

Speaker Enclosure Design Tool

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ABSTRACT

To date, there is no tool specifically built to design loudspeaker enclosures. The described application would allow a user to design any box shaped enclosure to fit their needs. This tool would also have the functionality of calculating the best enclosure volumes for any given speaker. This tool would be useful for acoustic engineers and audiophiles alike by allowing users of any skill level to build high quality, high output enclosures.

INTRODUCTION

In this report, there are some terms that hold multiple meanings, so they're definitions are outlined in the following paragraph for clarity.

A speaker in this context is short for a loudspeaker which describes a device that takes electrical signals and converts them into sound waves. Sound waves are defined by their frequency and their amplitude. The frequency of a wave is the tone the wave produces. The amplitude of a sound will be explained by a resonance frequency which means the tone or frequency in which the sound is loudest. This is not to be confused with the term volume, which is used to explain an amount of space, or more specifically, to describe the internal volume of an enclosure. An enclosure is a box on which a speaker is mounted. This project is focused on the design of these enclosures.

PROBLEM STATEMENT

Designing a speaker enclosure requires some design preferences that are unique to its application. There are three types of enclosures shown in Figure 1 that are commonly designed: sealed, ported, and bandpass [1].

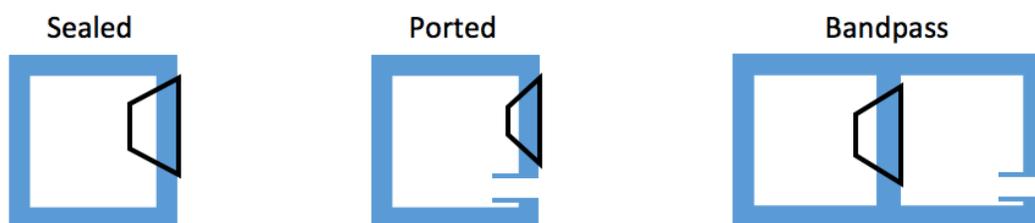


Figure 1: Commonly used enclosure types

Each one performs better at a specific range of frequencies based on the speaker, and each one has a different preferred volume for that speaker [2]. With ported and bandpass enclosures, there are many variables including port size and depth. A ported enclosure is one where air can flow

freely in and out of the box while bandpass enclosures have part of the box ported and the rest of the enclosure is sealed where the speaker is between the two. Bandpass enclosures have two preferred volumes while the other two have only one preferred volume. More design preferences include the frequency at which the enclosure will perform best and how aggressive or damped the tuning should be. All of these variables are dependent upon the speaker's properties. Furthermore, an enclosure can have multiples of the same speaker.

Audio engineers use one of two different approaches for these designs: the enclosure is built to fit an existing set of speakers, or the enclosure needs to be built using any speaker while keeping material costs to a minimum. Acoustic engineers currently contact the manufacturer of the speaker to look up its recommended enclosure size preferences for the number of speakers used [1]. Using these numbers, the engineers can begin a mock up for the enclosure. For bandpass and ported applications, a port must be designed or a "bolt on" port must be purchased. In the event that a recommended volume or port size is not provided by the manufacturer, the engineer must estimate the numbers based on similar applications, or the trend from other products.

To date, there is no tool that an audio engineer can use to calculate these numbers. The proposed tool would save these people hours if these numbers could be obtained without looking up products and contacting manufacturers. Not only would this tool provide designers and audiophiles with calculation possibilities, but would also make it simpler than ever to visualize and design the perfect enclosure.

REQUIREMENTS & SPECIFICATIONS

The sponsor uses laptops that are currently running Windows 10, so this tool must be an application that runs on this operating system or the latest Windows OS. This windows

application must be able to take speaker specifications and calculate the recommended enclosure volume and/or port volume from them. It also must have the ability to render a speaker enclosure of the user's choice by selecting the type, speaker size, and all of the dimensions. Once rendered, the user should be able to adjust any of the measurements to fit their needs. There must be a way to take a calculation and render an optimal enclosure from the entered speaker parameters. Finally, a finished enclosure design should include all measurements needed to start building, as well as the design preferences entered. This would allow the user to make their own recommended volume calculations without researching or contacting the speaker manufacturer, which would allow anyone to design their own enclosure.

This tool was projected to function similarly to any file driven application such as Microsoft Word or Adobe AutoCAD, because each one has a toolbar and is designed for ease of use. Upon opening one of these applications, the user is allowed to either open a previous project or create a new one from scratch. When modifying the selected or created file, the user is open to a wide variety of modifications to which all are available on the toolbar. The file can then be exported or printed when finished for use outside of the application. To solve the problem stated above, the system must provide the following functionality.

First, the application must allow the user to render an enclosure for a specific size constraint. In other words, a person has a specific place that they wish to install speakers. This space can only fit a box with some maximum size. The user would then design an enclosure to fit the constraints to find the internal volume of that box when the board thickness is applied. The internal volume of the enclosure is the volume of the enclosure minus the volume of the material used to build the enclosure. This would be accomplished by creating a new enclosure file and choosing the enclosure type, enclosure dimensions, and material thickness. Once rendered, the

user could alter any of the inputs to their needs. Any adjustment would change the internal volume of the enclosure which will be adjusted in real time.

Second, the application must allow the user to calculate a recommended enclosure volume based on a specific speaker or set of speakers. This procedure will apply all of the properties of the speaker, such as those in Figure 2, and the tuning frequency to an algorithm that will return the volume at which that speaker will play best at the given frequency. This result is what would allow a speaker enclosure to be optimized for the speaker or speakers in it. This algorithm enables the user to make the most out of their speakers no matter what kind they were or how much they cost.

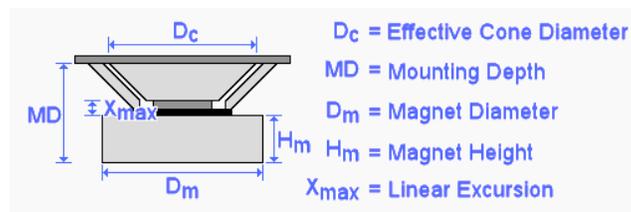


Figure 2: Speaker properties. Graphic courtesy of <https://www.diyaudioandvideo.com/Tutorial/DesignBuildSpeakerBox/>

Third, the application should be able to render an enclosure after calculating a recommended volume. For example, the user should be able to calculate the recommended volume of the enclosure and then take that information to render an enclosure that the user can adjust. Also, the user should be able to render an enclosure to produce an internal volume with which the user can find a speaker or speakers. This means that the algorithm used in finding an enclosure volume should be reversible. Doing so would allow the application to be useful to users at any point in the designing process.

Fourth, the parameters entered should be monitored and recorded into a database where a history of projects could be searched. For example, upon entering all of the properties of a speaker, the user can then come back later and search the database for that speaker. The user

would then have the ability to browse and select the speakers from the database as inputs to the system.

Fifth, the user should be able to save their progress on their current project. This would create a simple file that contained the details of what the user has designed up to the current point. This file should be able to recreate the project as the user left it including the enclosure render, if available, and all parameters that have been entered. This file could be saved into the database or into the filesystem. The file would contain all information necessary to recreate the environment of the system. Once loaded, the environment could be applied to render the enclosure and place all values in their appropriate places.

Finally, for use in a workshop, the user should be able to print off their blueprints or export the file as a pdf document. This would give the user the ability to share the finished project as a document or to write on the paper during the building process of the enclosure. This document would include the speaker make and model information to which the enclosure is tuned and the enclosure dimensions as they appeared in the render. The builder could then decide how exactly to cut the material to produce the design shown on the document.

DESIGN APPROACH

As shown in Figure 3, there are two ways to which a user can produce a design. One way is to take a speaker, calculate the enclosure information, and render the blueprints for that enclosure. The other way is to enter the enclosure design preferences, select the size constraints, and render an enclosure for a speaker of the selected size. With this basis, my design has two user interfaces for each approach above.

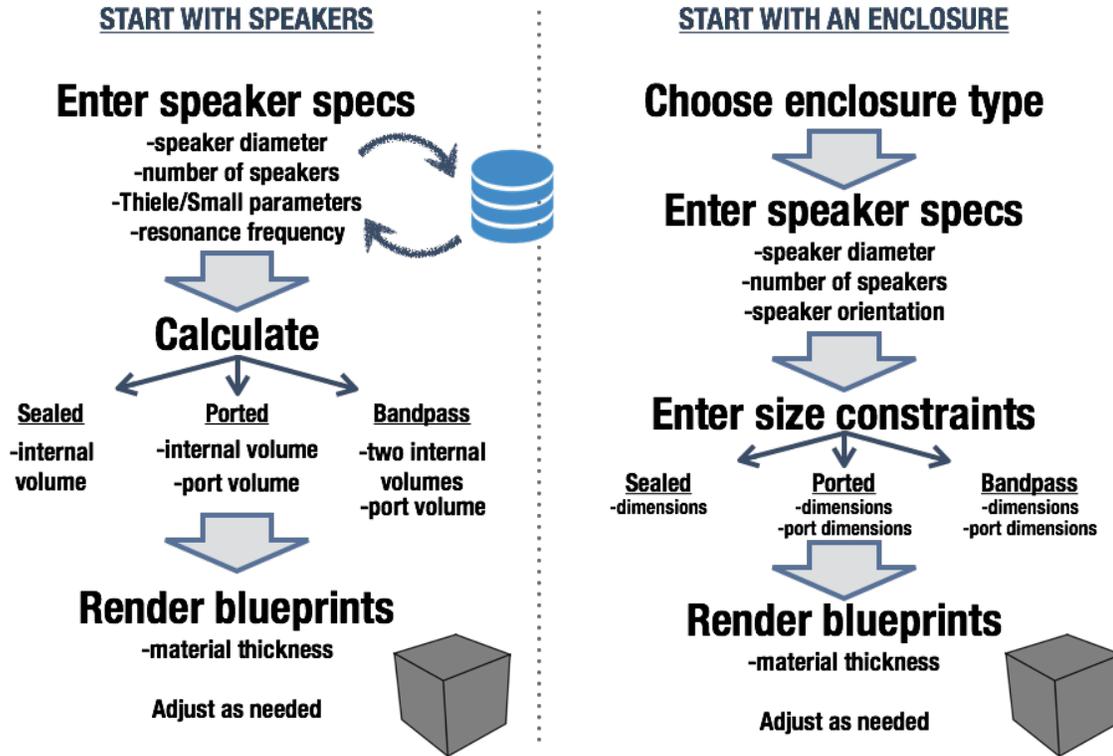


Figure 3: Application workflow

In order to maximize maintainability, this tool was written in C# using the .NET framework. This framework is used in many business environments worldwide which gives future developers a very large community in which to solve problems that may occur. Also, the C# language over this framework allows the software to be supported by Windows driven hardware which gives this project the ability to remain functional over time as long as the support continues. I also used PdfSharp, which is an extension to .NET framework, to provide plenty of support for graphic representation which was useful for rendering the enclosure on a printable pdf document.

Implementation occurred in the order of most useful first. Doing so allowed progress to be clear to the sponsor and to the project advisor. This progress was posted in a Git repository and on the senior project website log for others to monitor. The order of implementation was as follows:

1. Calculated and optimized recommended volume from speaker specifications
2. Calculated internal volume(s) of an enclosure from dimensions
3. Calculated dimensions of an enclosure from speaker size and enclosure volume
4. Generated pdf document of enclosure dimensions for printing or saving
5. Allow save and load capabilities
6. (Optional) Provide support for multiple speaker enclosures

The first step (1) required a custom set of algorithms to find certain properties of an enclosure that would optimize sound quality using properties of the speakers and some tuning preferences. There was to be a different algorithm for each of the three enclosure types, since each one was to have different outputs. Each algorithm needed to know some of the Thiele/Small parameters of the speaker used [3]. Using these parameters, a number was produced that represented the displacement of air in which the speaker pushed/pulled when driven. This displacement is what determines the resonance frequency of the speaker itself without an enclosure. The sealed enclosure algorithm takes frequency as well as the Compliance Ratio(α) as inputs to find a Box Volume (V_b). V_b is the optimal size of the air space to which the enclosure will perform at maximum efficiency in a perfect environment [3]. Obviously the environment in which the speakers will be playing in is far from perfect, so the enclosure can deviate from this volume a little without affecting the output significantly. With ported enclosures, there would also be a function to which the same parameters can be used to find the volume of the port. This volume allows the user to make the port any size or shape as long as the volume doesn't deviate significantly from its recommended volume. Furthermore, the Bandpass enclosure was to provide two internal volumes (one for the ported side and one for the sealed side). Since one side has a port, the optimal volume will be different since there is a lower resonance frequency of the enclosure. The benchmark to use as optimization was the manufacturer's recommended volume for their own speaker. Once computed, the user would be able to recalculate or adjust the parameters accordingly.

After choosing the enclosure type and the dimensions, the calculated internal volume should be calculated for the user to view (2). This functionality will simply let the user manage what the finished enclosure size would be before making any cuts or buying any material. The resulting volume would give the user a comparison to a manufacturer's volume or to this system's resulting volume. As an optional specification, a blueprint of the enclosure could be rendered as well for viewing purposes. The user should also have the ability to adjust any dimensions as shown in Figure 4, in which the internal volume would be recalculated.

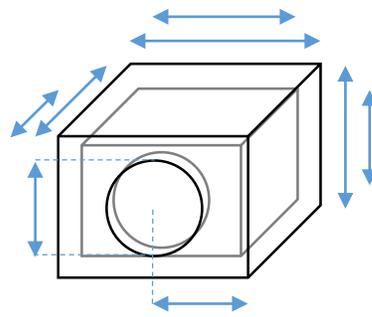


Figure 4: Enclosure adjustability

Next, the user should have the ability to generate dimensions of an example enclosure based on the previously calculated internal volume(s) (3). This would allow the user to transition from the first functionality to the second with ease. Basically a user should be able to generate a pdf design by entering a few inputs and clicking only a couple buttons. For example, after calculating the results of each enclosure type for a speaker, the user should have the option to push a button to carry the outputs of the calculation to the inputs of a render and display a blueprint of the optimal enclosure. Doing so would make this tool useful for a builder at any step of the design process.

Providing a pdf of the blueprint (4) would convert the list of dimensions into a rendered enclosure document for saving and/or printing. Pdf support is handled in the PdfSharp library

and therefore would use the system standard save and print programs to produce documents similar to Figure 5.

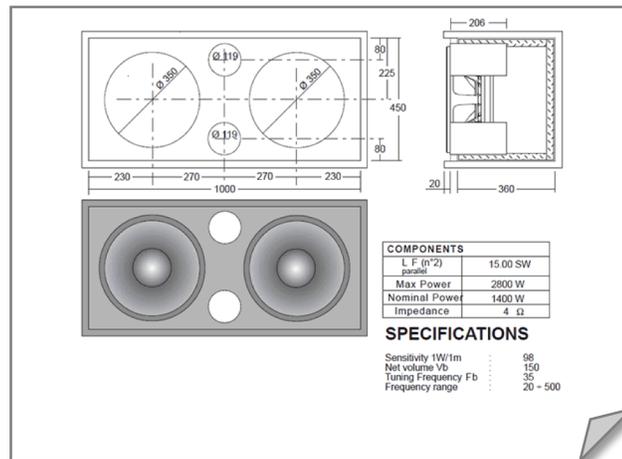


Figure 5: Pdf example blueprint. Graphic courtesy of <http://www.lean-business.co.uk/speakerplans/>

Tracking the history of a user's projects (5) would be an overlaying functionality of the system, primarily the calculation function. Upon calculating the optimizations of a speaker, the parameters can be entered into a database as records for future use. These records could then be pulled from a search of the database to make designing quicker. This would help the user design multiple enclosures for a commonly used speaker. Also, these records could be pulled to prevent recalculating the same results if the same inputs are found in the history.

Designing enclosures with more than one speaker (6) would add a level of complexity to every functionality implemented up to this point. As an optional specification, this would allow the user to create designs that have speakers mounted on more than one side of the enclosure, as well as add another dimension to the recommended volume calculation. While this functionality would have been very useful to my sponsor, this was pushed to the end of the project in the interest of time.

RESULTS

After implementation, this project turned out to be useful for audiophiles who are interested in creating custom sized enclosures for one speaker. While the algorithm proved to be correct, this project provides an excellent base for a highly complex design program that's geared towards users with limited acoustic knowledge.

The internal volume algorithms were proposed to have many inputs and single solutions that can be considered "optimal". Further research showed that the difficulty with this calculation was that there are many "optimal" solutions depending on the preference of sound. Simply stated, an enclosure is tuned for a specific type of response, which resulted in a more complex optimization algorithm than that which was proposed. Furthermore, very little research has been done for bandpass enclosures in general and so was left out of the project in the interest of time. With all this being said, the algorithms written for ported and sealed enclosures were within the range of provided internal volumes by the manufacturer for ten randomly selected speakers.

The project did meet the second specification by providing an internal volume for enclosure dimension inputs. This portion of the project did result in being more complicated than proposed simply due to unit conversions. The calculations were made using cubic centimeters, so this ended up being the base unit that the system used. All other units used were converted from this on every view.

The third specification was similar to the second in that the only difficulty came with unit conversion. The system will add two inches to the diameter of the speaker and use this as the height and width of one side of the enclosure because the enclosure needs to have enough space on one side to house the speaker. A depth is then reverse calculated from the recommended

volume to find the depth of the enclosure. Taking into account the material thickness, an example enclosure is resulted and ready for rendering.

After reading about creation of pdf documents, I arrived at a commonly used library called PdfSharp which did exactly what I needed it to do. I was able to create a document, draw shapes and text to represent the enclosure design, and save or print it using standard windows processes. The only issue with this functionality was the lack of time available to make something interesting and dynamic on the pdf. By the end of this project the resulting document did provide the user with useful relevant information about their design, but was certainly not visually appealing. With more time and a more experienced graphic designer, this feature could look incredible.

The last requirement considering the saving and loading of progress ended with the sponsor ruling it unnecessary. With the algorithms only requiring roughly four inputs and only one output, there was no need to spend time on a relatively useless feature such as saving a few numbers. Although, with the expandability of this project, this requirement could be useful when the designs and algorithms become more complex. The simplicity of this system arrived at rectangular enclosures with only three numbers characterizing them. In a system with complex shapes that require many characterization values, saving and loading would become far more useful.

Finally, the optional multiple speaker support feature was simply impossible with the research at hand. This feature would have required calculations that couldn't prove to be truly optimal based on the lack of research. With more resources and time, this could be considered the most useful part of any enclosure optimization tool in the future. This calculation is not provided by most manufacturers and so would be the only source of this information available.

CONCLUSION

This tool, as is, is not entirely useful in the professional world. My sponsor and others in the enclosure designing business could retrieve the information I have made available by a simple phone call, email, or Google search. Although, this tool is a base to which others could build upon in order to create a cutting edge application that redefines how enclosures are built in the future. This project also has the potential to allow anyone with general speaker knowledge to design and build without paying for professional help.

This tool would give anyone from an acoustic engineer to an everyday enthusiast the ability to build optimal, high quality speaker enclosures. In the hands of a custom enclosure builder, countless hours of work could be saved by making the calculations through this tool as opposed to contacting manufacturers and flipping through user manuals.

REFERENCES

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BIOGRAPHY

After graduation I will be pursuing two different careers, one of which I am currently involved with. I am co-owner and lead software designer of Heliponix LLC. This company has the aim to redefine agriculture by moving it indoors to small everyday appliances. This company was founded at Purdue and has since moved to Washington, Indiana until further progress is made.

My second career will begin immediately after graduation where I will start as a Business Analyst intern at Metronet here in Evansville, Indiana. This position is temporary over the summer but will conclude with a full time offer in the department of my choosing. I plan to live in the area but am open to the idea of living anywhere on earth. I love doing most things and hope to continue trying new things for as long as possible.

This university has provided me with unimaginable experiences, whether they were from professors, fellow students, or even passers by who needed help. I have grown more here in the last four years than I probably ever will. I couldn't be more thankful.