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Incorporating measurement standards for sound power in an advanced acoustics laboratory course

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In an advanced acoustics laboratory course at Brigham Young University, students are introduced to ANSI measurement standards in the context of sound power. They are introduced to the anatomy of a typical acoustics standard and then plan and carry out sound power measurements of an electric leaf blower using both reverberation chamber and sound intensity methods. The students are required to write a technical memorandum describing a) the blower's radiated sound power levels over an appropriate frequency range, as obtained with the two methods; b) setup documentation and deviations from the standards' recommended practices; and c) how any deviations might have contributed to discrepancies between the sound power levels obtained with the two methods. In this paper, a description of the experience is given, along with overall impressions and plans for future improvements.

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1. INTRODUCTION

This paper, which originated as a talk in a special session on the use of measurement standards in acoustics education, describes an attempt to incorporate standards for measuring sound power in a recently developed advanced acoustics laboratory course at Brigham Young University. The course, "Acoustical Measurement Methods," is a graduate-level course that is taken by new acoustics graduate students and by senior undergraduate students who have previously taken "Introduction to Acoustics," an advanced undergraduate course.[1,2,3] The purpose of the course is to enhance the education[4] of students in the Acoustics Research Group by providing them with practical experiences using measurement techniques and analysis methods common in research and industry settings. The opportunity to participate in meaningful measurement, analysis, and reporting experiences better prepares them for internships, mentored research opportunities,[5] graduate study, and employment. As much as possible, the labs are unscripted so as to promote an inquiry-based environment that makes students design the measurement and analysis to complete the overall aim.[6,7]

The motivation for incorporating measurement standards in this laboratory course is to a) introduce students to the concept of standards, which they will be likely to encounter in industry, b) help them become familiar with the anatomy of a standard, c) understand how to use a standard in making a measurement, and d) learn how to report results, including uncertainties, supporting data, and the possible impacts of not always being able to follow the standard in every detail.

2. LABORATORY ASSIGNMENT

The assignment for the student in this laboratory course was relatively simple: a) conduct sound power measurements of an electric leaf blower using two different standardized methods, b) find the sound power radiated between 200 and 2000 Hz, and c) report on the results in a 2-3 page technical memorandum, including uncertainties and reasons for differences between the two measurement methods. Relevant supporting data and data quality analyses were to be included in an appendix. The choice of using a technical memorandum instead of a more traditional lab report is to teach the students to write succinctly in an industry-appropriate style.

For this lab, the class of 9 students was divided into two groups, and each group was responsible for taking the lead on the setup of the measurement for one of the standards. However, both groups completed the measurements and analysis according to both standards. The students had two weeks to complete the measurements and the memorandum. As with nearly all labs in this course, data acquisition was carried out using an in-house LabVIEW-based program, Acoustic Field Recorder, using National Instruments hardware, and students conducted analysis using MATLAB. Previous to this lab, students had been introduced to key analysis methods, such as Fourier analysis and auto and cross spectra.

There are several methods for obtaining sound power, but the two methods were selected based on how they complemented the other laboratory exercises and the most readily available BYU Acoustics facilities. In this case, the two ANSI standards used to obtain sound power of the electric leaf blower were a precision reverberation chamber method[8] and an engineering method based on *in situ* sound intensity measurements.[9] A third standard[10] was used to explain the intensity method. Two 50-min class periods were used to explain the purpose and anatomy of a standard and to explain various elements of the two standards. Copies of the standards were temporarily provided to the students during the lab under fair use.

3. DESCRIPTION OF RESULTS

Each student submitted an analysis as a technical memorandum. Example graphs and results from the submitted memoranda are used to describe the measurements made. Photographs from the intensity and reverberation chamber measurements are shown in Figs. 1 and 2, respectively. For the intensity method, the students had to consider the spacing and phase matching of the microphones to obtain the 200-2000 measurement bandwidth with the p-p cross spectral intensity calculation technique, and an appropriate record length. This was a nontrivial decision, given that both groups chose to highly resolved measurements

– 100 points per side, for 600 in all. This took a few hours to complete. In addition, they had to determine an appropriate measurement grid, both aperture and number of points, and a means of holding the blower to measure all six sides. In the analysis phase of measurements, the students found they needed to eliminate a number of measurement points when the blower's flow was incident on the intensity probe. Some students used the coherence between the probe microphones to determine which points to eliminate, and altered the sound power calculation accordingly. Figure 3 shows an example of the modified grid that one student reported.

Figure 1. In-situ intensity measurement of the electric leaf blower with nozzle removed. The two-microphone intensity probe is located on the two-dimensional gantry, beneath a foam windscreen.

Figure 2. Reverberation chamber measurement of the leaf blower with six microphones.

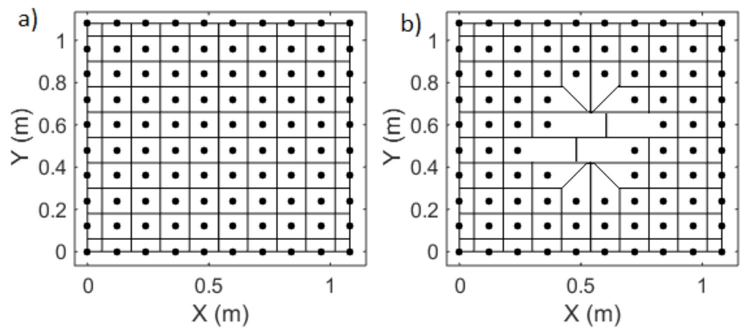

Figure 3. Alteration of the sound power calculation grid necessitated by the removal of flow-corrupted measurements.

For the reverberation chamber-based sound power measurement, students had to determine appropriate microphone locations (see Fig. 4), the number of microphones required, record length and number of averages in FFT processing, the number of source locations, the volume and reverberation time of the chamber (to calculate the total absorption), and track ambient conditions. This measurement in particular forced the students to examine the standard carefully because the chamber volume was slightly smaller than the 70 m^3 required, and the standard deviation between measured levels was too large. Thus the uncertainty was too large and students found they could improve results by repeating the measurements with different locations, as shown in Fig. 4.

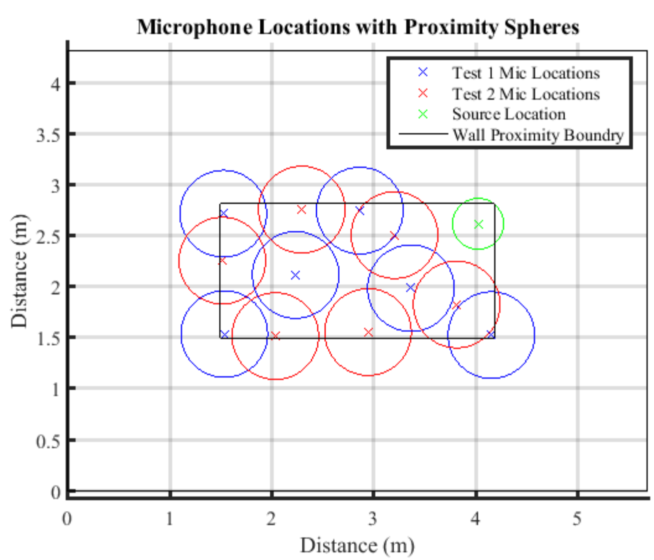

Figure 4. Locations of the six microphones used in the reverberation chamber sound power measurement for two trials.

Despite deviations from the standard in some cases, the sound power measurements agree favorably. Two of the students' sound power plots as a function of frequency are shown in Figs. 5 and 6. In one case, the student provided error bars to account for the uncertainty described in the standards. In Fig. 5, the reverb method yielded 103.1 dB re 1 pW for the 200 - 2000 Hz bandwidth, whereas the intensity method yielded 101.4 dB re 1 pW. For the comparison in Fig. 6, the reverb method yielded 102.6 dB re 1 pW and the intensity method yielded 102.3 dB re 1 pW. For all nine students (divided in two groups), their calculations for the bandlimited overall power level via reverb method only varied by 0.5 dB. On the other hand, via the intensity method, the results differed by approximately 2 dB. The intensity method was also the more time-consuming of the two methods, but the students learned in the process they could have drastically reduced the number of points. For example, as one student reduced the number of calculation points by a factor of two, the results at each frequency band changed by less than 0.1 dB, well below the allowable thresholds.

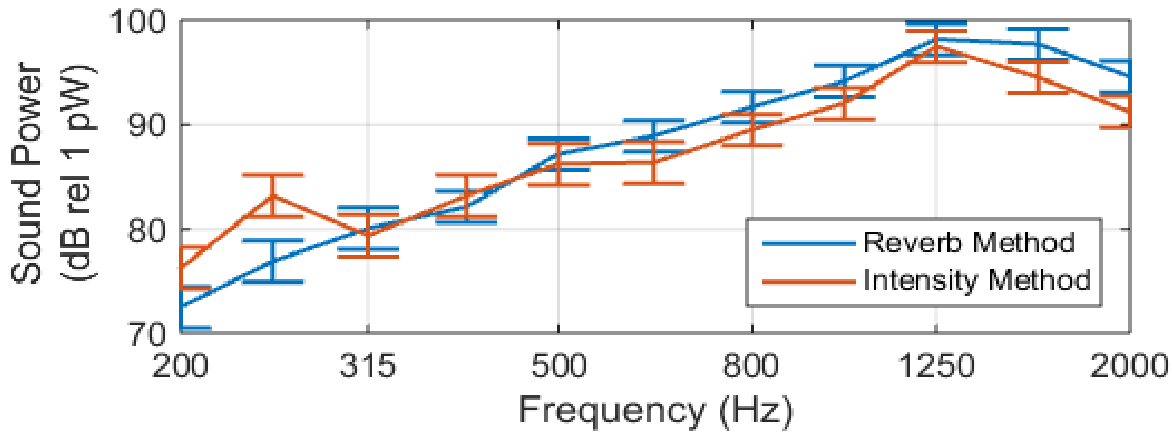

Figure 5. Comparison of sound power levels for the two standard methods, with error bars indicating the uncertainty published for each method.

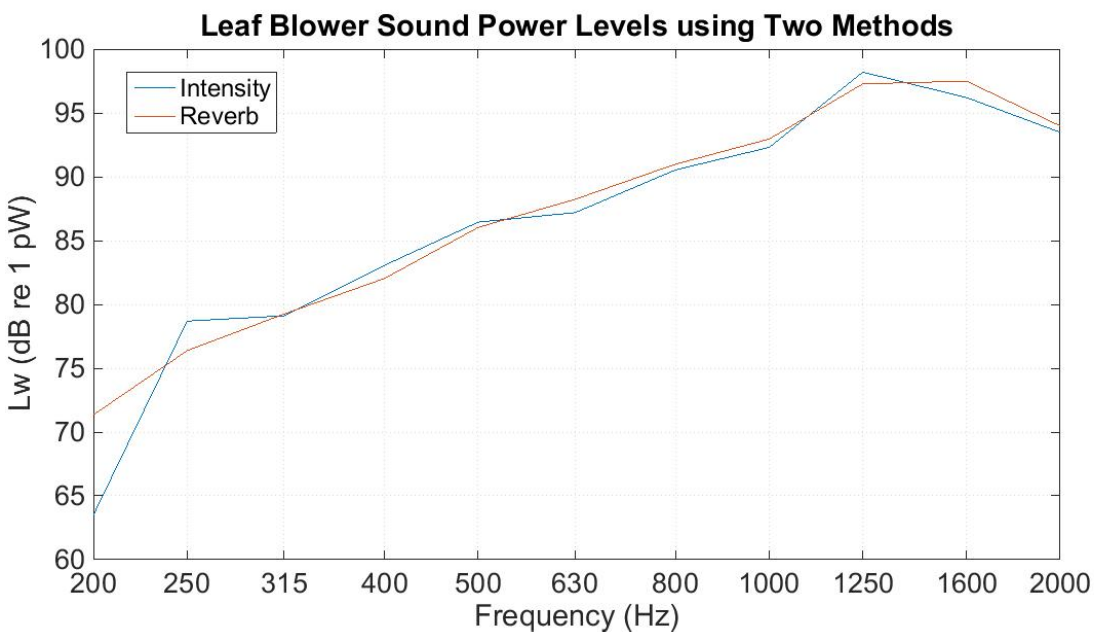

Figure 6. Another comparison of sound power levels for the two standard methods.

4. OVERALL IMPRESSIONS

I feel the opportunity to make a comparison measurement of sound power using very different standards represents a tremendous learning experience for the students. They practiced using sound intensity and spatially averaged squared-pressure measurements and learned about all the supporting data and considerations that are required in making a quality measurement. I had never been exposed to standards in my several graduate courses at two universities, but had to learn about them on my own while developing an intensity measurement capability as part of a project during my Masters degree. Thus, I was motivated to provide them an experience I had not had but felt was valuable. An informal survey of the students in preparing this paper revealed they felt similarly about its value, but they also indicated it was very time consuming. In the future, I need to give more guidance on how examine possible impacts due to deviations from the standard and report them in the technical memorandum. I may need to spend more time explaining the standards and give students more time to complete the lab, but, on the other hand, the students also admitted that the standards were too long and were hard to read and that they had tried to pull out pieces without fully reading them. The lab may be easier with a less complicated source than a leaf blower and its associated flow, and there are other changes to potentially make. However, considering the lab has only been done twice by the students, in 2015 and 2016, this set of measurements and analysis can be considered a successful unscripted, in-depth exercise for students to learn about the importance and utility of ANSI standards.

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