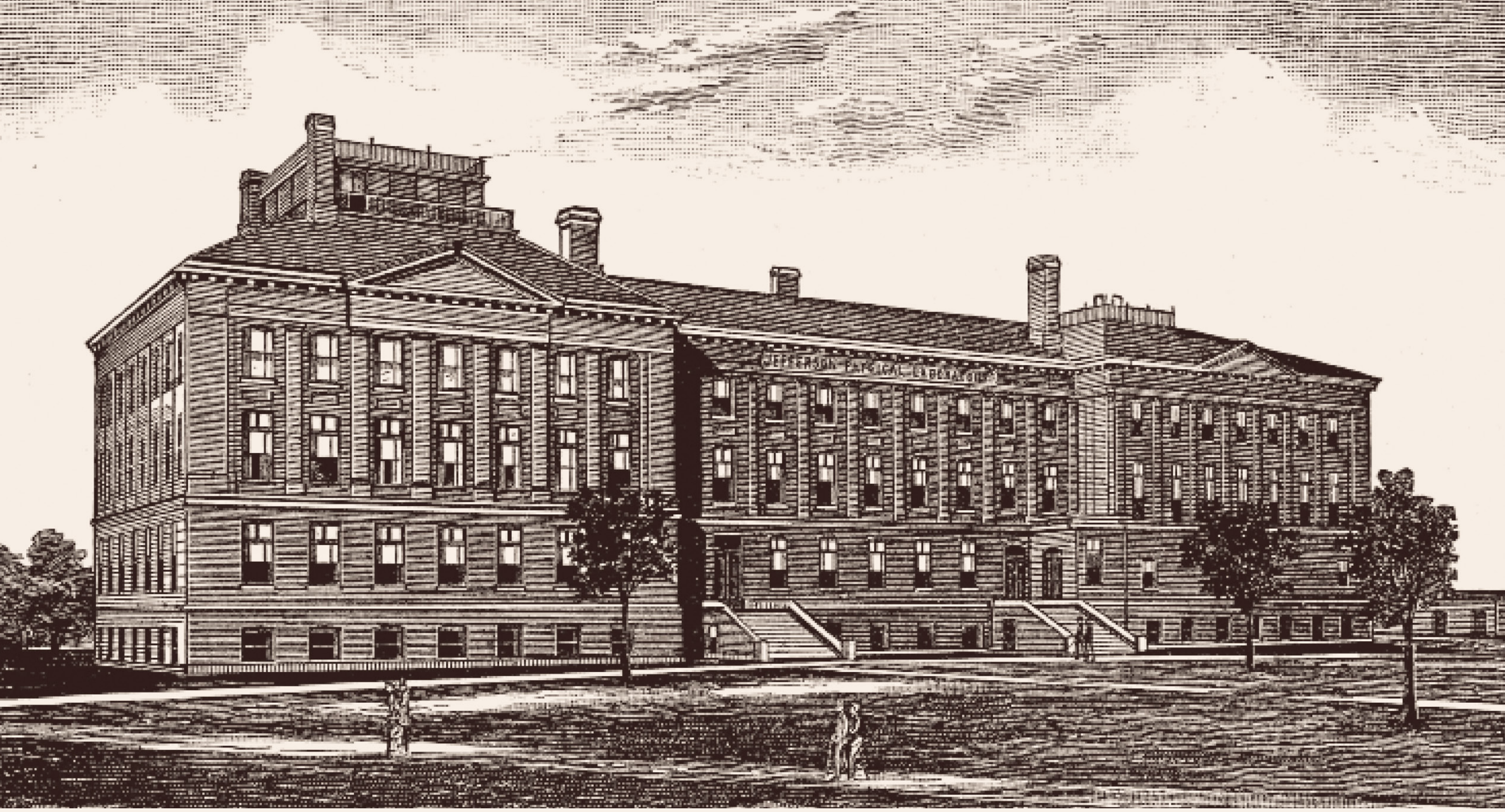

"AS IMMOVABLE AS A HIGH MOUNTAIN":

Wallace Sabine and the Founding of Architectural Acoustics

by Paul Horowitz

Fig. 1: Wallace Clement Sabine

"It was entirely due to Sabine's encouragement and it was under his direction that I undertook in the autumn of `97 [1897] the investigation of the extreme ultraviolet. From that time on with but two short interruptions I was in constant contact with him, first as a student and later as a colleague." Who was it that was thus encouraged? None other than Theodore Lyman,[1] to whom we owe the eponymous series, optical spectra produced by transitions to the electron's ground state.

[1] Lyman, T., "An Appreciation of Professor Sabine," *J. Acoust. Soc. Am.*, 7 (1936): 241. In his warm introduction, Lyman remarked "Professor Sabine combined virtues and talents very rarely found in a single individual. He was above all things the very personification of unselfishness. Gentle and retiring to a fault, he always avoided publicity and cared little for fame and nothing for rewards. Yet where the right was concerned he was as immovable as a high mountain."

Few are aware of Sabine's role in Lyman's career, but in the field of acoustics he stands as a giant, for he founded – and developed to a remarkable degree, especially given the equipment of the time – the science of architectural acoustics. As Winston Churchill remarked, "never let a good crisis go to waste." And indeed, it was a crisis that sparked a revolution in the design and construction of lecture halls and theaters.

Our story begins in 1895 with the unexpectedly awful acoustics in the newly built Fogg lecture hall (Figure 2, the current site of Canaday Hall), for which President Eliot[2] sought help from the young Sabine. In the words of Sabine's cousin Paul Sabine:[3]

This building had just been completed and this room was intended to be used to accommodate large lecture courses and for lectures open to the public. Its plan is one which from the tradition of the Greek amphitheater might be expected to be acoustically satisfactory. Moreover, in plan it is not markedly different from Sanders Theater, a much larger room which both for music and speaking is acoustically quite acceptable, so that the designers had no reason to expect prior to the event the acoustical calamity which was to reward their efforts. The lecture room of the Fogg Art Museum should in the light of all available knowledge of the subject, have been acoustically excellent. As a matter of grim fact it was extremely bad.[4]

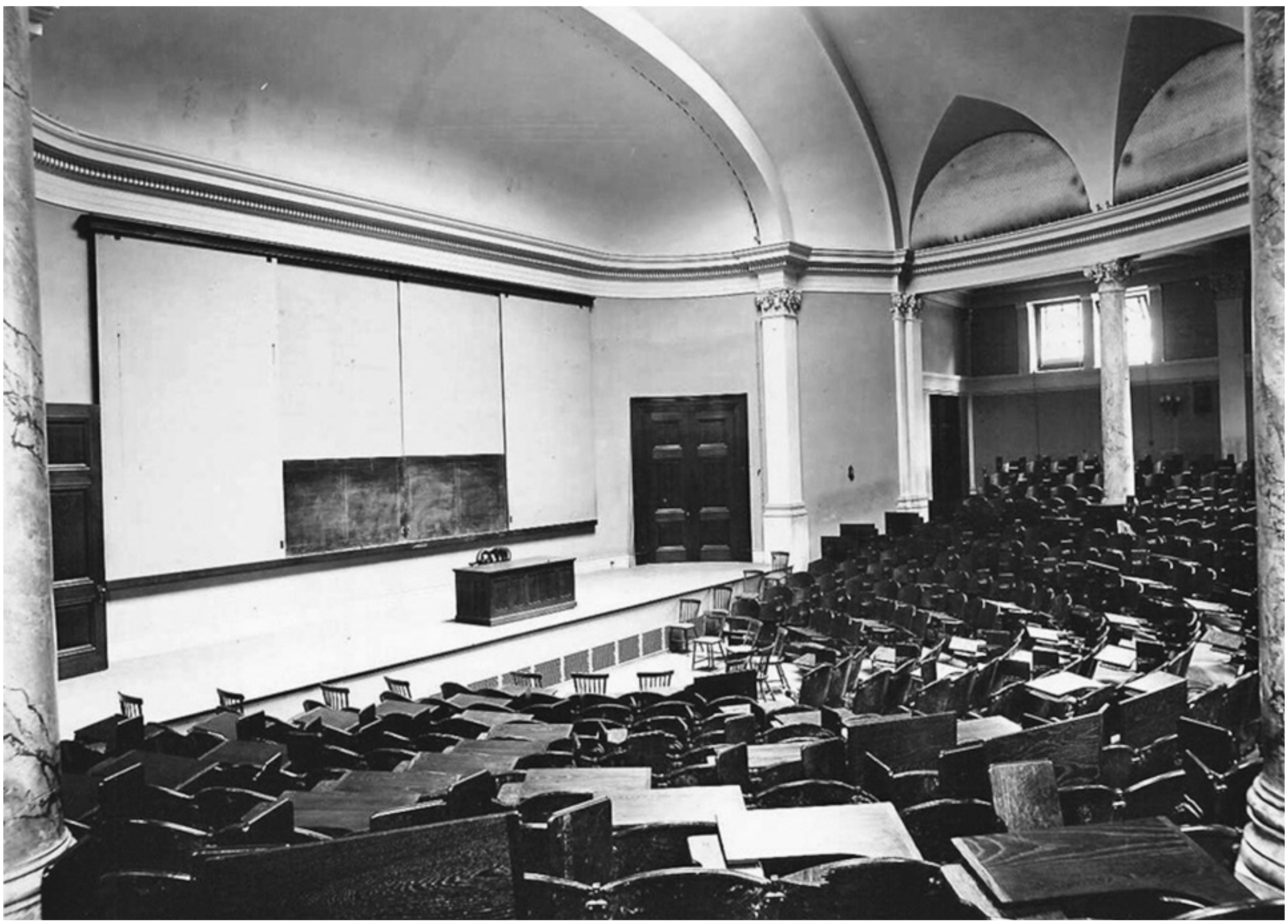

Fig. 2: The new Fogg lecture hall, circa 1895, where lectures were unintelligible. Note the hard surfaces, such as plaster walls and ceiling, and hard-surface student desks and seats; evidently it occurred to no one to equip the latter with cushions.

[2] Prodded by a complaint from his cousin and lecturer in fine arts Charles Eliot Norton.

[3] About the choice of whom Paul Sabine had this to say: "What to do? The college authorities did what I suspect college authorities are prone to do in all such cases, referred the problem to the Physics Department – and the Physics Department in turn placed the wailing infant on the doorstep of the youngest professor in the department." (Sabine, P.E., "The Beginnings of Architectural Acoustics," *J. Acoust. Soc. Am.*, 7 (1936): 242.)

[4] ibid.

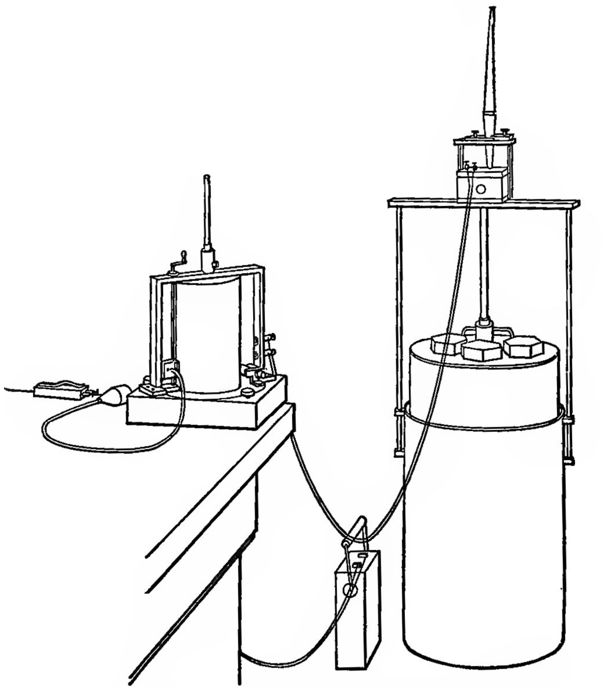

Fig. 3: Sabine's apparatus: air from a reservoir is released into an organ pipe by an electric valve; the listener pressed a key when the reverberant sound became inaudible. (Figure 1 of Sabine, W.C., "Reverberation," *The American Architect*, 1900.)

REVERBERATION

Sabine suspected that the hall's excessive reverberation time was largely responsible, and set to work with simple apparatus (Figure 3, an air-tank-driven organ pipe and a mechanical chronometer: 1895 was firmly in the pre-electronic era) and with dogged determination to make quantitative measurements of the flawed hall's reverberation time; the idea was that you can't tune it up if you can't measure it. The procedure he finally settled on (having abandoned his "preliminary gropings" involving optical observations of gas flames) was to mark the time from the end of the organ-pipe sound to the moment when the residual sound was inaudible.[5]

One might worry that a subjective method like this would be both imprecise and unrepeatable, but a set of measurements taken over multiple days, and with different observers (see an example in Figure 4), established to Sabine's satisfaction that it was adequate to the task – that task being to determine the acoustic "absorbing power" of different kinds and quantities of various materials.

Having established a procedure to quantify reverberation time, Sabine proceeded to measure the effect of various quantities of absorber in reducing the reverberation time. For this he chose the nearby supply of seat cushions from Sanders Theater (Figure 5). Here we let him tell the story:

> *With an organ pipe as a constant source of sound, and a suitable chronograph for recording, the duration of audibility of a sound after the source had ceased in this room when empty was found to be 5.6 seconds. All the cushions from the seats in Sanders Theatre were then brought over[!] and stored in the lobby. On bringing into the lecture-room a number of cushions having a total length of 8.2 meters, the duration of audibility fell to 5.33 seconds.*

> *Little by little the cushions were brought into the room, and each time the duration of audibility was measured. When all the seats (486 in number) were covered, the sound was audible for 2.03 seconds. Then the aisles were covered, and then the platform. Still there were more cushions – almost half as many more. These were brought into the room, a few at a time, as before, and draped on a scaffolding that had been erected around the room, the duration of the sound being recorded each time. Finally, when all the cushions from a theatre seating nearly fifteen hundred persons were placed in the room – covering the seats, the aisles, the platform, the rear wall to the ceiling – the duration of audibility of the residual sound was 1.14 seconds.*

That was just the beginning. Sabine then investigated the placement of the cushions, finding that it mattered little how they were arrayed, as long as their total area was exposed – in his words "the measurements of the cushions should be, not in running meters of cushion, but in square meters of exposed surface." He then tried other materials:

> *Curtains of chenille, 1.1 meters wide and 17 meters in total length, were draped in the room. The duration of audibility was then 4.51 seconds. Turning to the data that had just been collected it appeared that this amount of chenille was equivalent to 30 meters of Sanders Theatre cushions. Oriental rugs, Herez, Demirjik, and Hindoostanee, were tested in a similar manner; as were also cretonne cloth, canvas, and hair felt. Similar experiments, but in a smaller room, determined the absorbing power of a man and of a woman, always by determining the number of running meters of Sanders Theatre cushions that would produce the same effect.*

[5] In contemporary terms, Sabine's "reverberation time" amounts to a decay of 60dB (energy reduction of 10^6).

	Observer	Total Absorbing Power	Absorbing Power per Person
First night, whole audience	W. C. S.	123.0	.42
" " " "	G. LeC.	113.0	.39
" " half "	W. C. S.	58.3	.41
" " " "	G. LeC.	58.3	.41
Second " whole "	W. C. S.	66.2	.40
" " " "	E. D. D.	64.6	.39
			.40 (3)

Fig. 4: Measurements of the absorbing power (fraction of sound absorbed) in the "large lecture-room of the Jefferson Physical Laboratory" (J250), as a function of audience size, carried out by three observers over two successive nights in 1899. In Sabine's words "In view of the difficulties of the experiment the consistency of the determination is gratifying. The average result of the six determinations is probably correct within two per cent."]

For many weeks of nights Sabine and his helpers transported those now-historic cushions, doing their experiments between 2 and 6AM, and returning them before the next day's classes. A useful result was the finding that the ideal reverberation time for a lecture hall is 1.0 seconds, and for a concert hall 2–2.25 seconds. Along the way, Sabine established a reproducible unit of absorption, the square foot of open window. In his charming prose:

> *It is obvious, however, that if both cushions and windows are to be classed as absorbents, the open window, because the more universally accessible and the more permanent, is the better unit. The cushions, on the other hand, are by far the more convenient in practice, for it is possible only on very rare occasions to work accurately with the windows open, not at all in summer on account of night noises – the noise of crickets and other insects – and in the winter only when there is but the slightest wind; and further, but few rooms have sufficient window surface to produce the desired absorption. It is necessary, therefore, to work with cushions, but to express the results in open-window units.*

And the contemporary unit of sound absorption is the sabin (one square foot of open window), and the metric sabin (one square meter); the absorption of Sabine's cushions (at 512 Hz) were equivalent to 0.8 that of an open-window of the same area.

Having established optimal reverberation times, Sabine proceeded to "fix" the Fogg lecture hall, by installing wall panels of felt. In his words: "the room was rendered not excellent, but entirely serviceable, and it has been used for the past three years without serious complaint." But he was only getting started. Already he had a sophisticated appreciation of room acoustics and remedies; here is a sample (from the *Proc. Am. Inst. Architects*, 1898):

> *There is no simple treatment that can cure all cases. There may be inadequate absorption and prolonged residual sound; in this case absorbing material should be added in the proper places. On the other hand, there may be excessive absorption by the nearer parts of the hall and by the nearer audience and the sound may not penetrate to the greater distances. Obviously the treatment should not be the same. There is such a room belonging to the University, known locally as Sever 35. It is low and long. Across its ceiling are now stretched hundreds of wires [a traditional pre-Sabine remedy] and many yards of cloth. The former has the merit of being*

Fig. 5: A Sanders Theatre historic seat cushion, approximately 52" x 18" and 5" thick, of "wiry vegetable fiber covered with canvas ticking and a thin cloth."

harmless, the latter is like bleeding a patient suffering from a chill. In general, should the sound seem smothered or too faint, it is because the sound is either imperfectly distributed to the audience, or is lost in waste places. The first may occur in a very low and long room, the second in one with a very high ceiling. The first can be remedied only slightly at best, the latter can be improved by the use of reflectors behind and above the speaker. On the other hand, should the sound be loud but confused, due to a perceptible prolongation, the difficulty arises from there being reflecting surfaces either too far distant or improperly inclined.

Sabine proceeded to extend his measurements to cover the audible frequencies, and to include the effect of the audience. Here is an example of his descriptive prose:

In the very nature of the problem the most important data is the absorption coefficient of an audience, and the determination of this was the first task undertaken. By means of a lecture on one of the recent developments of physics, an audience was enveigled into attending, and at the end of the lecture requested to remain for the experiment. In this attempt the effort was made to determine the coefficients for the five octaves from C_2 128 to C_6 2048, including notes E and G in each octave. For several reasons the experiment was not a success. A threatening thunderstorm made the audience a small one, and the sultriness of the atmosphere made open windows necessary, while the attempt to cover so many notes, thirteen in all, prolonged the experiment beyond the endurance of the audience.

Sabine repeated the experiment successfully the following summer ("Moreover, bearing in mind the experiences of the previous summer, it was recognized that even seven notes would come dangerously near over-taxing the patience of the audience").

Sabine turned his attention to the absorbing properties of pretty much anything he could find. In his 1900 paper, he includes tables of the absorption coefficient (relative to an open window) of various wall surfaces ("plaster on wood lath, plaster on wire lath, plaster on tile," etc.), of various "settees, chairs, and cushions," of audiences ("audience per square meter, audience per person, isolated woman, isolated man"), and, most charmingly, of "Miscellaneous" (Figure 6).

As Sabine accumulated reverberation-time data from rooms of different sizes, trying to make sense of things, he noticed that, when plotting measurements of reverberation time T versus total absorbing area a, the data fell on nested hyperbolas. In other words, for any given hall the product $T \times a$ was approximately constant as the amount of absorber was changed. He called this the "hyperbolic law." And he further realized that the product $T \times a$ was proportional to the hall's volume. Put another way, he found

$$T_{reverb} = kV/a \qquad (1)$$

where V is the volume of the hall, a is the total absorbing area, and k is a constant whose value he found to be 0.171 when a is in units of square meters of open window.[6] As he wrote to President Eliot in 1898, upon this realization:

Miscellaneous

Oil paintings, inclusive of frames	.28
House plants	.11
Carpet rugs	.20
Oriental rugs, extra heavy	.29
Cheesecloth	.019
Cretonne cloth	.15
Shelia curtains	.23
Hairfelt, 2.5 cm. thick, 8 cm. from wall	.78
Cork, 2.5 cm. thick, loose on floor	.16
Linoleum, loose on floor	.12

Fig. 6: Absorption coefficient of miscellaneous materials, from Sabine's 1900 paper. He explains, helpfully "the values are per square meter, except in the case of plants, where the coefficient is per cubic meter."

[6] This is the famous Sabine formula for reverberation time, which allows calculation of the required total absorbing power when the hall volume and desired reverberation time are known. He gives a derivation in his 1900 paper (in a section called "Exact Solution") based on physical concepts like absorption at each of a sound wave's multiple reflections.

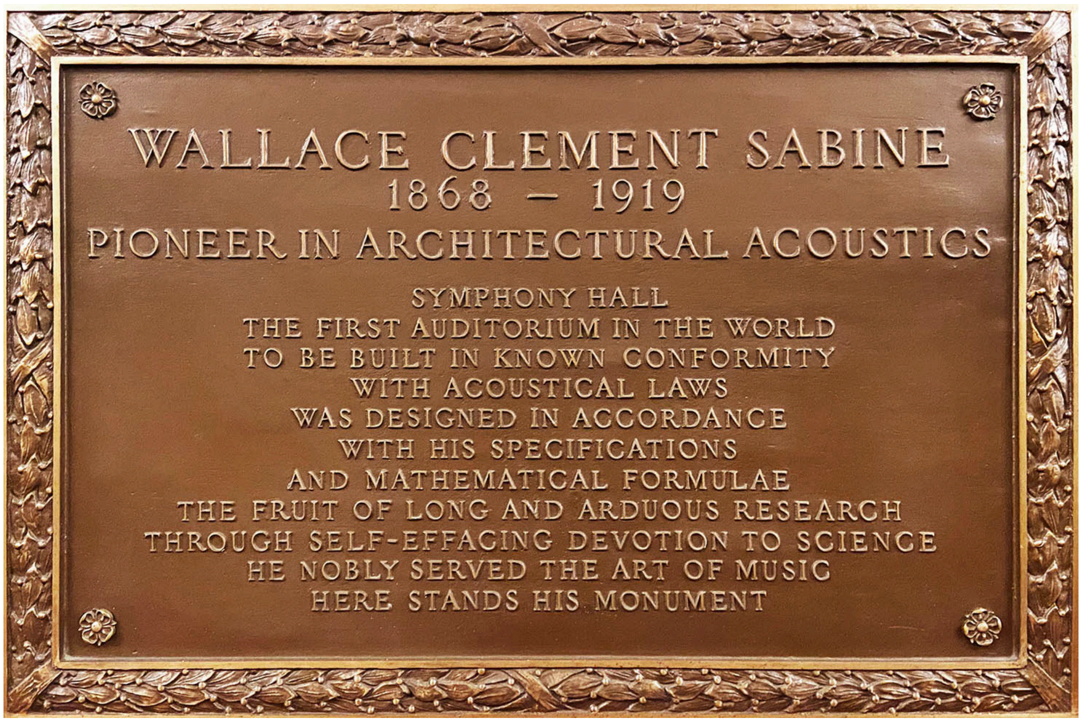

Fig. 7: This plaque stands in the main corridor of Boston's Symphony Hall. (Photo by Bridget Carr, used with permission)

> *Last night the confusion of observations and results in which I was floundering resolved themselves in the clearest manner. Now it is only necessary to collect further data in order to predict the character of any room that may be planned at least as respects reverberation.*

BOSTON SYMPHONY HALL

By this time Sabine's reputation had spread, and, with superb timing, he was called in to advise on the "New Boston Music Hall" (now Symphony Hall) – a "room being planned." Sabine already had considerable knowledge of other halls (for example the Leipzig Gewandhaus, the Old Boston Music Hall, Sayles Hall in Providence, and the Boston Public Library).

The original concept in 1893, favored by New York architect Charles Follen McKim, was to create a gleaming semi-circular hall in the style of ancient Greek amphitheaters. This would be a departure from the rectangular box-like halls that were admired for their excellent acoustics, the best of which was probably the Neue Gewandhaus in Leipzig. Happily, a serious financial crisis put this plan on hold, allowing our physicist time to do his research and thus intervene with some acoustical sanity. The amphitheater plan was abandoned, partly with the realization (conveyed in a letter to the architect from Henry Lee Higginson, chairman of the building committee and the founder of the BSO) that

> *While we hanker for the Greek theater plan, we think the risk too great as regards results, so we have definitely abandoned that idea. We shall therefore turn to the general plan of our Music Hall and of the halls in Vienna and Leipsic* [sic], *the latter being the best of them all…*[7]

President Eliot, already aware of Sabine's success with the Fogg Lecture Hall, connected him with his friend Higginson. Sabine, initially hesitant to become involved, bore down on his collection of reverberation data, and, after two weeks of intense study, came up with his hyperbolic epiphany (Equation 1): "I have found it at last!" he said. As his mother, who happened to be with him at the time, recounted, "His whole face smiles, though he is very tired."

[7] Letter from Higginson to McKim, 10/27/1898.

A DISASTER PREVENTED

The new Music Hall was intended to seat somewhat more than the hall it was to replace (2,600 vs 2,391). But the Leipzig hall was far smaller (it seated 1,560); so the initial plan, before Sabine intervened, was simply to scale up the dimensions of the Gewandhaus by a linear factor of 1.30. But a linear scaling, from Sabine's formula, would increase the ratio V/a (and therefore the reverberation time) by that same factor, thus a reverberation time of about 3 seconds (in the words of Leo Beranek, it would have been "an acoustical disaster"). Sabine worked with the architect and committees to address this problem, nicely solved by reducing the ceiling height, adding balconies, reducing seat spacing, and other measures. The result is a hall that was (and continues to be) among the best in the world.[8] In 1946, the plaque shown in Figure 7 was placed in Symphony Hall.

LATER WORK

Sabine's success with Boston's new hall led to a lifetime of consultation on hundreds of churches, cathedrals, auditoriums, and theaters. In some cases, the damage had already been done (as with the Fogg), and, as he succinctly put it, "in repair work for bad acoustical conditions it is generally impracticable to change the shape, and only variations in materials and furnishings are allowable." One example was the New Theatre in New York City, which opened in 1909, and which, according to Wikipedia, was "noted for its fine architecture" but had "a serious defect in the acoustics." Sabine used Schlieren photography on a model of the hall (illuminating it "by the light of a very fine and somewhat distant electric spark") while ensonifying it with "a proportionally scaled sound-wave." The Schlieren photographs show nicely the propagation of echoes throughout the hall. Sabine concludes:

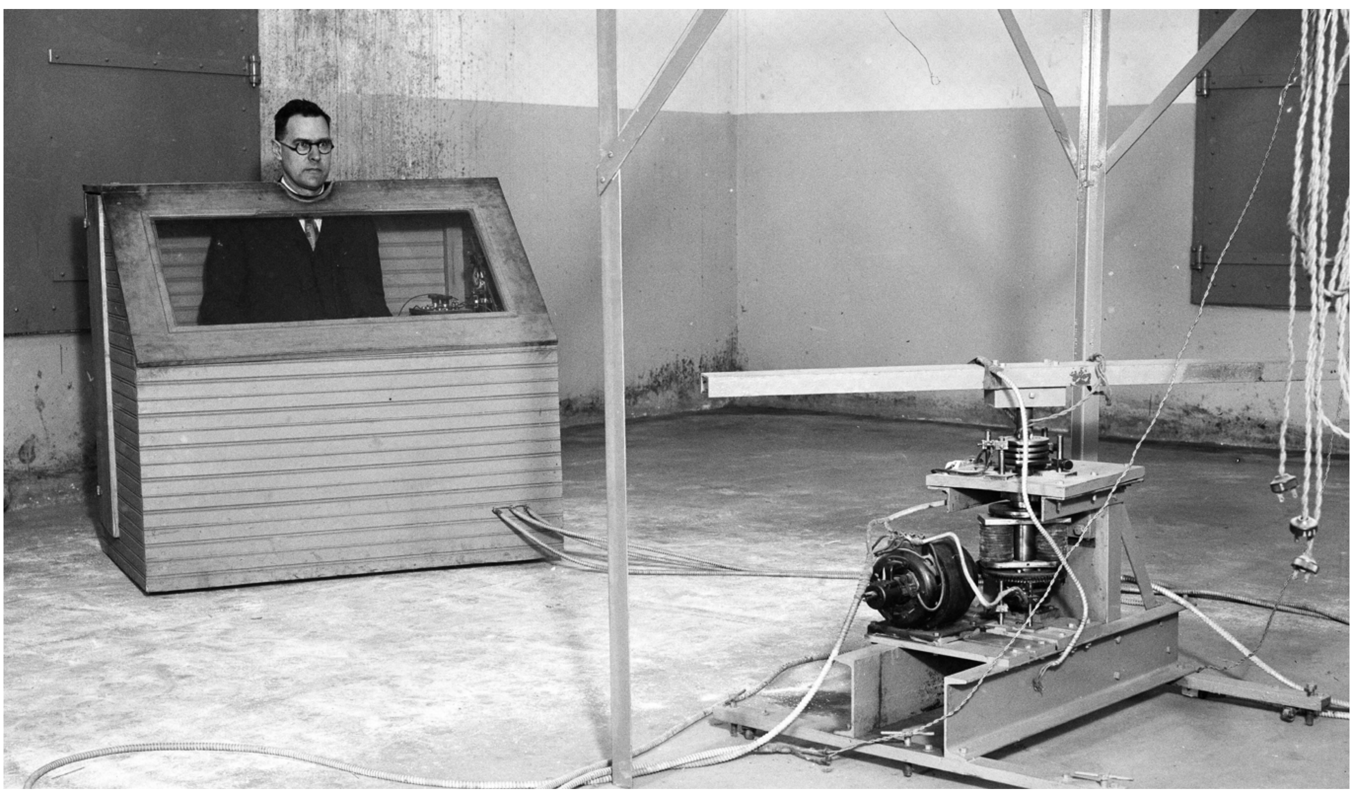

Fig. 8: To gauge intelligibility in a highly reverberant environment, Sabine used this box (shown without the front closure) in his reverberation chamber to eliminate absorption from the clothed body.

[8] In Beranek's admittedly subjective "Rank-Orderings of Acoustical Quality of 58 Concert Halls, Developed From Questionnaires and Interviews" (reference of footnote 12) the top ten, in order, are: 1. Grosser Musikvereinssaal, Vienna; 2. Symphony Hall, Boston; 3. Teatro Colón, Buenos Aires; 4. Konzerthaus, Berlin; 5. Concertgebouw, Amsterdam; 6. Tokyo Opera City Concert Hall, Tokyo; 7. Grosser Tonhallesaal, Zurich; 8. Carnegie Hall, New York; 9. Stadt-Casino, Basel; and 10. St. David's Hall, Cardiff.

> *The photographs… show the echoes produced in the horizontal plane passing through the marble parapet in front of the box.*
> . . .
>
> *While these several factors, reverberation, interference, and echo, in an auditorium at all complicated are themselves complicated, nevertheless they are capable of an exact solution, or, at least, of a solution as accurate as are the architect's plans in actual construction. And it is entirely possible to calculate in advance of construction whether or not an auditorium will be good, and, if not, to determine the factors contributing to its poor acoustics and a method for their correction.*

Quite apart from halls and churches, Sabine did some consulting for the Remington Typewriter Company, who wished to reduce their products' noises. With typical thoroughness, Sabine worked out a theory of the initial production of vibrations: "In percussion typewriting machines, the principal sources of vibration are in ascending order of importance (1) the space bar; (2) the recovery of typebars and keys; (3) the typeshift; (4) the carriage (a) release and (b) check; (5) the striking of the type." He then details each of these, followed by a consideration of the sound propagation mechanisms: "No portion of the noise of the typewriter is communicated to the air in any considerable measure at the actual point of impact. The sound we hear comes to us (1) from the extended surfaces of the machine, and (2) to a surprisingly great extent, from the table on which the typewriter rests and from which it has never been insulated in any effective manner."

Fig. 9: From his 1900 paper in The American Architect: "There is a room in the Jefferson Physical Laboratory, known as the constant-temperature room, that has been of the utmost service throughout these experiments." This contemporary photograph shows the entrance down the Sabine's reverberation chamber, one level below grade at the west end of Jefferson Laboratory. (inset: plaque placed by Prof. Richard Wilson)

This and other investigations led Sabine to study sound transmission through walls, starting with "measurements of the decrease in intensity (loudness) of the sound transmitted between two rooms when (1) one to six layers of half-inch felt intervened between them, or (2) when one to six layers of sheet iron, each separated from the other by one inch of airspace intervened, or (3) when two to six layers of sheet iron separated by half-inch layers of felt and one inch of airspace intervened. An original concept introduced in that paper was the plotting of the transmitted intensity on a logarithmic scale – the forerunner of the decibel!"[9] For some of these experiments Sabine used the "constant temperature room" in the sub-basement of Jefferson (Figures 8 and 9), used much later as the bottom site for the Pound-Rebka experiment.[10]

Even in his early work on the Fogg, Sabine had studied wall materials, for example plaster over tile or brick, compared with plaster on lath laid over studding. His interest at that time was primarily in their absorption of reflected sound. But by 1915 he had a full understanding of the attenuation of transmitted sound produced by what we now call acoustic impedance mismatch. In his article that year in *The Brickbuilder*,[11] he described how "any discontinuity diminishes the transmission of sound; and the transition from masonry to air is a discontinuity of an extreme degree. Two solid masonry walls entirely separated by an air space furnish a vastly better sound insulation than either wall alone."

[9] Quotation from Beranek, L. and Kopec, J., "Wallace C. Sabine, acoustical consultant," *J. Acoust. Soc. Am.* 69 (1981): 1.

[10] And Sabine's former student Lyman had his spectroscopy lab in the other sub-basement, just a few steps away; see P. Horowitz, "Testing Einstein's Prediction: the Pound-Rebka Experiment," *Harvard Physics Newsletter* (2021): 12.

[11] "The Insulation of Sound," *The Brickbuilder* 24, no. 2 (1915): 31.

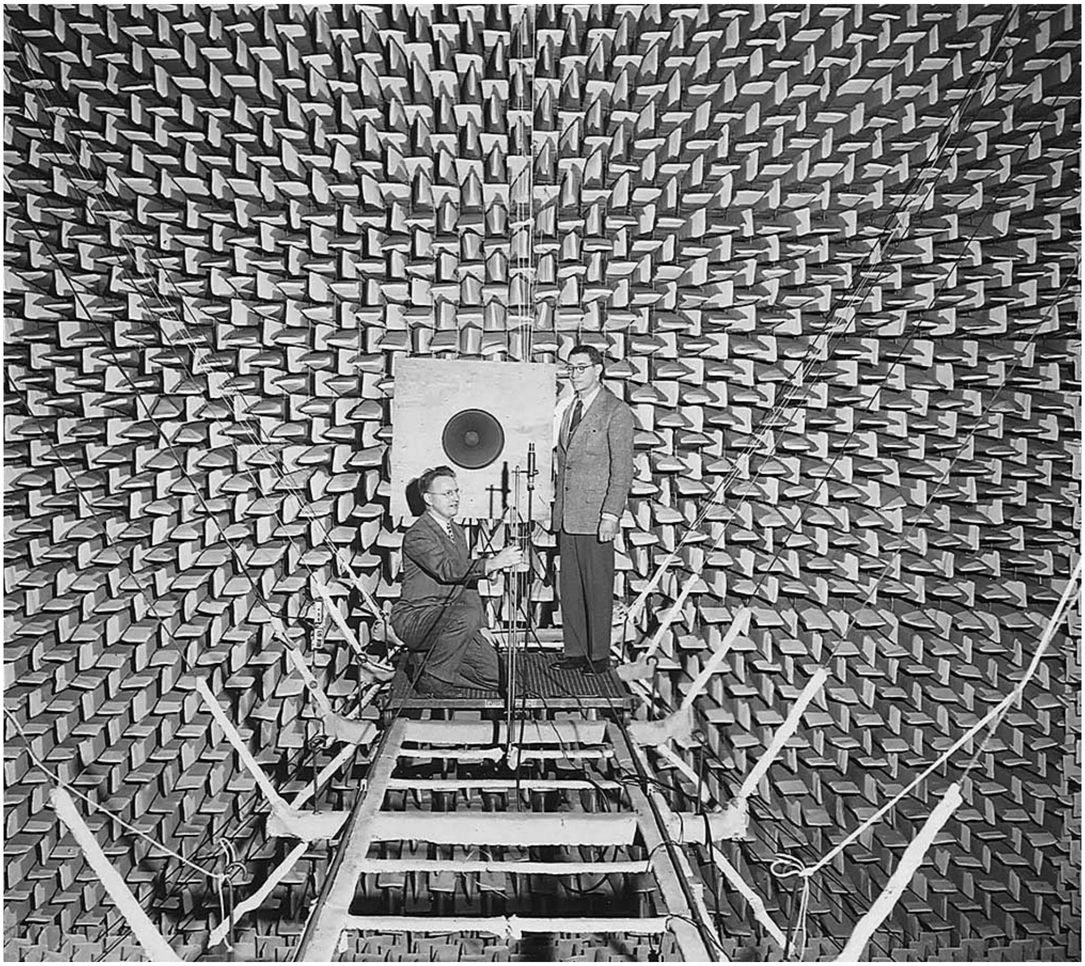

Fig. 10: "Beranek's Box" -- Harvard's anechoic chamber in 1948. (Harvard University Archives)

Sabine has some lovely descriptions of building construction gone wrong. He observes, wryly, that "it is always easier to explain why a method does not work than to know in advance whether it will or will not. It is especially easy to explain why it does not work when not under the immediate necessity of correcting it or of supplying a better." Then he proceeds to find the flaws in a home that was painstakingly built for good sound isolation:

> *The house in New York presented a problem even more interesting. It was practically a double house, one of the most imperative conditions of the building being the exclusion of sounds in the main part of the house from the part to the left of a great partition wall. This wall of solid masonry supported only one beam of the main house, was pierced by as few doors as possible – two – and by no steam or water pipes. The rooms were heated by independent fireplaces, The water pipes connected independently to the main. It had been regarded as of particular importance to exclude sounds from the two bedrooms on the second floor. The ceilings of the rooms below were, therefore, made of concrete arch; on top of this was spread three inches of sand, and on top of this three inches of lignolith blocks; on this was laid a hardwood floor; and finally, when the room was occupied, this floor was covered by very heavy and heavily padded carpets. From the complex floor thus constructed arose interior walls of plaster on wire lath on independent studding, supported only at the top where they were held from the masonry walls by iron brackets set in lignolith blocks. Each room was, therefore, practically a room within a room, separated below by three inches of sand and three inches of lignolith and on all sides and above by an air space.*

And, surprise of surprises, "In the rear bedroom, from which the best results were expected, one could hear not merely the shutting of doors in the main part of the house, but the working of the feed pump, the raking of the furnace, and the coaling of the kitchen range." And "rapping with the knuckles on the wall of [a basement] room produced in the bedroom, two stories up and on the other side of the great partition wall, a sound which, although hardly, as the architect expressed it, magnified, yet of astonishing loudness and clearness. In this case, the telephone-like nature of the process was even more clearly defined than in the other cases, for the distances concerned were much greater." Sabine used this example, which he said had "many interesting aspects," to teach about airborne versus conducted sound, the conversion between longitudinal and transverse waves, and mitigating measures to address the problem.

A CENTURY OF PROGRESS IN ARCHITECTURAL ACOUSTICS

With twentieth-century electronics – microphones, amplifiers, and accurate measuring instruments – and with the basis provided by Sabine's initial discoveries and careful measurements of sound absorption and reverberation time, architectural acoustics matured to the science it is today. The importance of many subtle factors was elucidated; these include effects such as "early sound," reverberant sound, diffusion, and a host of other parameters.[12]

"Beranek's Box" – An Anti-Reverberation Chamber

Among the leading figures in architectural acoustics was Leo Beranek (PhD, Harvard, 1940), whose measurements of dozens of concert halls worldwide established a solid foundation for concert-hall design.[13] Among his many accomplishments, in 1943 he built the first anechoic (echo-free) chamber in the US, needed for acoustic measurements in support of the war effort. A painstaking set of measurements on sub-scale anechoic chambers informed the final product, whose interior space of 38 x 50 x 38 feet was covered with 19,000 Fiberglas wedges (Fig. 10). The performance was excellent – only fractional dB's of departure from perfect inverse-square falloff from an acoustic source[14] over the range of 70 Hz to 10 kHz.

This author, having measured home-built microphones in Beranek's Box, can attest that the silence experienced in it is highly disorienting. A better testament comes from composer John Cage, whose experience in 1951 in the box[15] is said to have inspired his best-known composition *4'33"* (four minutes and 33 seconds of silence).

An Era of Sophistication

With the science of reverberation firmly in hand, research in concert-hall acoustics has focused on the subjective intangibles: what makes a hall have favorable characteristics, characterized as a sense of "proximity," or of feeling "warm," or "lively," or "rich," or "intimate"? Or, on the other side of the coin, "dull," or "flat," or "monophonic," or "shrill," or "brittle"? And, quite apart from the audience experience, what about the performers' ability to hear each other clearly?

It's fair to say that contemporary architectural acoustics has succeeded in its primary goal: to ensure, ahead of construction, that a new hall will not disappoint. Some of the more interesting questions relate to the ability of an audience member to image the separate instruments on stage. Recent work by a physics department graduate (Fig. 11) has provided hints: good "spatial hearing" appears to exploit phase coherence in the acoustic overtones, which is degraded by early reflections; this can be experimentally demonstrated by scrambling overtone phases with an all-pass network (which otherwise preserves the spectrum).

[12] Here are some from the authoritative *Concert Halls and Opera Houses – Music, Acoustics, and Architecture*, 2nd ed. by Leo Beranek (Springer, 2004): early decay time, binaural quality index, bass ratio, initial-time-delay gap, lateral fraction, acoustical glare and surface diffusivity, brilliance, balance, blend, and immediacy of response.

[13] He consulted on the design of Philharmonic Hall in New York, but, sadly, most of his recommendations were ignored or overruled by the architects and committees. In the words of acoustician Christopher Brooks, "he ought to have resigned on the spot." When the hall was completed in 1964, the result was unsatisfactory. Happily, Beranek found a receptive client 30 years later – for the Tokyo Opera City (TOC) Concert Hall, which utilized all of his findings. It opened in 1997, to overwhelmingly positive reviews. According to cellist Yo-Yo Ma (Harvard, AB `76), "This hall simply has some of the best acoustics in which I have ever had the privilege to play… What has been accomplished is a miracle!"

[14] Thus demonstrating an absence of reflected sound.

[15] "It was after I got to Boston that I went into the anechoic chamber at Harvard University… Anyway, in that silent room, I heard two sounds, one high and one low. Afterward I asked the engineer in charge why, if the room was so silent, I had heard two sounds. He said, 'Describe them.' I did. He said, 'The high one was your nervous system in operation. The low one was your blood in circulation.'" (Cage, J., "A Year from Monday," *Wesleyan* (2010: 134.)

WALLACE CLEMENT SABINE AWARD OF THE ACOUSTICAL SOCIETY OF AMERICA

David Griesinger
2017

The Wallace Clement Sabine Award is presented to an individual of any nationality who has furthered the knowledge of architectural acoustics, as evidenced by contributions to professional journals and periodicals or by other accomplishments in the field of architectural acoustics

PREVIOUS RECIPIENTS

Vern O. Knudsen	1957	Richard V. Waterhouse	1990
Floyd R. Watson	1959	A. Harold Marshall	1995
Leo L. Beranek	1961	Russell Johnson	1997
Erwin Meyer	1964	Alfred C. C. Warnock	2002
Hale J. Sabine	1968	William J. Cavanaugh	2006
Lothar W. Cremer	1974	John S. Bradley	2008
Cyril M. Harris	1979	J. Christopher Jaffe	2011
Thomas D. Northwood	1982	Ning Xiang	2014

Fig. 11: The tradition lives on: among other awards (including the gold medal of the German Tonmeister Society) Robert Pound's student David Griesinger (PhD 1978) received the Sabine Award, whose citation concludes "The implications of this research [into the neural mechanisms of aural perception] for acoustic design of spaces built for music and speech is substantial. It represents an equivalent paradigm shift in the field of architectural acoustics to similar paradigm shifts that David has instigated throughout his career. His enduring interest in the human perception of sound is manifested by the ongoing research, continued writing and publishing of technical papers, and true inventions in the field to which he has contributed so much."

Another development, which would have made Sabine jealous, is the use of active measures (electronic enhancement) to improve concert hall sound. An example is the LARES system,[16] which uses sophisticated digital processing and an array of distributed loudspeakers to subtly compensate for acoustic deficiencies. When done well, such enhancement sounds completely natural, and listeners usually do not even realize that it is in use. One of these systems was installed in the Jay Pritzker Pavilion in Chicago, an outdoor venue designed in part by Frank Gehry, and accommodating up to 11,000 people; a sense of naturalness is preserved by sophisticated processing and time-aligning the multiple spaced radiators to convincingly enhance the (degraded) direct sound. According to one listener,[17] "I have never in my life heard sound projected so faithfully and beautifully over such a great distance. It was an ethereal experience." And, quite apart from improving the sound reaching an audience, well devised experiments with enhancement can help illuminate the factors that are important in human sound perception.

IT ALL STARTED WITH SABINE

Sabine's pioneering work continues to stand as a monument to careful scientific study, uncolored by one's preconceptions. His attention to detail, ability to learn so much from so little information, simplicity of conception and execution, and clear love of the subject are characteristics of a great scientist. His name, and his 1898 "eureka" formula (equation 1), appear in nearly every publication and every study on architectural acoustics.

SOURCES AND REFERENCES

In addition to the references cited in the text and footnotes, the following were used in the preparation of this short history:

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- Stebbins, Richard P., *The Making of Symphony Hall*, published by Boston Symphony Orchestra, Inc., 2000;
- miscellaneous journal articles and other online sources;
- and helpful conversations and communications with David Griesinger and Michael Sammut.

[16] Lexicon Acoustic Reinforcement and Enhancement System, invented by Griesinger and Steve Barbar in 1988 while at Lexicon, Inc. Hundreds have been installed worldwide, in concert halls, opera houses, conference rooms, churches, sound stages, and outdoor music venues.

[17] Steve Robinson, senior vice president of WFMT radio.