# The dependence of sound radiation on position of acoustic source in an enclosure

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# ABSTRACT

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In some applications, acoustic sources may be confined to a small enclosure but still radiating sound outwards through the enclosure. However, the sound power that is radiated from the enclosure may potentially be impacted by the location of the source within the enclosure and the properties of the enclosure. The dependence of source position on sound power radiated from the enclosure was investigated using a small rigid rectangular enclosure with a flexible aluminum panel as one of the sides of the enclosure. An acoustic source was moved to numerous locations in the enclosure and sound power measurements were made using the ISO 3741 standard. Results will be shown to numerically quantify the effect of acoustic source position on radiated sound power. These results are used to develop a calibration curve between the sound radiated by the enclosed source vs. the sound radiated by the source in a free field environment. This curve can be used in the development of an alternative method of determining sound power for a source.

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# Chapter 1: Introduction

## 1.1 Background

Noise control is a major issue for many product developers and manufacturers, especially those who specialize in loud products such as appliances and tools. Thus, there is a need for reliable noise measurement methods. Sound power is a universally accepted metric for determining noise radiation from an acoustic source. It is considered a global metric because it quantifies the total sound emitted and does not depend on observer distance. The International Organization for Standardization (ISO) has established ten sound power measurement standards.[1-10] Seven of these standards require specialized acoustic environments like anechoic or reverberation chambers, making them inconvenient and expensive for many. Alongside the standards, ISO has published two technical specifications that utilize structural vibration methods to compute sound power.[11,12] However, these specifications do not afford high accuracy. Addressing these limitations, a new sound power measurement method is being developed. This method, called indirect vibration-based sound power measurement (I-VBSP) method, involves placing an object that makes noise inside a small enclosure, thereby creating an "acoustic tent" around the object. A 3D scanning laser Doppler vibrometer (SLDV) is then used to scan one vibrating surface of the enclosure and the total sound power is estimated. This method requires a calibration between free field and enclosed sound power of acoustic sources. In the creation of this calibration, it becomes important to understand how the sound power radiated from the enclosure changes with respect to the acoustic source position inside the enclosure. If the sound power of an enclosed object has a large dependence on position, then any potential calibration would be inaccurate for certain source locations. Thus, there is a need to quantify the effect of source location on enclosed sound power.

## 1.2 Previous Work

Preliminary work has been conducted at Brigham Young University to determine the effect of source position on enclosed sound power. One such study used a rectangular enclosure with four high impedance medium density fiberboard (MDF) walls, one rigid wall (the ground) and a thin mylar face as the acoustic tent enclosure.[13] The placement of a powered blender relative to the first and second axial pressure nodes was investigated. It was found that the sound power results indicated location-dependent variations when a combination of node and non-node locations were used for measurements. Above the 1 kHz one-third octave (OTO) band, the results varied over a range of +/- 1.5 dB from the average. However, when the sound power results with the source located at the node locations for the first and second axial modes were removed, there was less variation in sound power measurements. For these non-node location measurements, all but two OTO bands above 1 kHz had a variation of less than +/- 0.5 dB from the average. These results suggest that the position of the acoustic source relative to the first and second harmonic axial node planes does indeed influence the sound power produced from the enclosure.

The focus of this research is to develop a calibration between the sound power of acoustic sources within an I-VBSP enclosure and the corresponding sound power in free field. The enclosure utilized for this research differs from the enclosure used in previous work, and it incorporates a greater number of acoustic sources to establish a more robust calibration. The calibration process involves assessing the flexibility users have in object placement within the enclosure while maintaining acceptable sound power results. This builds upon the foundational work of previous research, which explored the impact of source placement on enclosed sound power. The goal  is to quantify this influence for a significant variety of acoustic sources, ultimately providing error estimates for the final calibration.

# Chapter 2: Methods

## 2.1 Free field measurements

The calibration process for the enclosure involved seven carefully selected acoustic sources: a Bluetooth speaker, edge grinder, circular saw, sander, rotary saw, blender, and hand mixer. These particular sources were chosen because of their ability to maintain a nominally constant volume velocity within the desired frequency range (100 Hz to 10 kHz) and to produce levels well above the noise floor of the reverberation chamber when placed within the enclosure. Free field sound power measurements of these seven sources were taken in the reverberation chamber at Brigham Young University. The measurements were conducted using the ISO 3741 standard, utilizing 6 ¼" PCB 130F20 microphones. These microphones were positioned at a minimum distance of 1.5 m from the source and at least 1 m away from all other microphones and reflective surfaces, as specified by the standard.

## 2.2 Enclosed measurements

The I-VBSP measurement method requires an enclosure that surrounds the acoustic source of interest. The dimensions of the rectangular enclosure used for this calibration project are 0.78 m x 0.66 m x 0.56 m. These dimensions were chosen to mirror the dimensions of the reverberation chamber. Each side of the box consists of two layers of medium density fiberboard (MDF) with a damping foam material between them. The top is made of a thin aluminum sheet that is clamped down on the edges by a steel frame as shown in Fig. 1. The bottom is left open, allowing the enclosure to create a seal with the floor, effectively enclosing the acoustic source. In Fig. 2, the enclosure is shown tilted back so that the acoustic source may be repositioned.

***Figure 1: Top-down view of the I-VBSP enclosure.***

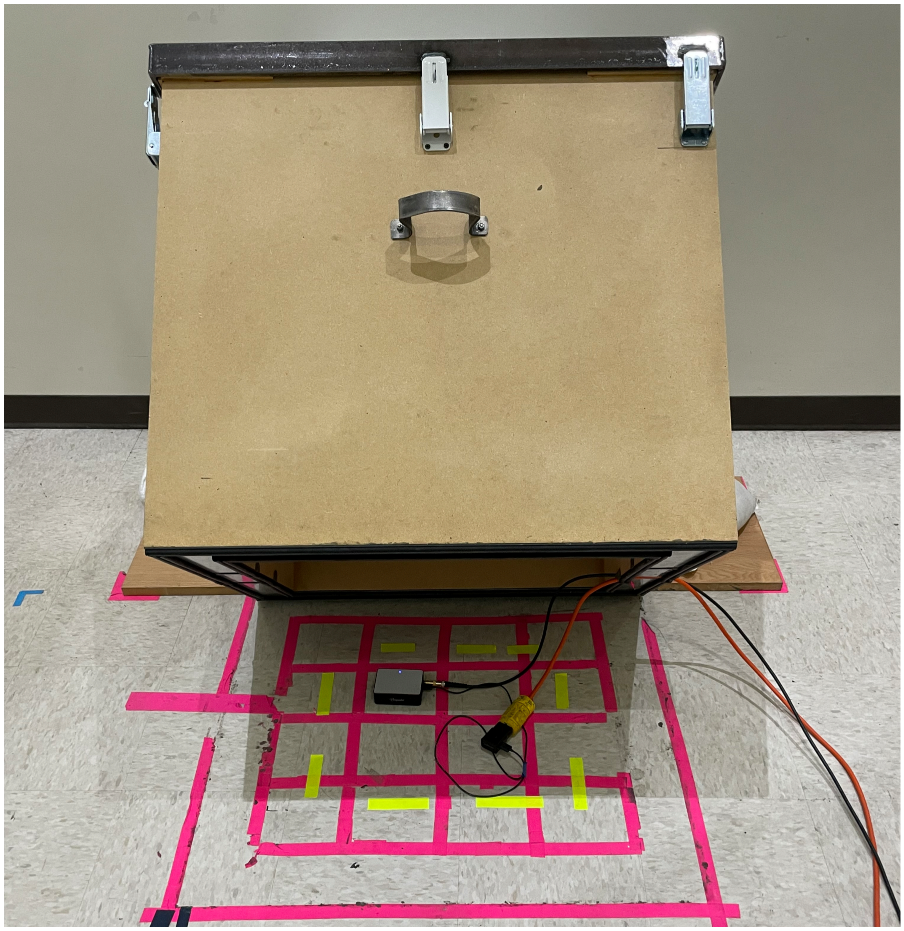

***Figure 2: Picture of the enclosed sound power measurement set up for a Bluetooth speaker.***

Each acoustic source was placed inside the enclosure and sound power measurements were taken. Like the free field measurements, all enclosed measurements were taken in accordance with ISO 3741 in the reverberation chamber. For each acoustic source, the source was moved to 11 different locations shown in Fig. 3. These source locations were grouped into three categories: edge location, node location, and non-edge non-node location. These locations were chosen to investigate how the position of acoustic source relative to these nodes and edges affect the sound power produced from the enclosure.

For each acoustic source, the average enclosed sound power was calculated across the OTO bands. The average enclosed measurement was then subtracted from the free field sound power measurement to obtain the calibration for that source. All seven calibrations were then averaged together to produce the final calibration of the enclosure.

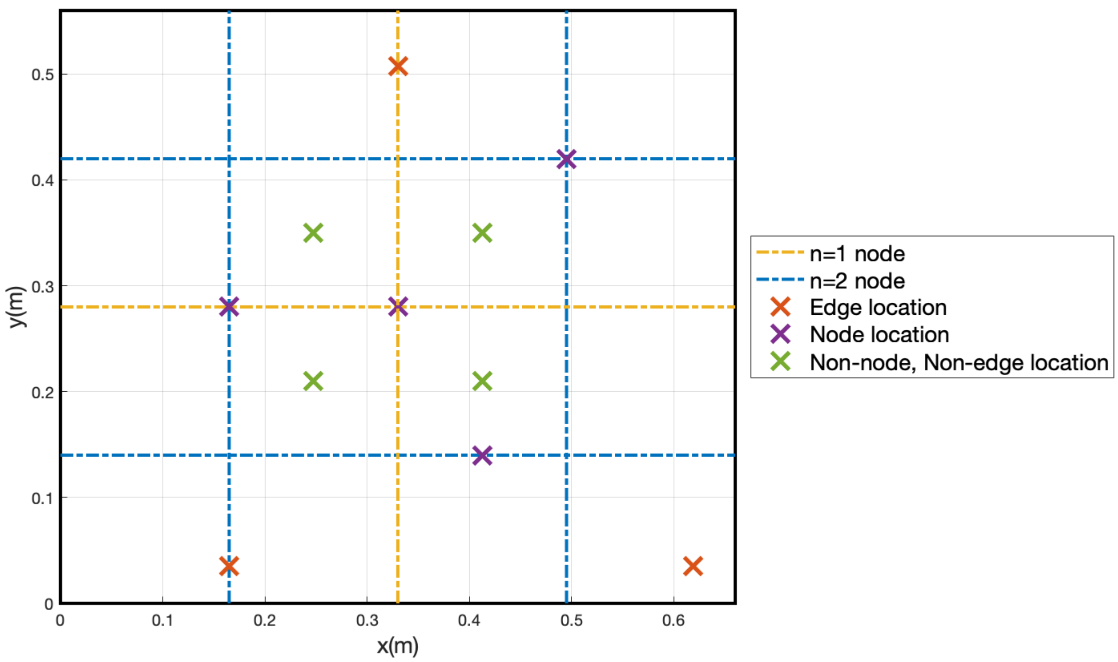


***Figure 3: Top-down view of the 11 locations that each acoustic source was placed. All sources were placed on the ground in these locations.***

# Chapter 3: Results

## 3.1 Enclosed Sound Power Measurements

Enclosed sound power measurements were taken in each of the 11 locations for the seven acoustic sources. Figure 4 shows the enclosed sound power measurement results of the Bluetooth speaker across the OTO bands. These results are grouped into the three categories that are once again delineated by color. As shown in the red curves, the ‘edge location’ sound power measurements show an increase in sound power around 500 Hz compared to the other location measurements. The ‘node location’ measurements also exhibit more variation in sound power in the 250-1000 Hz region, as well as a distinct grouping between 1-2 kHz. However, the ‘non-edge non-node’ location measurements, shown in green, are much more consistent from location to location. These results indicate that the enclosed speaker measurements exhibit a considerable degree of location dependence. This is likely due to the relative size of the Bluetooth speaker to the node plane positionings. The Bluetooth speaker measures 0.09 m by 0.07 m while the smallest distance between first and second harmonic nodal planes is 0.14 m. This means that the Bluetooth speaker can fit all of its noise radiating components entirely between the first and second harmonic nodal planes created by the enclosure. However, for larger sources, the location dependence becomes harder to distinguish through sound power measurements.

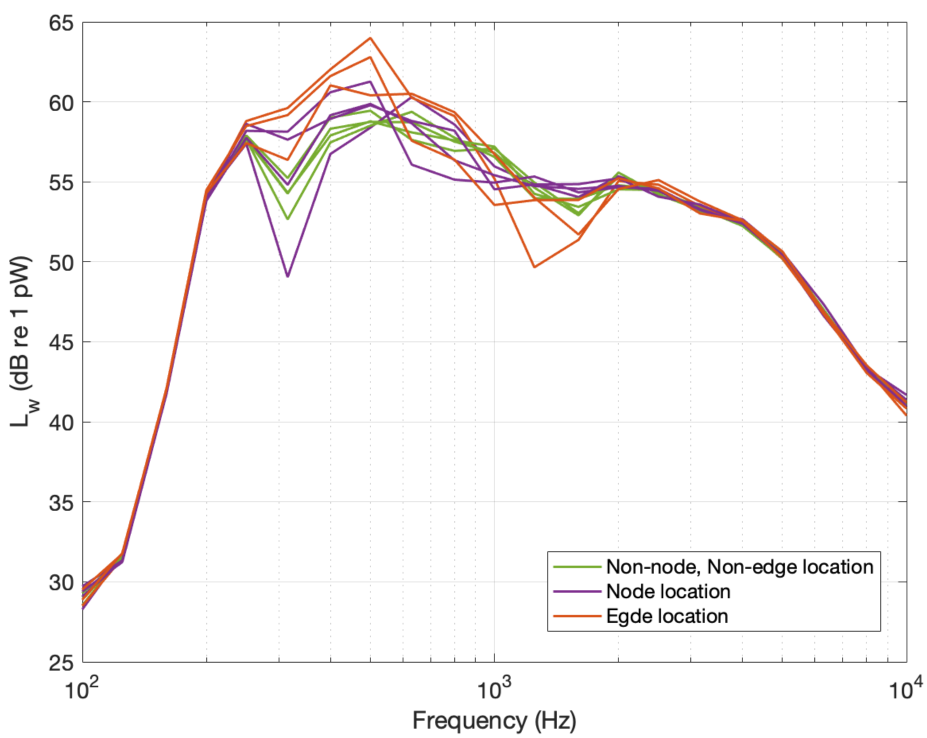


***Figure 4: Sound power measurements from the Bluetooth speaker while enclosed.***

One such example of a larger acoustic source is the circular saw that measures 0.18 m by 0.21 m. This means it cannot fit its entire structure between the first and second harmonic nodal planes. Figure 5 shows the enclosed sound power measurement results of the circular saw across the OTO bands. Like the enclosed speaker measurements, the enclosed saw measurements show a spread in sound power, particularly below 1 kHz. In contrast however, the circular saw results do not exhibit any predictable response based on location type. There are no general trends or distinct groupings that all sound power results of a certain location type follow. Thus, for larger acoustic sources, the enclosed power from that source is less location dependent than for smaller sources.

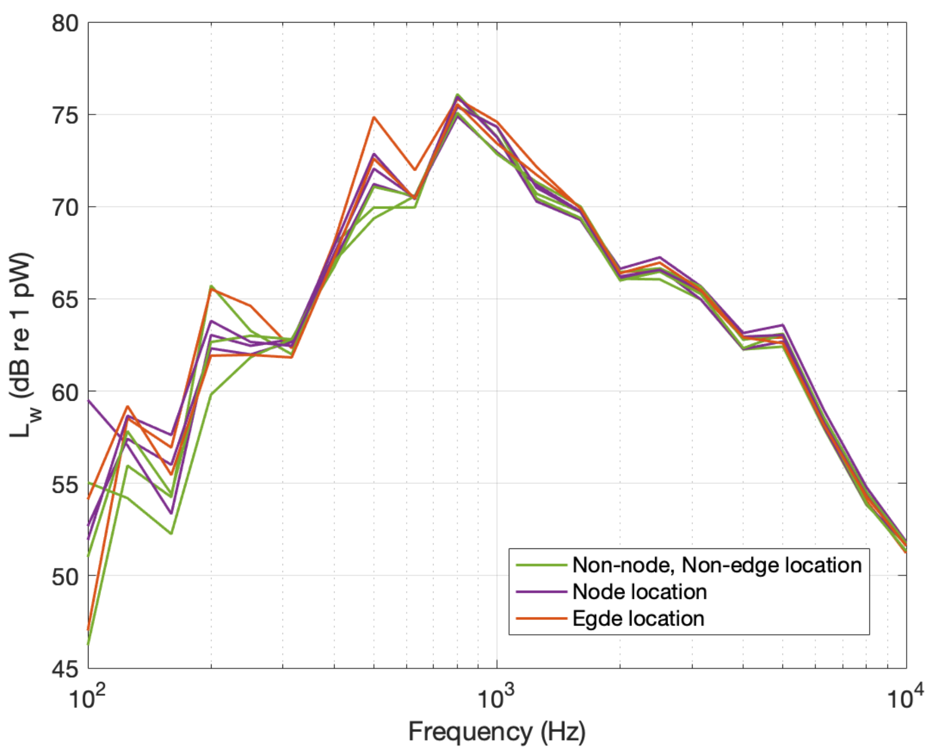


***Figure 5: Sound power measurements of the enclosed circular saw.***

## 3.2 Calibration

Figure 6 shows two calibrations created for the enclosure. One calibration, shown in green, was derived solely from measurements taken at 'non-node non-edge' locations for each average. The other calibration was calculated using all location types. Overall, the two calibrations exhibit remarkable similarity, differing by only 1 dB at 500 Hz. The strong correlation between these two calibrations suggests that any location-dependent variations in the overall calibration become insignificant when multiple source types are averaged together. This is likely attributed to the fact that larger sources tend to exhibit reduced location dependence in enclosed sound power results. This result highlights the considerable flexibility users have in placing the acoustic source within the enclosure while maintaining an accurate calibration.

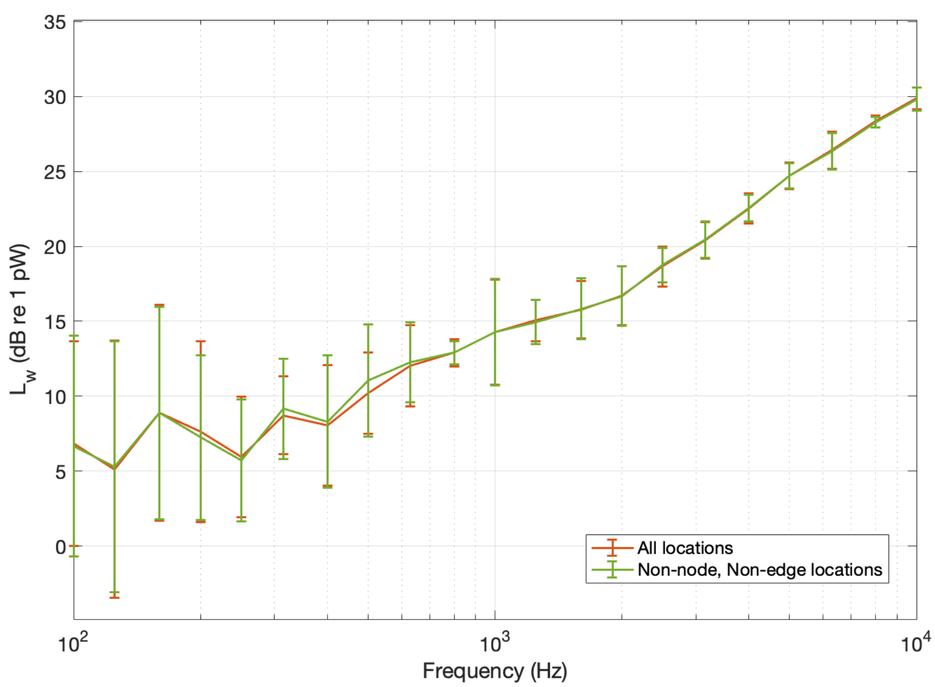


*Figure 6: The two calibration curves created for the enclosure.*

## 3.3 Conclusion

A total of seven nominally constant volume velocity noise sources were used to calibrate an I-VBSP enclosure. Through the process of relocating each acoustic source to 11 different positions and comparing the enclosed sound power across position types, it became evident that smaller acoustic sources demonstrate a higher degree of location dependence compared to larger ones. To address this, an overall calibration was developed by averaging calibrations from each source type. When each of the source calibrations were averaged together, the final calibration showed minimal dependence on source location relative to nodal planes or edges. As a result, users of this enclosure can confidently place a source in various locations without compromising the calibration's accuracy.

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