

Title: Sirenology, or the Aesthetics of Acoustic Synthesis

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1. INTRODUCTION

In my ongoing project, which I call Sirenology, I have created a conceptual backdrop to talk about making sirens in a contemporary sound art context. As someone with a background in physics, my curiosity for the siren as a source of sound, and more specifically how it generates sound, is the catalyst. Previously, I have described Sirenology as the method of using sirens to study how instruments store knowledge about music at large (Linder Miñambres, 2025). Here, I argue that this body of knowledge about sirens is stored in the corpus of siren disks that I have designed myself and with a wider community of musicians who have participated in my workshops and ensemble performances with sirens.

The sirens I have built have a musical purpose. However, they have a rich history rooted in science and warfare, seemingly oblivious to sound as an aesthetic practice. Sirens were used as scientific instruments in acoustic labs of the 19th century and then went on to become the mechanism for sonic warnings about impending danger. Even so, sirens as scientific instruments and warning devices can still be analyzed in the framework of Sirenology when artists deploy them as musical instruments.

Reflecting on the experiences gained in my research on sirens, I aim to describe specific instances of siren lutherie, composition and performance that have been significant in identifying new avenues of exploration and making forward progress in siren epistemology. Following these examples, I wish to draw a distinction between particular instances of siren designs and broader analytical frameworks by which to make sense of the knowledge that sirens store about sound and music.

The essence of scientific inquiry is to move from specific observations toward broader, all-encompassing laws and theories that explain natural phenomena beyond a specific time and place. Conversely, the artistic output of Sirenology is not concerned with finding universal ways of explaining the particular, but rather with exploring the aesthetic qualities of sound in an experiential way, actively acknowledging the dialectical relationship that art shares with science, especially in music and sound creation, which is a physical phenomenon. This text is meant as an artistic statement on how I navigate the duality between the scientific and generalizable versus the specific and aesthetic qualities of sound in my practice. The siren is an artifact that embodies this tension between science and art, and the distinct ways practitioners of each discipline engage with sound—it is an instrument (in the most general sense of the word) via which I can articulate how I relate to either one. I have

written this article to be a glimpse into my artistic practice rather than a tutorial, and I invite the reader to listen and stay curious about what a siren can sound like.

2. A 19TH CENTURY TECHNOLOGY FOR A CONTEMPORARY SOUND ART PRACTICE

The siren was invented by Charles Caignard de la Tour in 1819. It is a sonic apparatus that can function in both air and water, which is the reason why it is called *sirène*, meaning mermaid (Rehding, 2014). Sirens generate sound waves by periodically obstructing a flow of compressed air. My siren instruments, as well as De la Tour's invention, rely on rotating disks to perform these obstructions. Siren disks have perforations that create compressions and rarefactions, as air passes through the holes on the disk or it is blocked from passing. Sirens, however, are not constrained to this configuration, as there are also sirens that periodically obstruct a flow of air by means of a turbine and a stator—like air raid sirens. When these compressions occur at audio rate, the resulting waveform is audible to the human ear. The siren then went on to become an instrument in physics labs of the 19th century, mainly used to study perceptual qualities of sound, like pitch, interference or combination tones.

There are several reasons why I find the siren an extraordinary artifact to interact with sound. First, it is an instrument that is acoustic but does not generate sound by vibrating parts of its material body, unlike resonators, strings, tubes, or membranes (Jackson, 2011). They synthesize sound from just air, which was a controversial observation at the time of its invention, when acoustic waves were described as emanating from vibrating objects as physical phenomena (Rehding, 2014). This idea that a series of compressions, with the air either "on" or "off", follows very much a binary, or even proto-digital, idea of sound much ahead of its time (Rehding, 2016). Just as persistence of vision retains an image in the brain long enough to blend static frames into continuous motion, the siren illustrates a key psychoacoustic principle: we perceive sound as a continuous stimulus even when the instrument generates physically discrete pulses of air. The siren also confirms that our perception of sound has limits—although pitch and rhythm are perceptually distinct, they exist on a physical continuum (Rehding, 2014). Once air pulses reach 20 Hz, they are perceived as pitch. Because of these relationships between the siren and the perception of sound, the disks serve as a blank slate for studying and experiencing sound: they function as acoustic synthesizers.

Instruments present themselves to users as "black boxes" when they opaquely process an input into an output, without revealing their internal workings (Hertz & Parikka, 2012). I would argue that sirens possess an obscure quality that makes them appear magical to those experiencing them for the first time. It is this very mystery that drew me to research them further. When experiencing sirens as musical instruments, there is an initial disconcertment regarding how they produce sound—the way a designer's or player's actions translate into audio is unclear to the observer. Perhaps they can be described as epistemic black boxes.

My art's purpose, therefore, is to ask questions and unveil ideas about sound and physics that are part of our collective understanding—uncovering the knowledge behind the sounds a siren can make. This endeavor is not new, as I described above how sirens have been an instrument essential to understanding the psychoacoustic experience of sound. The epistemic role the siren holds historically calls into question the idea that history progresses linearly, suggesting instead that it is recursive (Armitage, 2006).

3. SIRENOLOGY AND ACOUSTIC SYNTHESIS

The Sirenology project was initially conceived as a workshop and has since taken different forms, including solo performances and also the formation of an ensemble, which I will talk about in later sections. My goal for the workshops was to teach participants how to create siren disks and then to analyze their designs and uncover the musical knowledge reflected within them. I am interested in the affordances of sirens, i.e. how the instrument presents itself as a unique set of possibilities for each person to interact with. My research into how the siren stores knowledge stems from a deeply personal and specific place of interest in this instrument's potentialities.

I divide the craft of building sirens into two parts—the infrastructure of the siren instrument, then the design of the disks. The infrastructure includes all mechanical parts necessary to set the disk in rotation and pump air through it. In my case, I repurpose fans and build adapters for the motors to spin cardboard disks. I 3D print nozzles for the tubes carrying compressed air coming from an air pump for aquariums, and use microphones to amplify the sounds of the siren disks. The second part of the lutherie is the designs of the disks themselves. The fabrication method can be rather basic, starting with a sketch on paper for which we use hole punchers and box cutters for the perforations, or it can be more intricate and mathematical, starting with design in a vector graphic software for which we use a laser cutter to create the pattern on the disk.

3.1. Acoustic Synthesis is Open-Ended

The system for acoustic synthesis I used to kick off the Sirenology workshops two years ago has evolved significantly. See the germinal system for Acoustic Synthesis in the image on the right. Initially it was based on my own informed understanding of the siren and it served as a pedagogical tool for workshops, a generalizable idea on how to create sounds from siren disks. This germinal system for Acoustic Synthesis visualizes the pattern on a siren disk ring that is equivalent to a single sound wave cycle. This system accounts for the relationship between hole placement and the frequencies and phase of the synthesized waveforms. The waveform in the Acoustic Synthesis diagram to the right displays the amplitude over one full disk rotation while the graph below the waveform displays the correspondent hole layout. Such a system of Acoustic Synthesis implies an analytical relationship with the sound of the siren, and implies that all designs can stem from it, that waveform and system have an bijective relationship (though it is non-exhaustive). Notably, in my first workshop I instructed the participants to create a siren disk before hearing one themselves. I wanted them to relate to the sound of the siren through an abstract idea about how the patterns on a disk translate to sound (Linder Miñambres, 2025).

What most motivated me to reconsider the Acoustic Synthesis model were the many blind spots in this initial system about how sound is generated by the sirens and also about how they must be played. First, the Acoustic Synthesis model only considers single-cycle waveforms, much like a locked groove vinyl record that simply cycles through a loop, without travelling inward toward the center of rotation of the record. Secondly, it assumes that the player can only play one sound at a time and has no possibility of changing any parameters in the sound in a continuous way. For instance in disks with geometries that extend beyond the symmetry of a single two-dimensional circle, there are qualities of the sound that can be manipulated via playing, via moving the nozzle over the disk to change the components of the frequency spectrum over time, for instance.

Now I have allowed my pedagogical approach to be more sound-forward, prioritizing experience, and embodiment over theory. Through gently observing sirens in action—at workshops, rehearsals—my understanding of Acoustic Synthesis became more malleable. The video above and the case studies in the coming sections collect field notes documenting some of the fringe cases that the initial Acoustic Synthesis system did not account for, including:

1. effects that are attributed to the geometry of a circle,
2. the three-dimensional nature of acoustic sound waves,
3. patterns that extend beyond the geometry of a single ring,
4. the extended possibilities of amplification,
5. shapes of the holes,
6. the shape of the air nozzle.

To explain the first case, let us consider two rings at different distances from the center of rotation with the same number of holes. The fundamental frequency of both these rings will be the same, but their timbre will differ. This is due to a form of pulse width modulation: there is more space between the holes in the more distant ring, which adds upper partials to the frequency spectrum of the sound. To explain the second case, let us imagine a disk with two rings with the same number of holes but opposing phases. In the case of an electronic signal, we would have a phase cancellation, and no sound output. However, the siren produces an acoustic, three-dimensional wave, making this cancellation possible but extremely unlikely. In the third case, when the symmetry of the patterns extend from one dimension (a ring) to two dimensions (the surface of a circle) we can introduce smooth transitions between timbral elements, for example. I have drawn inspiration for disks with such symmetries from optical synthesis, more specifically the work of Jacques Dudon (1999). As for amplification, we can extend the sonic possibilities of the siren with microphones. A significant example would be the usage of two microphones to create a comb filter when moving them across a ring on the siren disk in opposite directions and creating a signal together with a delayed version of itself. To exemplify the remaining cases, see the case studies below in section 4.

3.2. Siren Assemblages

My approach to acoustic synthesis initially mirrored the work of 19th-century acousticians who used sirens to study frequency and phase independently. It sought to replicate their experiments by isolating different variables of the acoustic waves, much like a scientific experiment. These physical phenomena explain how the siren sound is generated, but they do not account for all the sounds a siren disk can make. This complexity is more easily explained to workshop participants via their own experience of these sounds when embodied by the disks, rather than exclusively through abstract ideas of how patterns become sounds.

The corpus of disks I have designed serves as a living archive, storing the collective knowledge generated by myself and my collaborators. Each disk is the result of a serendipitous assemblage—an intersection of setting, space, designer, and available tools (Mooney, 2011). Each siren disc is a unique assemblage of actants that allows for that siren sound to exist. In this sense, I want to say that the siren has "thing-power", it has agency to produce effects and influence human and nonhuman assemblages (Bennett, 2010). In other words the design, and by extension the composition and performance of siren sounds, is the result of the agency the siren has to present itself as a generator of sound to a specific person in a specific time and space. Each disk comes together as the result of the assemblages of composers and their knowledge about music, as well as their tools and the setting.

4. DESIGNING, COMPOSING AND PERFORMING WITH SIRENS

An acoustic synthesis system implies an analytical relationship with the sound of the siren. As I mentioned before, in my first workshop, I did not let the participants hear the sound of a siren disk before attempting to create one themselves, requiring them to relate to the sound exclusively through the abstract ideas in the system for Acoustic Synthesis. However, now I have allowed my pedagogical approach to be more sound-focused, allowing designs to build on one another. This focus infiltrates every stage of the existence of the instrument. I do not think that the task of the siren luthier is separate from composition for, and performance of, siren instruments. A single person tends to embody all roles of designer, composer and performer. Two especially representative case studies can help illustrate the way I think about sirens today as sound art artifacts.

Case Study I: A Sinusoid Siren Disk

I created this set of two sinusoid disks (see above) for a solo performance featuring two amplified siren instruments at Fylkingen in September 2025. A microphone and air nozzle, mounted on opposite sides of the disk, amplified the synthesized waveform. Simultaneously, I played the disks dynamically using another handheld nozzle and microphone.

To explain how I arrive at the disk patterns, I often describe my process as echoing the scientific method, starting with a hypothesis or a question about the possibility of a phenomenon. Most of my previous disk designs used circular holes and a circular nozzle, thus synthesizing waveforms that resemble a square wave. For these disks, I asked the question: "How can I play a sine wave with a siren disk?"

I found that to play a sinusoid-esque sound with a siren disk, you must use a rectangular nozzle for the compressed air and a specific oval-looking shape (Milne, 1921). Having discovered how a siren can play a sine tone, I pivoted to focusing on sound and my subjective experience of the phenomena at hand. At this point in the process, my main concern becomes aesthetics, and I start composing. The outer rings of each of these disks are tuned a minor 3rd apart—a justly tuned minor 3rd, which is the same frequency ratio that we hear in air raid sirens. With this choice, I wanted to double down on the fact that sirens can become musical instruments when recontextualized, even when they use the same sound as air raid sirens.

Case Study II: Ensemble Sirenology

My intention for holding a Sirenology workshop was to explore ideas beyond the ones that reflected my artistic intuition. As a hybrid between these workshops and my solo performances I formed a siren ensemble, which I called Ensemble Sirenology, along with sound artists Ryan Packard and Malte Dahlberg. Inadvertently, this ensemble became a resource of siren specialists—a community that I can consult about siren sounds and performance, and benefit from their different expertise, experience, and sensibilities.

So far Ensemble Sirenology has performed twice, both times designing a bespoke set of siren disks (see a selection of disks above). The nature of the disks was unique both times, reflecting something greater about the project which I have already mentioned: that the design of the siren disks has become more sound-focused over time.

In preparation for our first performance, we designed disks individually. For the second, however, we explored the sound of the corpus of disks that I have been collecting and decided together upon a sound we would want to recreate in our performance. Based on that, we designed new disks that would suit our desires to play in specific ways, as well as the acoustics of the space the performance would take place in.

Our performances for amplified sirens have been grounded in improvisation, albeit with a set of intentions. During these performances I have discovered sounds that the siren can make that I had never heard played before, either by me or the other ensemble members, illustrating once again that design, composition, and performance cannot be separated. Just as the siren has recursively produced different types of knowledge about sound throughout history, my practice of creating sound with the siren is similarly unchronological—past performances inform new designs. This idea is counterintuitive if we understand instruments as static objects with limited possibilities that only the designer had agency over.

The amplified disks sound quite electrical and digital, but there are moments of clarity where the audience understands that we are playing an acoustic instrument that is physical, material, mechanical. During performance, we inevitably touch the disks with the microphone and play a scratching sound; we also brush other items against the disks, finding sounds that are not always inscribed in the patterns on the disks. I think there is a poetry in the fact that the sounds we are playing bring a moment of sonic clarity for those listening.

5. ACOUSTIC, ELECTRONIC, DIGITAL, OR OTHERWISE: THE ORGANOLOGY OF A SIREN

Sirens are seldom described in treatises or textbooks about the physics of musical instruments but rather only in textbooks about acoustics. Fletcher and Rossing (2010) do not cover sirens in their textbook about music acoustics but they are extensively described by Helmholtz in his famous acoustics treatise *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (1895). This exemplifies the fact that sirens are more widely understood as instruments of science rather than music. Notably, though, there is an obscure treatise on how to make music with sirens that dates from the 19th century. In *Allgemeine Theorie der Musik* (1852), Opelt tried to describe how a siren can be used to produce musical tones, and more specifically, polyphonic sounds. This text was largely forgotten and there are no documented musical practices of the time that follow Opelt's line of thinking, but his theory of sirens indeed resembles some ways electroacoustic music is thought of today (Rehding, 2021).

Sirens create an acoustic wave, and can thus be considered acoustic instruments. According to the Hornbostel–Sachs system for the classification of instruments, the siren is a free aerophone (von Hornbostel & Sachs, 1961). This system categorized instruments according to the way the body of the instrument produces sound. However, the means by which a siren produces sound is provocative beyond the fact that it does not have a body that confines the air that produces its sound. The sound it generates is made up of discrete pulses (following a digital logic) and it can be designed thinking about its patterns as waveforms (like we think of electrical waves).

To talk about the ways musical instruments reflect knowledge about music, Thor Magnusson classifies them as acoustic, electric or digital in his description of instruments as epistemic tools (2009). I do not think that Magnusson's classification is meant to be understood as an organological framework, but I have found it useful to talk about the siren. According to Magnusson, instruments fall under these categories depending on how their designers relate to the ways in which they produce sound: through material exploration for acoustic instruments, or through ideas of physics and digital signal processing for electronic and digital instruments. The siren relates to all of these at once, as an instrument that embodies the possibility of all of these ways of thinking. The siren luthier cannot simply explore the material properties to find new sounds because they do not emanate from the vibration of its body. We also need to think about how the patterns on the disk relate to wave mechanics, signal processing and physics.

It is not lost on me that the community I engage with the most is made up of synth enthusiasts who have the sensibility to see that the siren speaks the same language as the electrical waves traveling through their instruments. I would like to position Sirenology beyond the technical understanding of waves, to expand into understanding the instrument within a complex web of connections—territory Aura Satz has already explored in her film *Preemptive Listening* (2024), which questions whether sirens have to be intrinsically alarming.

6. A LUTHIER'S CALL FOR ALTERNATIVE ORGANOLOGIES

My observation is that technoscientific organologies tend to be normative, they tell us what instruments are good candidates to be included in different categories. As luthiers, we can interpret these categories as signposts more than as discreet categories, but siren description begs the question of whether a more porous and open-ended alternative classification is possible. There are descriptive approaches to organology, like that of Tresch & Dolan, who propose we analyze the ethics of an instrument to understand its purpose (2013).

Instruments like the siren represent the possibility of other organologies that are focused on the aesthetics of sound and can be generative in the development and design of instruments. In the same way Magnusson focuses on the role of the luthier for his classification, I argue that there is a need for a non-technoscientific classification of instruments in this same spirit, especially when recognizing that there is no neutrality in sound as understood as a physical phenomena and that knowledge about sound can indeed be situated (Goh, 2017).

If categories by which we classify instruments are fixed and impermeable there are necessarily cases with cracks and fissures in between. I suggest that the solution to this is not to get more granular with categories but rather to switch our perspective on how this classification is performed in the first place. Perhaps there are alternative organologies that can emerge from a more descriptive approach of contemporary music making practices.

There is already a pathway toward alternative organologies proposed by Sarah Davachi that I find particularly alluring (2025). The centre of attention of her work is timbre as a quality of sound that is not only technical but related to affect, and how that can serve as a way of talking about the sound of musical instruments. I would like to propose another avenue that focuses on developing a descriptive organology that is generative for those of us designing instruments. A question to ask ourselves in this quest would be: what purpose do these taxonomies serve us in our practice as luthiers?

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