

# Characterizing and Reducing Acoustical Noise Radiation in Small Piezoelectric Blowers

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**The purpose of this paper is to outline the progress being made in classifying acoustic radiation emitted by piezoelectric blowers and developing methods for reducing said radiation. A description of the function and purpose of a piezoelectric blower is given. The problem of noise generation is outlined and described. Methods to characterize and identify the source of acoustic noise are discussed. A DNS approach to modeling turbulent air flow is presented. The benefits of a valid DNS model are discussed along with the complications inherent in DNS modeling. A DNS model of a piezoelectric blower is described and methods for validating the model are presented.**

## I. INTRODUCTION

The utilization of piezoelectric ceramics has been broadened and adapted to a variety of circumstances and applications in recent years. One such application includes the use of piezoelectric ceramics in air pumps. These air pumps are referred to as piezoelectric blowers. The blowers are designed to have a small profile when compared to a traditional cooling fan. They can have dimensions as small as 10mm x 10mm with only a 1.2mm nozzle height. Figure 1 shows a 20mm x 20mm blower side by side with a quarter dollar.

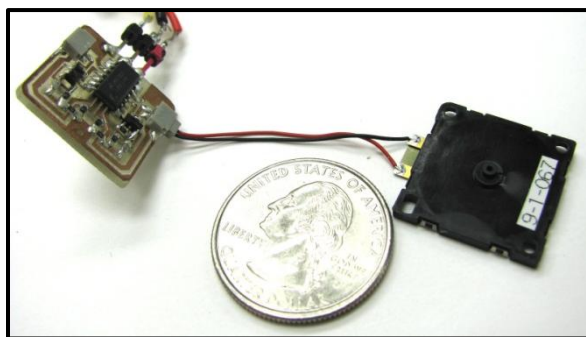


Figure 1 - A piezoelectric blower connected to a circuit board that drives and oscillates the ceramic at 25,000 Hz. A quarter dollar is larger than the blower device.

Standard piezoelectric blowers have a high flow rate (1.0 L/min) and maintain a high pressure (2.0 kPa). Traditional cooling fans generally compromise high flow rates for low pressure gradients. Another advantage to using a piezoelectric blower is they consume less power because there is no motor required to spin fan blades. The motor mechanism is replaced by a piezoelectric ceramic. The ceramic is excited with an oscillating voltage which causes the ceramic to vibrate at 25,000 Hz. This ceramic is attached to a pumping chamber which pushes air out of an exit nozzle. Figures 2&3 show how air flow is created by the movement of the ceramic.<sup>1</sup> The small profile and effective cooling capabilities open new possibilities for heat dissipation and cooling systems. Generally, computer processing power in small mobile devices is limited by the cooling capabilities. A larger processor produces more heat and requires a more complex and powerful cooling system. By using these blowers, small electronic devices can be designed with larger processors, be cooled effectively and not compromise the size or power requirements of the system.

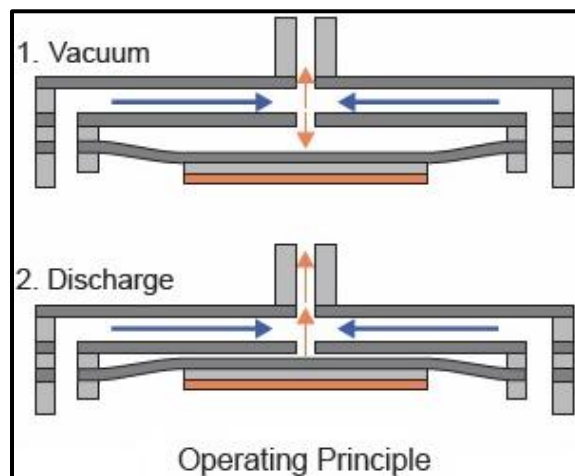


Figure 2 - A cross sectional view of the blower that shows the operating principle behind the air flow. The location of the ceramic is shown during vacuum and discharge processes.

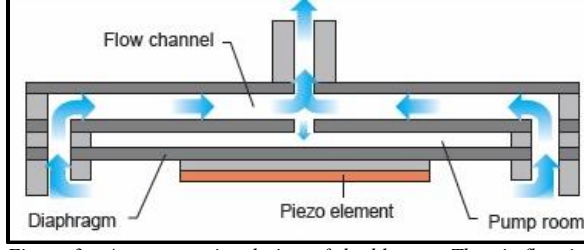


Figure 3 - A cross sectional view of the blower. The air flow is highlighted by blue arrows. The "Pump Room", "Piezoelectric ceramic", "Diaphragm", and "Flow Channel" are labeled.

However, piezoelectric blowers emit acoustic radiation. The noise is not damaging to the human ear but is undesirable and irritating during prolonged exposures. The overall sound pressure level measures approximately 52 dB ( $P_{ref} = 20\mu\text{Pa}$ ) at 0.5m from the blower nozzle. If piezoelectric blowers are to be used in electronic devices such as phones, tablets, laptops or any other electronics that are in close proximity to humans, the source of the noise generation must be understood and minimized. Currently, the design of the blowers limits their market to cooling systems that are inherently noisy. Research is being done to characterize the noise and find the noise generating mechanism in the blowers.

This paper will investigate the properties of the acoustic noise radiation and explore possible sources of the noise. Plate radiation theory will be used to identify any acoustic radiation due to structural vibrations. Possible methods for reducing and minimizing acoustic radiation will be investigated by using Direct Numerical Simulation (DNS). The complications of DNS modeling of turbulent air flow will be discussed. A DNS model of a blower will be presented and methods for validating the model will be discussed.

## II. NOISE CHARACTERIZATION

The acoustic noise radiated by the blower can be measured using a free field microphone in an anechoic chamber. Figure 3 shows the frequency spectrum from a sample of piezoelectric blowers. The figure shows how amplitudes can vary between blowers. The large spike at 25 kHz in Figure 3 corresponds to the driving frequency of the blower. The audible hearing range for humans<sup>2</sup> is 20 to 20,000Hz. Therefore, it is only necessary to

understand and minimize the frequencies less than 20,000Hz.

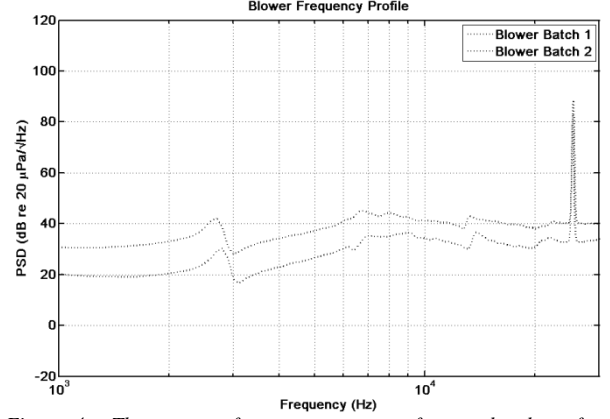


Figure 4 - The average frequency spectrum for two batches of blowers. The spectrum shows frequencies from 1000 to 30,000Hz. The data was taken with the microphone positioned next to the blower (less than 1cm from the nozzle).

Two sources of noise are assumed to contribute to the total acoustic radiation. *First*, the structural vibrations of the blower can excite structural modes<sup>3</sup> and radiate sound. *Second*, the turbulent flow of air through the blower can cause mixing<sup>4</sup> and radiate sound.

Plate radiation theory<sup>5</sup> is a method that can be used to calculate the amount of sound power that is radiated from a plate due to a structural mode. This is done by dividing the plate into  $R$  number of sub plates and finding a radiation resistance matrix  $[R]$  for the entire plate.<sup>5</sup>

$$[R] = \frac{\omega^2 \rho_0 A_e^2}{4\pi c} \begin{bmatrix} 1 & \frac{\sin kd_{12}}{kd_{12}} & \frac{\sin kd_{1R}}{kd_{1R}} \\ \frac{\sin kd_{21}}{kd_{21}} & 1 & \vdots \\ \frac{\sin kd_{R1}}{kd_{R1}} & \dots & 1 \end{bmatrix} \quad (1)$$

A column vector  $\{\tilde{V}_e\}$  can be formed that contains the transverse velocity for each individual sub plate.<sup>5</sup>

$$\{\tilde{V}_e\} = [\tilde{v}_{e1} \ \tilde{v}_{e2} \ \dots \ \tilde{v}_{eR}]^T \quad (2)$$

The radiated sound power  $\bar{P}(\omega)$  depends on frequency and can be calculated using the radiation resistance matrix (1) and the transverse velocity column vector (2).

$$\bar{P}(\omega) = \{\tilde{V}_e\}^H [R] \{\tilde{V}_e\} \quad (3)$$

This value can then be compared to a measured value of sound power at the corresponding frequency.

To predict the amount of sound power radiation due to structural vibrations, the surface of the blower was assumed to be a vibrating plate. A Scanning Laser Doppler Vibrometer (SLDV) was used to scan the surface of the blower while the blower was running. The SLDV measured the transverse velocities needed for the velocity column vector in equation (2). The SLDV showed that two structural modes were excited in the audible frequency range. The first was at 4.18 kHz and the second was at 8.81 kHz. Using plate radiation theory, the radiated sound power was calculated for both structural modes. These values were compared to a measured sound power from the same blower in an anechoic chamber. Table 1 shows the percentage of blower noise that is due to structural vibration modes. For both modes, there is very little contribution to the total sound power at those frequencies. Thus, plate radiation theory suggests that the majority of acoustic radiation is due to turbulent mixing as air flows through the blower and not structural vibration modes.

*Table 1 – Shows the amount of sound power radiated by the blowers two structural modes. (Reference power is  $10^{-12}$  W/m<sup>2</sup>)*

Mode [kHz]	Total	Structural Modes Contribution	
	Actual Measured Sound Power in Anechoic Chamber	Calculated Power from Plate Radiation Theory	Percent of Radiation due to Structural Modes
4.18	223.87 (pW) 23.5 (dB)	18.29 (pW) 12.62 (dB)	8.17%
8.81	4178.3 (pW) 36.21 (dB)	4.49 (pW) 6.52 (dB)	0.11%

### III. A DNS MODEL OF THE BLOWER

#### A. Purpose

The majority of acoustic radiation is generated by turbulent air flow through the blower. A method for modeling the flow and predicting the corresponding acoustic field can help understand the noise generation and how to reduce it. If a model can be developed that can accurately predict the sound pressure field of a blower, then model parameters can

be modified and the corresponding changes in the acoustic field can be noted. Relationships can be found between geometrical parameters in the flow path and sound power radiated. With a valid model, a flow path could be optimized such that it minimizes acoustic radiation.

#### B. Complications of DNS

Air exits the nozzle of the blower at approximately 22m/s. This results in the jet of air having a Reynolds number of approximately 1200. For an axisymmetric jet of air, the approximate maximum Reynolds number for laminar flow<sup>6</sup> is 1000. Hence the air at the nozzle exit is turbulent. There are many turbulence models<sup>7</sup> used in computational fluid dynamics. However, Direct Numerical Simulation (DNS) was used to model the blower. DNS<sup>8</sup> solves the Navier Stokes equations without the use a turbulent model.

To capture all the turbulence in a system, a DNS model must have sufficient spatial and time step scales. All the turbulence must be resolved in the computational mesh and the time step must be small enough to capture the motion of the smallest eddies. If the time step is too large or the mesh is too course the model can predict laminar flow because the dissipative forces will be too strong. These dissipative scales are known as the kolmogorov<sup>9</sup> scales. These scales can be used to predict the required time step and mesh size of the model.

A DNS approach to modeling is complex and computationally expensive. Generally, it is not used to solve turbulent problems because the amount of processing power and the required processing time is too high. However, the small nature of piezoelectric blowers allows DNS to be utilized. The DNS approach can accurately model the physics of the blower and not compromise the acoustic field<sup>10</sup> generated by the turbulent flow. Conventional turbulent models average the turbulence in a flow field. This would reduce the accuracy of the corresponding acoustic pressure field.

#### C. Model Description

A model has been developed that assumes an axisymmetric body about the nozzle of the blower. An oscillating velocity load is applied to the bottom of the pumping chamber. The load is modeled as a single pumping piston and can be given an amplitude value. While running, the ceramic on the back of the blower was scanned with an SLDV and the RMS

velocity amplitude was taken from the scan. The measured amplitude value is applied to the load in the model. Figure 5 shows a profile view of the DNS model and labels the boundary conditions.

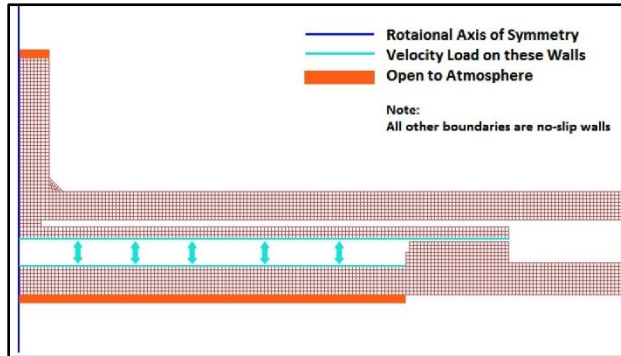


Figure 5 - Profile of DNS blower model. The rotational axis of symmetry, velocity load and atmosphere boundary conditions are shown. Note: The mesh is not the actual mesh size.

The pink area seen in Figure 5 is the space air can occupy inside the blower. Air is pulled into the blower through the orange space on the bottom of the blower and exits through the orange space above the nozzle. The model requires 7 days to run. Both the velocity field and pressure field can be post processed. Modifications can be made to the nozzle length, diameter or chamfer and to the flow channel width, height and corner fillets.

#### D. Model Validation

The DNS model is currently undergoing validation testing. This is being done primarily in two ways: First, the predicted velocity profile is being compared to a measured velocity profile. Second, the frequency spectrums at specific locations near the jet are being compared to corresponding spectrums measured in an anechoic chamber. Once the model is validated, more progress can be made in defining relationships between sound power and the flow path geometry. The effects that various structural components have on acoustic radiation can also be studied.

A velocity profile of a jet produced by a piezoelectric blower was measured using Particle Image Velocimetry<sup>11</sup> (PIV). The results from a preliminary model run are displayed in Figure 6 for comparison to the PIV results. The result shown in Figure 6 underestimates the velocity profile but this is due to using a bad estimate for the RMS value of the ceramic velocity amplitude. The model prediction does however match the profile of a

turbulent jet. Final results with the correct load input amplitude are being generated but are not yet available for comparison.

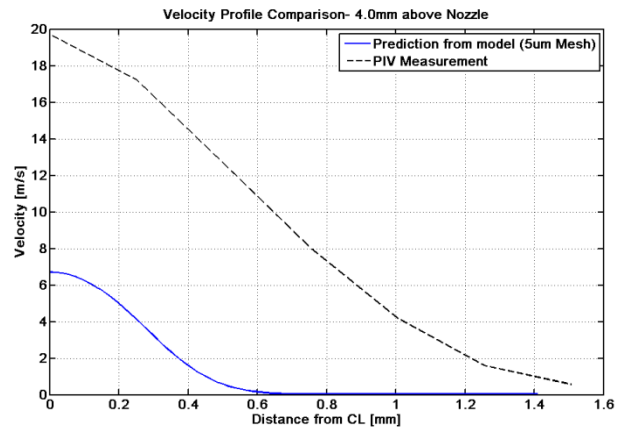


Figure 6 - The velocity profiles of the blower's jet of air at 4.0mm from the exit plain of the nozzle. PIV results compared to a preliminary DNS model prediction.

A preliminary sound pressure measurement was taken near the exit plain of the jet in an anechoic chamber. The frequency spectrum at that location was also extracted from the DNS model. The comparison is shown in Figure 7.

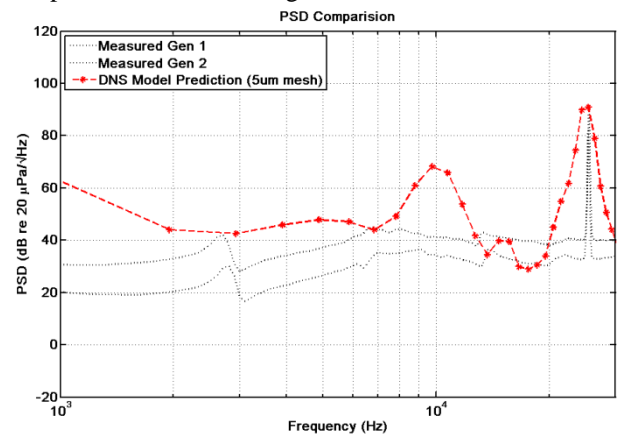


Figure 7 - Measured frequency spectrums taken near the exit plain of the nozzle are compared to the predicted spectrum from a DNS model.

More precise measurements in the anechoic chamber are needed to validate the model. The spectrum of a jet can change drastically depending on the angle<sup>12</sup> at which the measurement is taken. Figure 7 only shows one point extracted from the model. The validation of the DNS model is still underway. It is expected that the velocity profiles will match by using the correct load input. It is expected that with better measurement techniques the

frequency spectrum will also fall within the measured ranges seen in Figure 7.

#### IV. CONCLUSION

Piezoelectric blowers are currently limited to markets with cooling systems that do not value or necessitate noise control. To expand into larger markets such as personal electronic devices where noise control is required, methods for reducing the acoustical radiation need to be developed. Radiation plate theory can be used to provide evidence of structural vibration modes contributing to the acoustical radiation. The data gathered with the SLDV provides indirect evidence that turbulent mixing is the source of the noise generation and not structural vibration modes.

DNS modeling of piezoelectric blowers is a method that can be used to reduce or minimize acoustic radiation. Model validation can be done by comparing predicted velocity profiles to measured velocity profiles. The DNS approach allows for accurate prediction of the sound pressure field. With a validated model, modifications can be made to parameters in the flow path and corresponding sound pressure levels can be predicted. A relationship can be derived between geometrical dimensions and acoustical radiation. This data can then be used to minimize said radiation and improve blower designs.

#### REFERENCES

- 1) Murata Manufacturing Co., Ltd., Global Online, <http://www.murata.com/products/micromechanics/fature/microblower/index.html#A002>
- 2) L.E. Kinsler and A.R. Frey, (2000), "The Ear", *Fundamentals of Acoustics*, Fourth Edition, John Wiley and Sons, Inc., New York, pp. 312-315.
- 3) F.Fahy and P.Gardonio, (2007), *Sound and Structural Vibration Radiation, Transmission and Response*, Second Edition, UK: Oxford.
- 4) C.K.W. Tam, (1991), "Jet Noise Generated by Large-Scale Coherent Motion", *Aeroacoustics of Flight Vehicles: Theory and Practice*, Volume 1:Noise Sources, Edited by H.H Hubbard, NASA Langley Research Center, Hampton, Virginia, pp. 311-390.
- 5) F.Fahy and P.Gardonio, (2007), "Sound Radiation by Plates", *Sound and Structural Vibration Radiation, Transmission and Response*, Second Edition, UK: Oxford, pp. 159-168.
- 6) R.C. Blevins, (1984), *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Company, Table 9-2. Submerged Laminar Jets.
- 7) D.C. Wilcox, (2006), *Turbulence Modeling for CFD*, Third Edition, DCW Industries Inc., La Canada, California.
- 8) D.C. Wilcox, (2006), "Direct Numerical Simulation," *Turbulence Modeling for CFD*, Third Edition, DCW Industries, Inc., La Cañada, California, pp. 431-435.
- 9) H. Tennekes and J.L. Lumley, (1972), "Small Scale Turbulence", *A First Course in Turbulence*, The MIT Press, Cambridge, Massachusetts, pp. 19-25.
- 10) D.C. Wilcox, (2006), "Direct Numerical Simulation," *Turbulence Modeling for CFD*, Third Edition, DCW Industries, Inc., La Cañada, California, pp. 432.
- 11) M.Raffel, C.Willert, and J.Kompenhas, (1998), *Particle Image Velocimetry: A practical Guide*, Springer-Verlag Berlin Heidelberg, Germany.
- 12) G.M. Lilley, (1991), "Experimental Considerations", *Aeroacoustics of Flight Vehicles: Theory and Practice*, Volume 1:Noise Sources, Edited by H.H Hubbard, NASA Langley Research Center, Hampton, Virginia, pp. 262-274.