From:

The SoundScape of Modernity

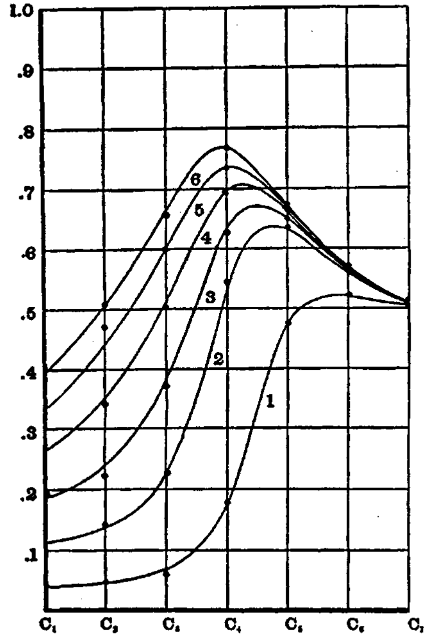
Emily Thompson, 2002

II Sabine After Symphony Hall

Wallace Sabine's initial investigation of reverberation raised as many questions as it answered, and after the opening of Symphony Hall in October 1900, Sabine turned to those questions seeking answers. He first convinced himself of the accuracy and consistency of musical taste through his experiments with the faculty at the New England Conservatory of Music. He then returned to the more physical aspects of architectural acoustics.

In 1904, Sabine began to expand on his earlier study of reverberation by examining the frequency dependence of the sound-absorbing powers of materials. Sabine's earlier work had focused exclusively on the effect of materials upon a sound of frequency C_4, or 512 cps, and he now set out to discover whether or not a given material absorbed sounds of different frequencies to differing degrees. This study followed the same method as his earlier work, supplementing the data collected at 512 cps with data for six other frequencies ranging from 64 to 4,096 cps. Sabine discovered that the absorbing properties of materials varied considerably over this range, and since the variations were not simple functions of frequency, he plotted the result for each material as a curve. (See figure 3.1.)

In the course of this investigation, Sabine utilized the equations that he had derived while working with his original source of 512 cps, although he



3.1
Curves showing the frequency-dependence of the sound-absorbing power of felt, as determined by Wallace Sabine, c. 1906. Curve 1 is for a single layer of felt, 1.1 cm thick. Each successive curve is for additional layers. The frequency ranges from C_1 = 64 cps to C_7 = 4,096 cps, and the absorbing powers vary considerably over this range. Wallace Sabine, *Collected Papers on Acoustics* (Cambridge, Mass.: Harvard University Press, 1922), p. 99.

acknowledged that these equations might, in fact, not be valid for other frequencies. Referring to the reverberation formula:

$$t = \frac{.164\ V}{a},$$

Sabine admitted, "It is debatable whether or not this definition should be extended without alteration to reverberation for other notes than C_4 512. There is a good deal to be said both for and against its retention. The whole, however, hinges on the outcome of a physiological or psychological inquiry not yet in such shape as to lead to a final decision. The question is therefore held in abeyance, and for the time the definition is retained."[10]

The psychological inquiry to which Sabine referred was a determination of the frequency-dependence of the human sense of loudness. Sabine's method of measuring reverberation—and the experimental technique embedded in his reverberation equation—required that an auditor determine the time at which a sound in a room became inaudible. At this time, it was assumed that the sound had dropped to one-millionth of its original intensity. If sounds of different pitches were perceived as inaudible at different intensity levels, this difference would somehow have to be taken into account. Only then would the equation be valid for all frequencies within the range of human hearing.

It was apparent to Sabine that human hearing was indeed variably sensitive to sounds of different frequencies, and he needed to understand this variability if he were to continue to depend on the ear as his instrument of detection. In 1910, Sabine published a brief memorandum on the results of a preliminary investigation into the perception of loudness. He tested a number of auditors to determine the relative energy required, at each of seven frequencies, to produce a sensation of equal loudness for each sound.[11] Even as he attempted to objectify the subjectivities of the human ear, however, Sabine encountered new obstacles. In this experiment, as in virtually all of his work, Sabine could only express the intensity of a sound relative to the minimum audible intensity for each pitch. There was no way to measure the absolute intensity of a sound, nor even to produce consistently a sound of constant intensity from a single source. "It is very unfortunate indeed," Sabine lamented, "that there are no standard sources of sound."[12] The limitations of the available sources and detectors impelled Sabine to reconsider the utility of techniques for visually representing sound, and he returned to the tradition of looking at sound in order to explore local effects in rooms such as echoes and interference patterns.

In order to understand the propagation of sound and the creation of distinct echoes, Sabine built scaled models of rooms and employed the "Toeppler-Boys-Foley method" to photograph the movement of sound waves through these models. (See figure 3.2.) As Sabine himself described it, "the method consists essentially of taking off the sides of the model, and, as the sound is passing through it, illuminating it instantaneously by the light from a very fine and somewhat distant electric spark. After passing through the model the light falls on a photographic plate placed at a little distance on the other side. The light is refracted by the sound-waves, which thus act practically as their own lens in producing the photograph."[13]

3.2
Photographic series showing the propagation of sound through a scaled model of the New Theater (Carrère & Hastings, New York, 1909), taken by Wallace Sabine, c. 1913. The New Theater (later known as the Century Theater) was plagued by numerous problems, some of them acoustical, including the echoes depicted here. It was demolished in 1930. Wallace Sabine, *Collected Papers on Acoustics* (Cambridge, Mass.: Harvard University Press, 1922), p. 185.

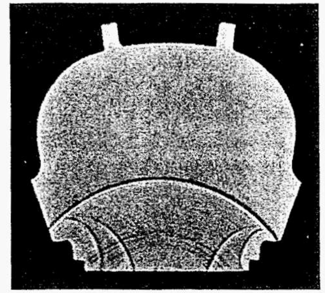
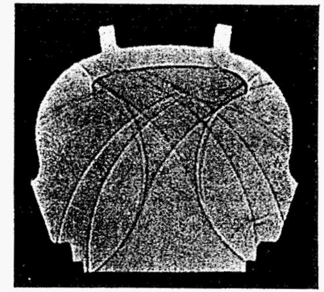


Fig. 22



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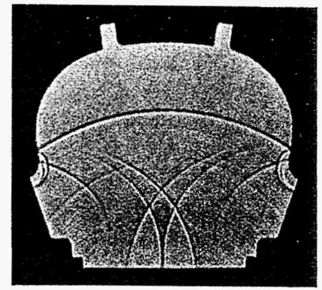

Fig. 23

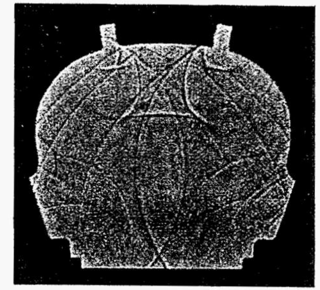

Fig. 26

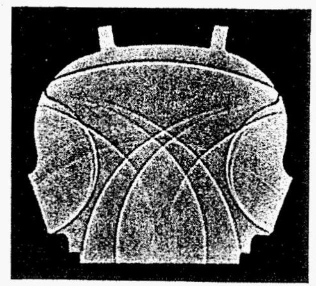

Fig. 24

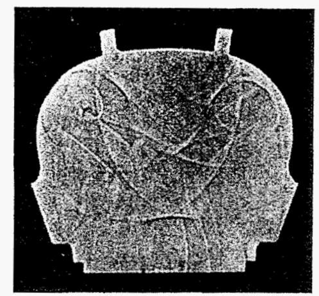

Fig. 27

Sabine's interest in local acoustical effects also led him to devise a means by which to visualize the spatial variations of sound intensity that resulted from the interference of direct and reflected waves of sound in a room. In 1910, he constructed a map of the Constant Temperature Room of the Jefferson Physical Laboratory, "in which the intensity of the sound has been indicated by contour lines in the manner employed in the drawing of the Geodetic Survey maps."[14] (See figure 3.3.) Although Sabine's goal was to understand the variation of sound intensity, the means by which he generated this map are perhaps more interesting than the map itself, for this investigation appears to constitute Sabine's first significant engagement with electroacoustical tools.

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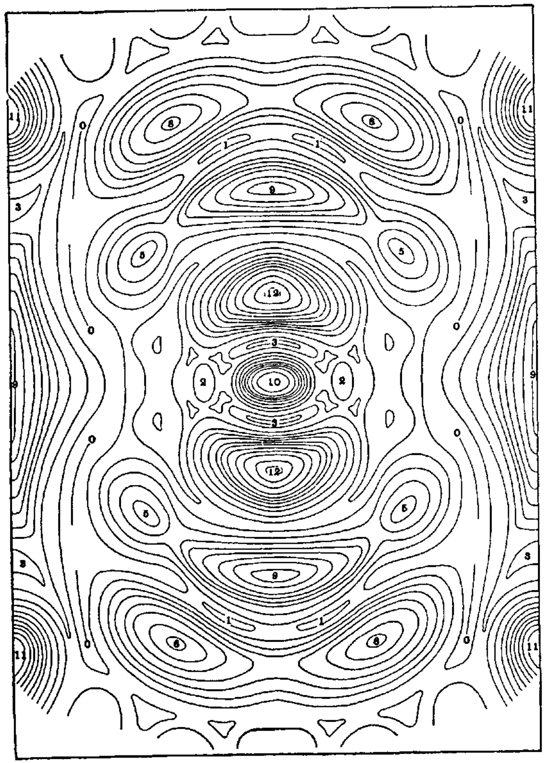
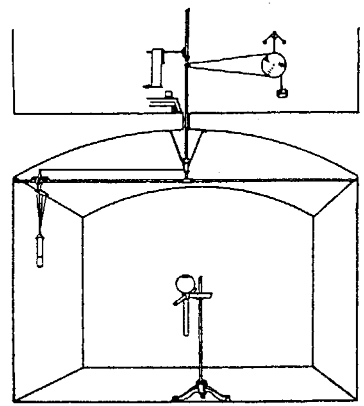
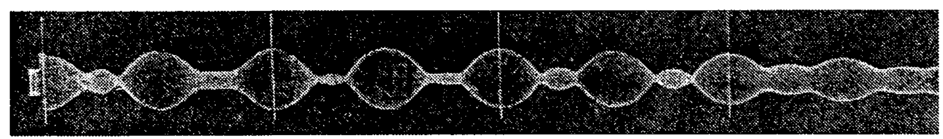


3.4
Wallace Sabine's experimental setup for mapping the distribution of sound intensity in the Constant Temperature Room, c. 1910. The source of sound, an electrically driven tuning fork of 248 cps, was mounted on the stand in the center of the room. The apparatus suspended from the ceiling simultaneously rotated and drew inward the telephonic detector suspended from the left side of the pole. Paul Sabine, *Acoustics and Architecture* (New York: McGraw-Hill, 1932), p. 41.



3.5
Fragment of Wallace Sabine's motion picture film record of the sound intensity registered by the electroacoustic detector as it moved through the Constant Temperature Room. The image shows the magnitude of vibration of the silvered string of a galvanometer connected to the detector. The vertical lines allowed Sabine to map this image to specific points in the spiral path of the detector. Paul Sabine, *Acoustics and Architecture* (New York: McGraw-Hill, 1932), p. 42.

In this study, Sabine did not employ an air-driven organ pipe as his source of sound; he instead used an electrically driven tuning fork. The detector—usually his own two ears—was, in this case, a telephone receiver or earpiece.[15] The tuning fork was placed at the center of the room and covered with an amplifying resonator. The receiver was rigged to a complicated mechanism that was just two waltzing mice short of a Rube Goldberg machine. A falling weight caused the long pole on which the receiver was mounted to rotate; at the same time, the rotary motion caused the receiver to be gradually pulled from the end to the center of the pole. The result was that the receiver traveled a continuous spiral path through the room at a constant height. (See figure 3.4.) The telephonic receiver generated an electrical current that represented the variations in sound intensity it encountered as it spiraled through space. That current was then fed to a sensitive "Einthoven string dynamometer," where it set up vibrations of varying amplitude in a silvered string. Sabine rigged a motion picture camera to photograph the image of the vibrating string onto a strip of film (see figure 3.5), and the constantly changing intensity of vibration could then be read off the



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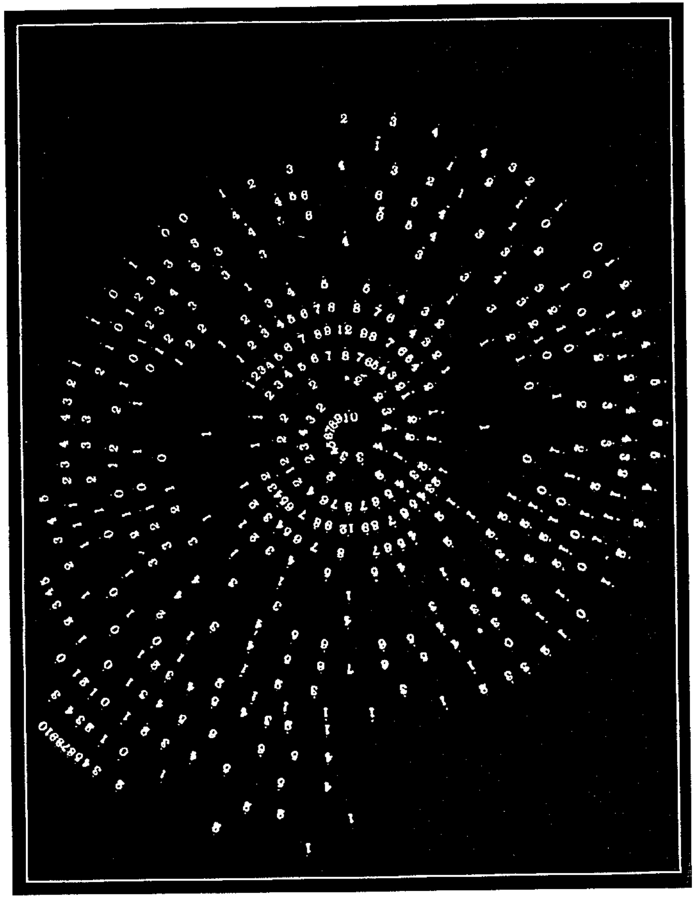

developed image on that film. Sabine mapped those intensities back onto the spiral path traversed by the receiver, to create a point-by-point plot of the relative sound intensity in the room. (See figure 3.6.) Finally, by connecting locations of equal intensity, Sabine created the contour map illustrated in figure 3.3.

While Sabine published his map in 1912, he chose not to include an account of how he obtained it.[16] This suggests that he was not fully comfortable with his new electroacoustic technique, and he apparently remained uncomfortable with it throughout his career. Sabine did not know if his telephone receiver responded uniformly to sounds of different frequencies, or if it—like the human ear—was particularly sensitive to sounds of particular pitches. Nor was his electrical source obviously an improvement over the organ pipe he generally depended on. For Sabine, these devices were undependable, and he used them only to generate images of sound. These images enabled Sabine to begin to understand qualitatively the local behavior of sound in rooms, but the electrical signals he used to obtain them were otherwise of little use or interest to him.[17]

The complicated spatial effects registered in Sabine's contour map were primarily an artifact of the laboratory. Under normal circumstances, the sounds that an auditor encounters are not pure, steady-state tones generating stationary interference patterns, but complex and constantly varying combinations of sound waves of different frequencies and intensities. In a typical room filled with music or speech, interference patterns continually shift and change, and most local effects are fleeting or they average out over time. Thus, while Sabine labored in his laboratory to understand the full complexity of the behavior of sound, he simultaneously was able to work in the world outside his laboratory with a far more generalized model of that behavior. Sabine's reverberation equation remained an extremely powerful tool, and he applied it to an increasing number of architectural projects.