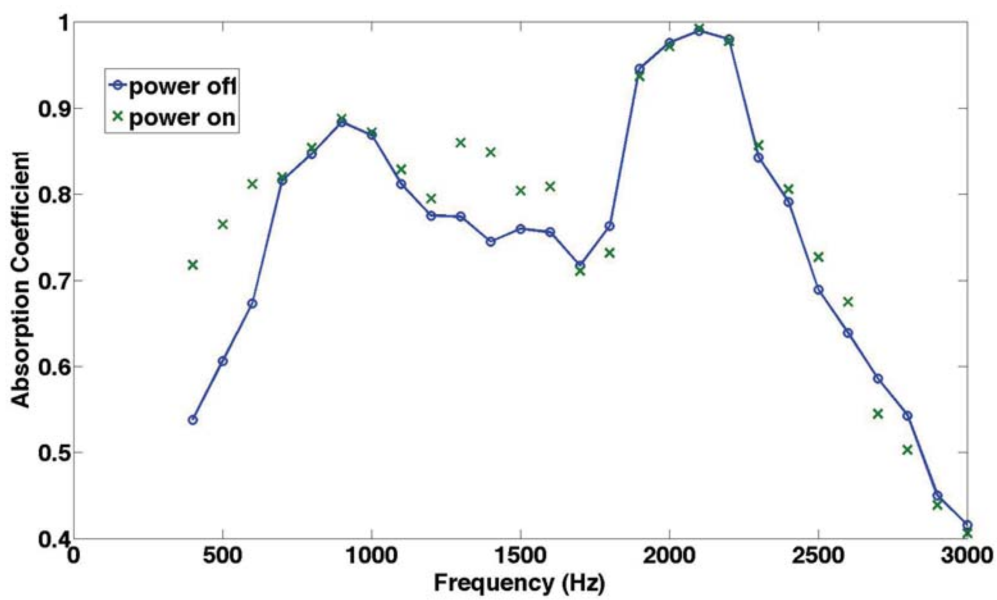

Figure 10. Calculated absorption spectrum of liner sample as depicted in Figure 9. Compares power off to power on to piezo-electric film.

Table 4. Properties of Encapsulated Composite Samples

Type	Designation	Color	Durometer hardness	Tensile @ break MPa (psi)	Elongation @ break %	Elasticity Modulus MPa (psi)
SM	JHS5	pink	D40	6.8 (980)	160	3.9 (560)
9318	JHS3	yellow	A55	3.0 (440)	130	2.0 (310)

III. Summary

Researchers have successfully completed the first phase of the project. They have developed liner samples with piezo-electric actuators bonded as a back wall and they have demonstrated that the energized piezo-electric can change the normal incidence impedance. The researchers found that the original design of the piezo-electric samples was too delicate to be used in acoustic environments greater than 120 dB. They revised the design to improve robustness. The encapsulate used to strengthen the piezo-electric film affects the stiffness of the film and, therefore its impedance. Further research is planned to assess whether the encapsulate has an adverse impact on control authority of the piezo-electric film and how to configure the encapsulate to minimize the impact. The researchers found that, while excitation of the piezo-electric with a dynamic voltage noticeably affects the acoustic response, the sample lacks authority to alter the impedance significantly. The researchers have begun plans to redesign the electroding to increase control authority. It should be noted that the change of impedance seen by exciting the piezo-electric was accomplished without control of the phase of the electrical excitation relative to the phase of the acoustic excitation. The researchers expect that the control authority will improve not only with better designed elctroding but also with control of the phase of the electric excitation. The researchers have developed mathematical models of the impedance of the liner incorporating the active back wall. The mathematical models use measured data, for which the researchers developed experimental procedures.

Acknowledgements

The researchers wish to acknowledge the technical staff of the NASA Langley Research Center Liner Technology Laboratory, in particular Carol Harrison and Jerry Lyle, for their assistance in data acquisition and data reduction. The researchers are grateful to the NASA Aeronautics Research Mission Directorate for the funding to support this research.

References

1. Farrar, D., Ren, K., Cheng, D., Kim, S., Moon, W., Wilson, W. L., West, J. E., and Yu, S. M., “Permanent Polarity and Piezoelectricity of Electrospun α-Helical (α-Amino Acid) Fibers”, Advanced Materials, vol 23, pp 3954-3958, 2011

2. Jones, M. G., Parrott, T. L., and Watson, W. R., "Uncertainty and Sensitivity Analyses of a Two-Parameter Impedance Prediction Model", AIAA paper 2008-2928, May, 2008

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01- 01 - 2014	Technical Memorandum	

4. TITLE AND SUBTITLE
Adaptive Back Sheet Material for Acoustic Liner Applications - ARMD Seedling Fund Phase I Final Report

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Gerhold, Carl H.; Jones, Michael G.; Farrar, Dawielle

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
694478.02.93.02.13.33.23

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-20344

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2014-218154

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 71
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
A recently developed piezo-electric composite film is evaluated for its usefulness in application in acoustic liners. Researchers at the NASA Langley Research Center Liner Technology Facility developed experiments to measure the electrical response of the material to acoustic excitation and the vibrational response of the material to electrical excitation. The robustness of the piezo-electric film was also assessed. The material's electrical response to acoustic excitation is found to be comparable to a commercial microphone in the range of frequencies from 500 to 3000 Hz. However, the vibrational response to electrical excitation in the frequency range of interest is an order of magnitude less than may be necessary for application to acoustic liners. Nevertheless, experimental results indicate that the potential exists for the material to produce a measurable change in the impedance spectrum of a liner. Work continues to improve the authority of the piezo-electric film.

15. SUBJECT TERMS
Acoustic Liner; Adaptive Noise Control; Duct Acoustics

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	17	(443) 757-5802