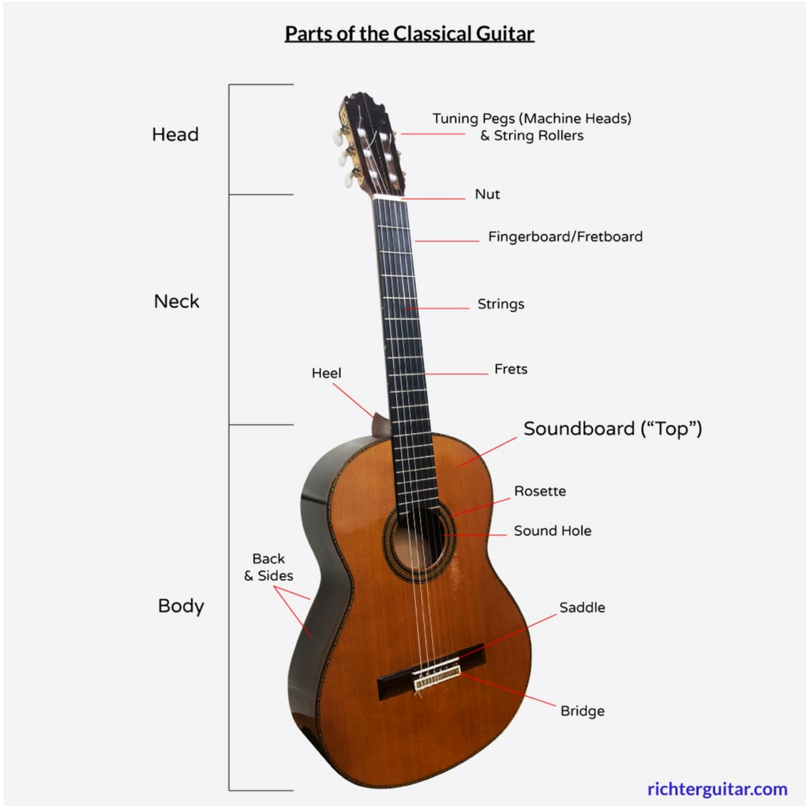
Preface

This document reflects the research done by the team of students – consisting of Iris Nycz, Anzhe “Angela” Tao, Lyra Layne, and Nandita Kumar – who worked on the Soundports collaborative project in summer 2023. It is intended to provide context for terms, topics, and concepts we determined would be valuable to the further development of this project, so that future groups may use this document as a resource in their own work. Our experience with this project involved spending a lot of time conducting background research and literature review; it is our desire that future groups will have this information readily available in order to be able to quickly progress and expand experimental research on the topic. In an attempt to facilitate this, we, in this document, walk through the history and background of soundports, summarize adjacent research, and provide recommendations for going about future work.

A Note on Soundports and Sound Holes

Although it is common for the hole located in the soundboard of the guitar to be referred to as a “sound hole” and an auxiliary hole on the side of the guitar to be referred to as a “soundport,” within this paper, any hole in the body of the guitar will be referred to as a “soundport” and will be presumed to be located in the top of the guitar unless stated otherwise. This semantic difference is in the interest of allowing more dynamic usage of the term as a reference to a function as opposed to a specific feature.



Parts of the Classical Guitar - Diagram by [Jonathan Richter]

Guitar History and Mechanics

While the origin of the guitar is unclear, written references to the instrument date back to the Renaissance. Since the 14th century, many aspects of the guitar have been developed and refined – including standards of size, shape, and bracing – but one feature that seems to have remained unchanged is its soundport (Wheeldon; Pittaway). The industry standard circular-and-central soundport is acknowledged by guitar maker Christian Stoll as, at least "from a purely static point of view," structurally suboptimal. Stoll asserts that off-center soundports require less bracing and increase the vibrating surface of the guitar (Stoll). This surface – the top of the guitar, also known as the soundboard – is what produces most of the sound when the instrument is played, as guitar hobbyist Dan Sissors explains. While it seems more intuitive that a guitar's soundport would be the source of sound, the soundport actually serves to moderate the air movement within the guitar. The way the air within its body moves "can either deaden or reinforce the vibrations of the top" of a guitar (Sissors). Soundport size, shape, and placement can thus have a considerable effect on sound, but most of the innovation in this area is informal – done by hobbyists luthiers "experiment[ing] more by instinct and trial and error than by physics" (Sissors). The science of guitar soundports is a field just waiting for formal study.

Variations on Guitar Soundports

Changing the size, shape, and position of guitar soundports has been shown to have consistent effects on the sound a guitar makes (NBN Guitar). Smaller soundports tend to project more bass in the sound of the guitar while larger soundports project more treble and provide a more open tone (Stoll). Guitars traditionally have circular soundports, but the ports can sometimes be oval or D-shaped to create a subjectively different sound, an example of which is the design of a Manouche guitar. Soundports are rarely designed with angles since they can potentially create unpleasant sonic artifacts (Stoll).

Soundports are usually positioned on the soundboard at ¼ of the scale length of the guitar. Moving the soundport vertically along the soundboard has been said to influence the tone color of the guitar; moving the soundport horizontally, however, can have consequences on the ability of the guitar to project sound in different registers (Stoll).

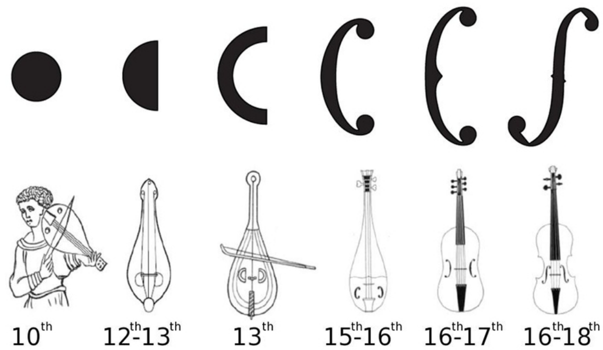
Less is known about the effects of placing a soundport on the side of a guitar. These can be implemented instead of or in addition to a soundport on the soundboard. While these soundports are often just one hole on the side of the guitar, they can also be implemented as a set of smaller holes. Side soundports are most commonly used to help the player monitor the sound of the guitar since they are not very effective at projecting sound to an audience. However, little is known about their direct effect on the sound produced by the guitar. Side soundports can project a different range of overtones that the player would not hear through only a top soundport (Werner).

Many luthiers design guitar side soundports with magnetic covers which allow the player to fully or partially cover the soundport if they so choose. Guitars with more soundport area are often louder than guitars with less soundport area since they are able to project more air and cause fewer sound waves to cancel each other, so toggleable soundports allow the guitarist some control over the volume of the instrument.

Research on Other Soundports

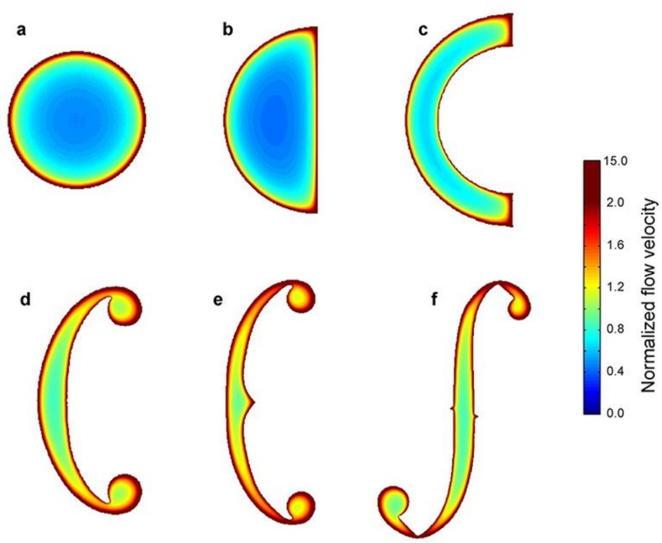
Violins

While mainstream soundport design innovation in guitars is seemingly underdeveloped, this is not the case for all instruments. Violin soundports, for example, have evolved greatly throughout the instrument’s history, as shown below.



(Image courtesy of MIT News)

A recent study at MIT, as reported on by Jennifer Chu, demonstrated that more elongated soundports a violin allows the instrument to produce more sound while taking up less space on its body. Modeling air flow through different shapes of soundports showed that air flowed fastest at the edges of the port, while “its interior, whether open or partially filled, did not significantly affect the airflow” (Chu). Based on this, the development of the “f-holes” seen in modern violins makes sense; better space-efficiency while maximizing the peripheral edges of the soundports resulted in a more acoustic power-efficient design.



(Image courtesy of MIT News)

However, it is important to note that optimal soundport design for a violin does not fully carry over as optimal for guitars. This is exemplified by the fact that f-hole guitars do exist, but are said to have a “mellow[er], softer and twangy sound” that makes them more popular in jazz or blues settings (Fraser).

Speaker Boxes

Origins of Soundport

The concept of the soundport in speaker boxes can be traced back to the early 20th century. The primary purpose of introducing a port into a speaker box was to enhance the bass response. By allowing air to move in and out of the enclosure, the port could reinforce certain low-frequency sounds, making them more pronounced. At that time, speaker boxes were often simple, sealed enclosures that housed speakers without much consideration for optimizing sound propagation (Knudsen).

Thiele & Small's Contribution

The 1960s and 1970s saw a significant leap in the understanding of speaker box design, largely due to the work of Helmut Thiele and Richard Small. Their research provided a mathematical framework for understanding the relationship between the speaker, the enclosure, and the port. This led to the Thiele/Small parameters, which are still used today to optimize speaker design (Thiele).

Design Innovations

Over the years, the design of soundports has evolved from simple cylindrical tubes to more complex shapes. Flared ports, for instance, reduce air turbulence at the port's entrance and exit, leading to reduced port noise and a cleaner bass response.

Another innovation was the introduction of adjustable ports. These allow the listener to modify the port's length or diameter, thereby tuning the bass response to their liking or to the room's acoustics.

Materials & Placement

The materials used for soundports have also evolved. While early ports were often made of simple cardboard tubes, modern ports can be made from a variety of materials, including plastic, metal, and even high-density foam. The choice of material can influence the sound's coloration and the port's durability.

Placement of the port has been another area of experimentation. While many traditional designs feature front-facing ports, some modern designs have rear or even downward-facing ports. The placement can affect how the bass interacts with the room and can be chosen based on aesthetic or acoustic reasons.

Recent Evolution

In recent years, the integration of computational modeling and simulation techniques has revolutionized the design process for speaker box soundports. Engineers can now create virtual prototypes of speakers and experiment with various port configurations in a virtual environment before manufacturing physical prototypes. This approach saves time, resources, and allows for rapid iterations, ultimately leading to more refined designs and better-performing speakers.

Sound Pressure

One common thread seen in the investigation of optimal soundports in both violins and speaker boxes – and thus a topic worth looking into in regard to that of guitars – is the movement of air within the object and how a soundport might modulate that. This concept can be more broadly explored as sound pressure.

Sound pressure refers to the variation in air pressure caused by sound waves as they travel through a medium. It is measured in units of pascals (Pa) and quantifies the intensity or strength of a sound wave. Sound pressure level (SPL) is often used to express the logarithmic scale of sound intensity relative to a reference level, usually in decibels (dB).

Inside the bodies of musical instruments, sound pressure plays a crucial role in producing and amplifying sound. When a musical instrument is played, vibrations create variations in air pressure within the instrument's cavity. These pressure variations interact with the instrument's shape, material, and internal structures, leading to the characteristic tone and timbre of the instrument.

Soundports are designed openings in the body of an instrument, strategically placed to influence the sound pressure and acoustic properties. Soundports can have a significant impact on an instrument's sound characteristics. By allowing a controlled release of air pressure, soundports can modify the resonance patterns, harmonics, and overall projection of the instrument's sound. When positioned properly, soundports can enhance the instrument's responsiveness and tonal balance, enriching the playing experience for the musician and the listener.

Avenues for Future Work

1. Developing parallel simulations to compare the effects of different types of soundports on guitars (traditional, f-hole, offset, no soundport, etc.)
    - Aspects that could be investigated (not an exhaustive list):
        - Variations in sound pressure
        - Relationship between guitar size/internal volume and soundport size
        - Acoustic power
    - Contact Dr. Adriana Hera (ahera@wpi.edu) in the Academic and Research Computing Department for guidance using COMSOL as a modeling and simulation software. Note: To best make use of this time, brainstorm specific objectives you'd like to accomplish beforehand to discuss with her.
    - Make use of scanned Fusion360 guitar models on fretology.org for simulations
        - Traditional soundports: Gibson LG-3, Gibson L3, Gibson Southern Jumbo, Martin000
        - F-hole soundports: Gibson Blue, Scharpach Blue
        - Unconventional soundports: Parker Pearwood, Benedetto Blue

            - Resource for Fusion360: [Fusion 360 for Guitar Crash Course]
                - Using Fretology models as a starting point and developing more uniform guitar models where the soundport is the main – if not only – difference may minimize other variances that may affect sound

    - Dr. Dan Russell, professor of acoustics at Penn State University, has simulated modal analysis done on a Gibson Hummingbird. His results can potentially be compared to simulations developed for the Soundports project in order to verify their integrity, especially if they utilize a guitar model similar to the Hummingbird (such as the Gibson LG-3 from Fretology).

    - In our research, we found references to software used to model speaker cabinets that can “calculate the precise port dimensions required for optimum performance” (Buddingh). Gaining access to similar software could prove useful in investigating the soundport specifications necessary for optimum guitar performance.

2. Physical experimentation with variation in soundport location
    - Previous groups have investigated how soundport size affects guitar sound output, simulated using tape to cover the soundport of a ¾ size guitar, but soundport location has not been investigated
    - Playing, or at least listening to, guitars with varied soundports would provide future teams with invaluable experience regarding the subject of this project and investigation, regardless of viable data collection, rigorous experimentation, etc.

3. Develop the frameworks for an interactive interface for determining optimal soundport dimensions and location, given instrument specifics
    - While developing a usable platform is important, we’d like to stress the need for substantial research and experimentation into this topic before any tool can be useful.

Resources & References

Resources

Soundports

- The Sound Hole and its Influence on the Sound
    - Briefly explains the function of the soundport, as well as its relationship to the internal reinforcement structure in the guitar body.
    - Article discusses how soundports differ between various types of guitars; qualitative descriptions of differences in guitar structure and sound profile are given.
- Guitar Side Sound Ports
    - A luthier's guide to constructing a guitar to accommodate a side soundport.
- Modern Classical Guitar Design: Soundports
    - A short article presenting some benefits to having a secondary soundport on the side of the guitar.
- Power efficiency in the violin (MIT)
    - News article reporting on a study from MIT that examines the history of soundport design in violins from the 10th-18th centuries.
    - The study focuses on the effects that differences in soundport shape have on the flow velocity of air through the soundport.
- Fretology
    - Acoustic guitar research, preservation, and education project.

Dan Russell

- How the sound gets out – Sound holes and ports | danlovesguitars.com
    - Examples of various types of soundports as well as guitars they appear in.
- Dan Russell's Acoustics and Vibration Animations (psu.edu)
    - Large collection of animations illustrating acoustics and vibration, waves and oscillation concepts.
    - Modal Analysis of an Acoustic Folk Guitar

- Visualizations of how a guitar body resonates, and how the air at the soundport moves at different frequencies.

Speaker boxes

- Loudspeaker Enclosure Design Guidelines
- Improved Speaker Cabinet Design Using Test/Analysis Correlation

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