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Daxton Hawks REU Prospectus

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Performance of Phase and Amplitude Gradient Estimator Method for a Plane-Wave Tube Environment

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Introduction

The current standard for obtaining acoustic vector intensity is using a finite-difference *p*-*p* method, which will be referred to as the traditional method. This method uses multiple phase-matched microphones to estimate the particle velocity and thereby the acoustic intensity, via the pressure gradient across the microphones.[1] While useful in making estimates of acoustic intensity, the traditional method has a limited frequency bandwidth. As the microphone spacing becomes large relative to the wavelength of the incident waves, the highest frequency at which accurate estimates can be obtained is limited.[2] The lowest frequency at which good estimates can be obtained is also limited by microphone spacing: if the microphone spacing is very small relative to the wavelength, the phase mismatch of the microphones can be larger than the phase difference between the recorded signals. Thus we see the microphone spacing determines the frequencies over which the traditional method functions properly.

The phase and amplitude gradient estimation (PAGE) method developed here at BYU is capable of overcoming the deficiencies of the traditional method. The PAGE method works similar to the traditional method, but rather than estimating the pressure gradient from the real and imaginary parts of the complex pressures, the gradients of the amplitude and phase of the complex pressure are used separately to estimate the acoustic vector intensity. The amplitude and phase are expected to vary more linearly than complex pressure over a distance between two microphones. As frequency increases, the phase difference that wraps repeatedly between $+\pi$ and $-\pi$ can be unwrapped. This phase unwrapping allows the PAGE method to bypass the frequency limitations of the traditional method.

The PAGE method has been used to calculate the active acoustic intensity, I_a, for broadband noise sources on a number of occasions prior to this project. Measurements have been made for laboratory-scale jet noise, [5] near-field intensity of static rocket firings, [6] as well as full-scale jet noise. [4] It has also been used to investigate interference fields[7] and various arrangements of monopoles.[8]

In addition to acoustic intensity, the PAGE method can be used to obtain other valuable energy-based quantities. The PAGE method is a way to estimate particle velocity, which relates to sound intensity, which is an energy- based quantity. The complex acoustic vector intensity has two components. The active intensity I_a (real) component indicates the flow of energy in propagating waves, and the reactive intensity I_r (imaginary) component deals with near fields of sources and standing waves. The kinetic energy E_k, potential energy E_p, and acoustic impedance Z are all also important acoustical quantities obtained using pressure and particle velocity. This work will begin the exploration of the ability of the PAGE method to improve the usable bandwidth of these energy-based quantities in a controlled environment.

Objective

The purpose of my research is to investigate the ability of the PAGE method to improve the frequency bandwidth of calculations of energy-based quantities from multiple pressure microphones. I will accomplish this by investigating sound waves in both plane-wave and standing-wave environments. I will compare the PAGE method calculations for I_a, I_r, E_p, E_k, and Z to those of traditional and analytical expressions, based on careful ambient condition monitoring. Quantifying the bandwidth extension of the PAGE method for these energy-based quantities will lay a foundation for further application.

Methodology & Procedures

In this section, I address the plane-wave environment and other equipment that will be used. An overview of ambient condition monitoring will be presented as part of the set-up. I also describe the experimental methods for both the anechoic and rigid termination and explain the methods I use for analyzing the data I record.

Figure 1. Photograph of the plane-wave tube and data-acquisition system.

The plane-wave tube as shown in Figure 1 is made of thick transparent plastic, has an internal diameter of 10 centimeters, and is 264 centimeters long from the source to the beginning of the termination. It has several bolts in the top, spaced 5 centimeters apart, which can be removed and replaced with microphones pointed into the tube, with the diaphragms flush against the side of the tube. The microphones that will be used are G.R.A.S. ½-inch pre-polarized pressure microphones. These capacitor-based microphones are useful because of their ability to receive input from very high frequencies at very low amplitude. The tube is connected to a loudspeaker that will emit broadband Gaussian noise. Both the loudspeaker output and the microphone inputs will be controlled via National Instruments data-acquisition system controlled by the BYU Acoustic Field Recorder (AFR) LabView software on a computer.

An anechoic termination at the end of the tube will be used to investigate a plane-wave field, and a rigid termination will be used to make measurements on a standing-wave field. Because the nature of sound is different in a plane-wave case than it is in a standing-wave case, we will make measurements using both types of terminations. The anechoic termination adds an additional 173 inches to the length of the tube.

An important element of our system is the ambient conditions inside and around the tube. The temperature, humidity, and atmospheric density and pressure inside the tube will all affect acoustical quantities, so it is important that those values are monitored. The acoustics research group at BYU owns a Kestrel Weather Meter, which we can connect via Bluetooth to AFR to monitor these ambient conditions.

When we start running our measurements, sound waves will be sent through the tube and pressures will be measured by four different microphones. The second microphone will be placed 5 centimeters further down the tube than the first one, the third 15 centimeters, and the fourth 30 centimeters. Placing the microphones at this spacing will allow us to analyze the data using inter-microphone spacing of 5, 10, 15, 25 and 30 inches.

AFR will record the data and will save a binary file for each of the microphones. I will use MATLAB code that was written previously to convert the pressure waveforms from each microphone, perform a Fourier transform, and obtain the single-sided complex pressure spectra. From these spectra, we can calculate I_a, I_r, E_p, E_k, and Z using both the traditional method and the PAGE method for different inter-microphone spacing. Using the traditional method will provide a basis of comparison upon which we can compare the usefulness of the PAGE method. In addition comparisons with analytical expressions for the energy-based quantities will be done for both the plane-wave and the standing-wave cases.

Scope & Limitations

My research will involve application of the PAGE method to obtain I_a, I_r, E_p, E_k, and Z from my measurements in the plane-wave tube environment. However, I will only consider these quantities based on first-order derivatives. Joseph Lawrence, an incoming graduate student, will work on the quantities based on higher-order derivatives. Additionally, I will only utilize the PAGE method for a plane-wave tube environment. I will not perform free-field experiments.

Significance of Project

As the understanding of the performance of the PAGE method increases, and how it increases our understanding of these energy-based quantities, we hope to extend the PAGE method to other applications. These applications include but are not limited to sound power and absorption, near-field acoustical holography, source localization, acoustic properties in semi-reverberant rooms, and active noise control.[3]

Timeline

- Week 1: Prospectus and familiarization with project
- Weeks 2-4: Initial data collection & analysis with anechoic termination
- July 5: Midterm presentation
- Weeks 5-8: Data collection & analysis with rigid termination
- Week 9-10: Final report preparation and presentation

Bibliography

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[8] E. B. Whiting *et al.*, "A comparison of different methods for calculating complex acoustic intensity," J. Acoust. Soc. Am. 139 (4), 2032-2032 (2016).