EXPLORATORY STUDY OF THE ACOUSTIC PERFORMANCE OF PIEZOELECTRIC ACTUATORS

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ABSTRACT: The proposed ducted fan engine has prompted the need for increasingly lightweight and efficient noise control devices. Exploratory tests at the NASA Langley Research Center were conducted to evaluate three piezoelectric specimens as possible control transducers: a Polyvinylidene Flouride (PVDF) piezofilm sample and two composite samples of Lead Zirconate Titanate (PZT) rods embedded in fiberglass. The tests measured the acoustic output efficiency and evaluated the noise control characteristics when interacting with a primary sound source. The results showed that a PZT sample could diminish the reflected acoustic waves. However, the PZT acoustic output must increase by several orders of magnitude to qualify as a control transducer for the ducted fan engine.

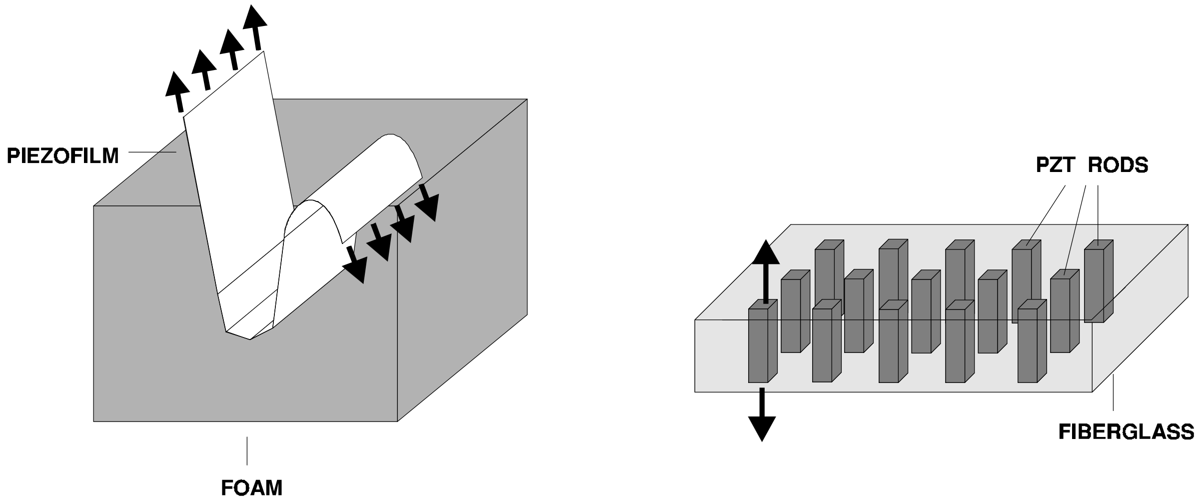
1. INTRODUCTION

The unique noise generating properties of the proposed ducted fan engines are forcing the aeroacoustician to consider new techniques to reduce the sound levels of these engines to acceptable levels. The proposed engine will be about ten feet in diameter, and ten feet long. This design is predicted to generate noise levels over 150 dB inside the engine, with very limited space for noise attenuation devices or liners. Among the techniques being considered as a solution for this unique problem is active noise control. One of the primary difficulties of providing an active noise control system for this application is the need for extended spatial control of the spinning modes inside a duct (ref 1). One possible method for achieving extended spatial control is to use a distribution of highly efficient, lightweight sound sources.

A current program at NASA Langley Research Center is investigating alternative sound sources and their application to the noise control problem. As a first step in the development process, two exploratory tests were conducted to evaluate the acoustic transduction properties of three piezoelectric samples. Piezoelectric materials vibrate and produce sound when driven by an input voltage. If sufficiently large acoustic outputs that would match the predicted levels of the proposed engine can be obtained directly from these piezoelectric samples, they may be used as direct in-duct acoustic actuators. However, if the direct acoustic outputs are insufficient, the piezoelectric material may have to be coupled with a heavier or larger structure to amplify the acoustic outputs.

2. DESCRIPTION OF PIEZOELECTRIC SAMPLES

Three piezoelectric samples, one Polyvinylidene Flouride (PVDF) piezo film sample and two Lead Zirconate Titanate (PZT) composites were tested. The first sample evaluated was a 28-µm-thick PVDF piezo film embedded in a block of foam. Figure 1a illustrates the sample in its test configuration and indicates the relative motion of the film. The other two samples were composites of PZT rods embedded in fiberglass. The cross-sectional areas of the PZT rods in the two composites were 1 mm^2 and 0.25 mm^2, spaced 4.5 mm and 2.3 mm apart, respectively. Both PZT samples had a surface density of 5% PZT. Figure 1b shows the configuration of the PZT composites.



(a)
PVDF in Foam

(b)
PZT Rods in Fiberglass

Figure 1. Piezoelectric Samples.

3. ACOUSTIC RESPONSE MEASUREMENT

The first test was to ascertain the acoustic response of the samples as functions of frequency and excitation voltage. This was done by mounting each sample normal to the axis of a 2-in by 2-in duct with a nonreflecting termination and measuring sound levels approximately one meter from the sample. The samples were driven at various input voltages over a frequency range of 200 to 2500 Hz in 100 Hz increments. Figure 2 shows a schematic of the setup.

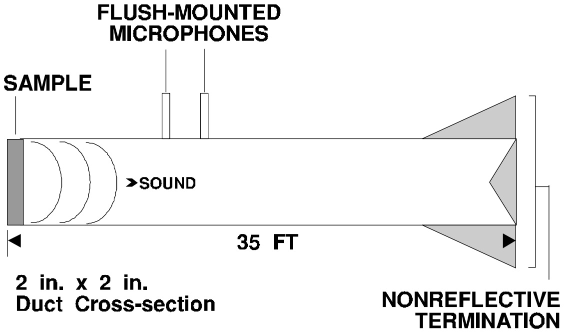


Figure 2. Progressive Wave Tube used to measure acoustic efficiency.

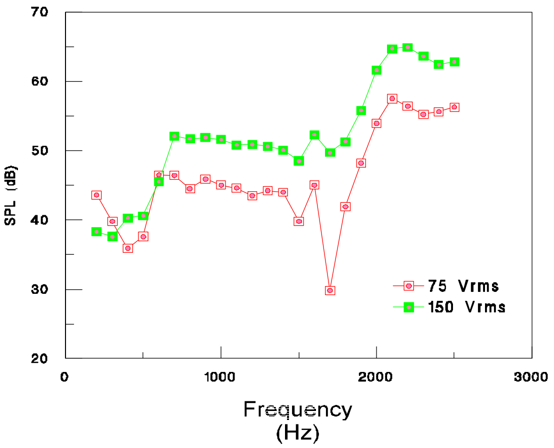


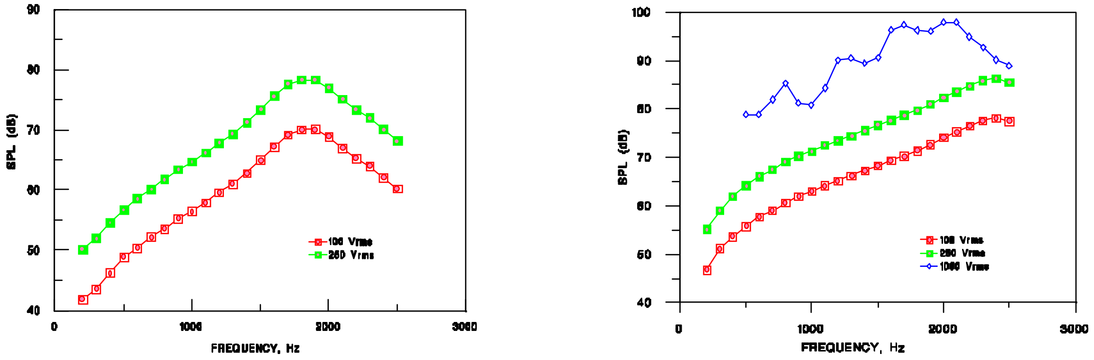
Figure 3. Acoustic output data for the PVDF Piezofilm.

Figure 3 shows a frequency response plot of the acoustic output for the PVDF piezofilm. The piezofilm was driven by an input of 150 V_{rms}, the maximum voltage the PVDF-foam configuration could sustain. A peak sound pressure level (SPL) of 64.9 dB (ref. 20 µPa) was measured. To test for linearity of acoustic output vs. voltage input, an input of 75 V_{rms} was used. The acoustic response for both input voltages, shown in Figure 3, illustrates that for most frequencies, the change in acoustic output is directly related to the change in excitation voltage or:

$$\Delta dB = 20 \log \frac{V_2}{V_1}$$

for this range of excitation voltage, indicating linearity. Some points in Figure 3 did not exhibit a linear increase with the change in voltage, most likely because the sound pressure levels were below the range of the acoustic measurement system.

The PZT piezoceramic samples were driven at 250 V_{rms}. Figure 4a shows the frequency response of the PZT sample with 1-mm^2-cross-section rods. The peak in the response curve (78.3 dB) indicates a resonant response of the sample for the frequency range tested. Figure 4b shows the frequency response of the PZT sample with 0.25-mm^2-cross-section rods. The response curve is similar to that of the previous PZT sample, but with a higher maximum SPL of 86.4 dB (ref. 20 µPa) measured. A shift in the peak and slope of the curves can be observed in Figures 4a and 4b. Both samples were also driven at 100 V_{rms} to check linearity. Figures 4a and 4b illustrate that with an increase from 100 V_{rms} to 250 V_{rms}, the change in decibels satisfied the equation above ($\Delta dB = 8$ dB), thus exhibiting linear behavior.



(a)
1 mm^2 Rod X-Section

(b)
0.25 mm^2 Rod X-Section

Figure 4. Acoustic output data for PZT piezoceramic samples.

4. NOISE CONTROL EVALUATION

The second test was conducted to investigate the ability of a piezoelectric sample to alter a simple standing wave field by controlling the termination boundary condition or acoustic impedance in a standing wave tube. The standing wave tube is a closed duct in which incident and reflected acoustic waves combine to create a standing wave (ref. 2). The standing wave tube was used to determine if the active sample could act as a nonreflecting termination for various phase settings relative to a primary sound source. The PZT sample with 0.25 mm^2 cross-section rods was used as the secondary source in this test since it gave the highest acoustic output of all three samples tested.

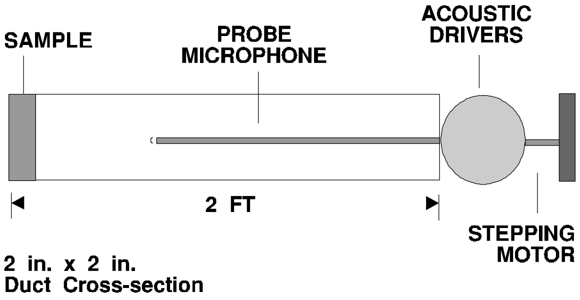
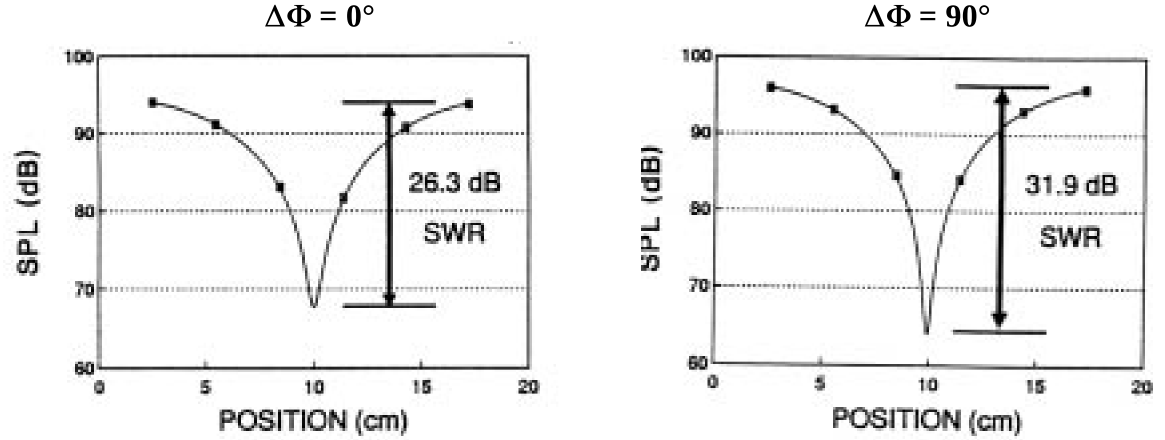


Figure 5. Standing Wave Tube

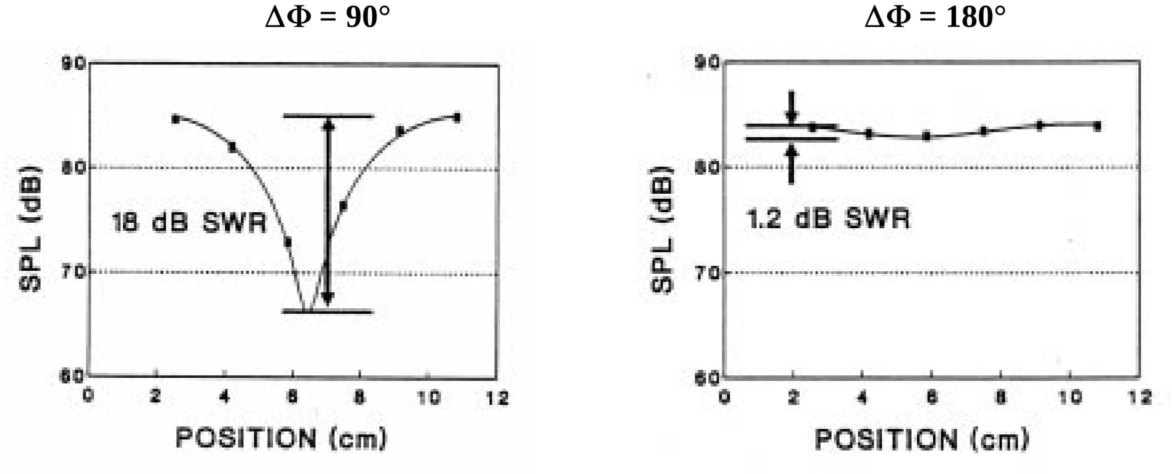
The sample was mounted at one end of a 2-ft long standing wave tube, as shown in Figure 5, with acoustic drivers on the other end to produce an incident sound field. The acoustic drivers and the sample were adjusted to produce the same acoustic output levels at each frequency tested. The standing wave produced in the tube was determined by fitting the data measured by the axially traversing probe microphone with the equation for a standing wave (ref. 2). Changes in the standing wave pattern were then measured as the PZT sample was driven at various phase settings relative to the acoustic drivers. A significant reduction in the standing wave ratio SWR would indicate that the reflected wave from the sample was being minimized.

The PZT sample was driven at 250 V_{rms} input, over a frequency range of 500 to 2500 Hz, in 100 Hz increments. The relative phase was varied from 0 to 180 degrees in 30 degree increments. Changing the relative phase settings varied the SWR at all frequencies tested. For this range of frequencies the change in SWR ranged from 4.2 dB to 44 dB. The relative phase settings at which the maximum and the minimum SWR were observed were different for each frequency tested. Figures 6a and 6b are plots of measured standing waves. Each plot shows SPL (ref. 20 μPa) vs. distance from the face of the sample. A typical SWR variation (in this case, an increase) is shown in Figure 6a. Figure 6b illustrates one of the significant reductions. The maximum standing wave ratio for this frequency was 18 dB when the sample was at a phase setting of 180 degrees. When the phase was set to 90 degrees, the SWR was reduced to 1.2 dB.

A survey of SWR versus phase setting at 1900 Hz, in increments of one degree, determined that the optimal phase setting was 82 degrees, which provided a SWR of less than 1 dB. This result indicates that the reflected wave from the sample is nearly eliminated.



(a)
900 Hz Frequency



(b)
1900 Hz Frequency

ΔΦ = Relative Phase Setting

Figure 6. SWR Plots for Various Relative Phase Settings.

5. CONCLUSIONS

The acoustic ouputs of the three piezoelectric samples were found to vary linearly with input voltage. The sample with the largest acoustic output was used as an active termination in a standing wave tube. A significant reduction in standing wave ratio was achieved, demonstrating that an active piezoelectric sample can eliminate a reflected wave. The acoustic output of the samples was far below the level necessary to control the ducted fan engine. To be useful for active noise control, the response of piezoelectric materials must be increased by several orders of magnitude. Amplifying the acoustic output of piezoelectric materials remains a challenge for the active noise control and advanced materials community.

REFERENCES

1 Rice, Edward J., "Spinning Mode Sound Propagation in Ducts with Acoustic Treatment and Sheared Flow," Aeroacoustics; Fan Noise and Control; Duct Acoustics; Rotor Noise; Progress in Astronautics and Aeronautics, Volume 44, AIAA, New York, NY, 1976.

2 Jones, Michael G. and Parrott, Tony L., "Evaluation of a Multi-Point Method for Determining Acoustic Impedance," Mechanical Systems and Signal Processing, Vol. 3, No. 1, 1989.