Wallace Clement Sabine and acoustics

Wallace Clement Sabine was the world's first and most celebrated acoustical scientist. He received his graduate training in the physics department at Harvard University and remained on Harvard's faculty until his death, in 1919. His reputation is based not only on his contributions to acoustics, but also on his teaching and administrative contributions to the physics curricula at Harvard and his services to the US during World War I.

The Jefferson Physical Laboratory has represented for many scientists an opportunity to learn, to exchange ideas with colleagues worldwide, and to explore the boundaries of science. (See the article by Gerald Holton, PHYSICS TODAY, December, page 32.) Sabine, who joined the Jefferson Laboratory two years after it opened, was one of the first beneficiaries of these resources.

Early years

Sabine's early education and his experiences at Harvard foreshadowed the lives of many other scientists who have studied there.[1] He came from the Midwest—Columbus, Ohio. Strong pressure from his mother, who said, "A farmer's life is not to be the portion of my son," motivated him to develop his aptitude for physics. He attended a college near his home, Ohio State University, where he came under the influence of an inspiring physics teacher, Thomas Corwin Mendenhall, who became his mentor and lifelong friend.

By chance, John Trowbridge, then the director of Harvard's Jefferson Physical Laboratory, had met Sabine two years before his graduation at a meeting of the American Association for the Advancement of Science in Philadelphia, where Trowbridge was chairman of a session. Sabine was so excited by that session that he was bold enough to tell Trowbridge of his determination to go to Harvard for his graduate studies. Trowbridge later said that his view of the value of large public scientific gatherings was broadened by the experience of meeting young men like Sabine.

Sabine received his Bachelor of Arts degree from Ohio State in June 1886, at the age of 18. After passing Harvard's qualifying examination, he began graduate study in the fall of 1886. Trowbridge welcomed him heartily to his own course; that year Sabine also studied with Benjamin Osgood Peirce, Edwin H. Hall, James Mills Peirce and William E. Byerly. At the end of his first year at Harvard, he was awarded a two-year Morgan Fellowship, which greatly relieved the financial burden on his parents of keeping two children in graduate school—Sabine at Harvard and a sister at MIT. During the next two summers he supplemented his fellowship stipend with employment at the Bell Telephone Laboratories.

During his second year, he assisted Trowbridge in developing laboratory experiments in electricity, electric lighting and photography. Trowbridge listed Sabine as coauthor on three papers published in 1888, two in the *Proceedings* of the American Academy of Arts and Sciences on the spectral absorption of ultraviolet light by metals, and the third in the *American Journal of Science* on the use of steam in spectrum analysis.

Sabine received a Master of Arts degree in 1888, at the age of 20, and in the fall continued to work at the Jefferson Lab with Trowbridge. A year later he was an appointed assistant with a stipend of $500. This position led to another joint paper with Trowbridge, on electrical oscillations in air, which appeared in 1889, also in the *Proceedings* of the American Academy. In the summer of 1890, he was put in charge of the Summer School of Physics, at a stipend of $400. For reasons that are not quite clear, Sabine never worked toward a doctorate, but Harvard awarded him an honorary DSc in 1914.

That same summer of 1890, Sabine received an appointment as instructor. He devoted much of his energy and talents to building up the department's laboratory courses and designing and making apparatus for instruction. In 1893, Sabine published his only book, *A Student's Manual of a Laboratory Course in Physical Measurements*. The manual contained outlines for 70 experiments in mechanics, sound, heat, light, magnetism and electricity. In June 1895, at age 27, Sabine was made assistant professor of physics.

About this time, Sabine began the independent research that made him, within a few years, the world's first and most celebrated acoustical scientist. This dual commitment—to research as well as to teaching—is directly attributable to the encouragement he received from both Harvard President Charles W. Eliot and Trowbridge, and to the superior resources of the new Jefferson Physical Laboratory.

Sabine's loyalty to teaching remained high. Years later, responding to a request for advice, he wrote: "My principal hope is that the [Carnegie] Institute may not serve to separate the research and the educational functions of scientific men.... The instructor who does not engage in research... soon teaches Science as isolated facts rather than as groups of problems. ... If he be engaged in research work, the spirit of it inevitably enters into his teaching. On the other hand, an investigator who does not teach serves a diminished constituency. Next to its direct results, the value of scientific work lies in its stimulating influence on every activity, not of the individual but of the country at large, and this can

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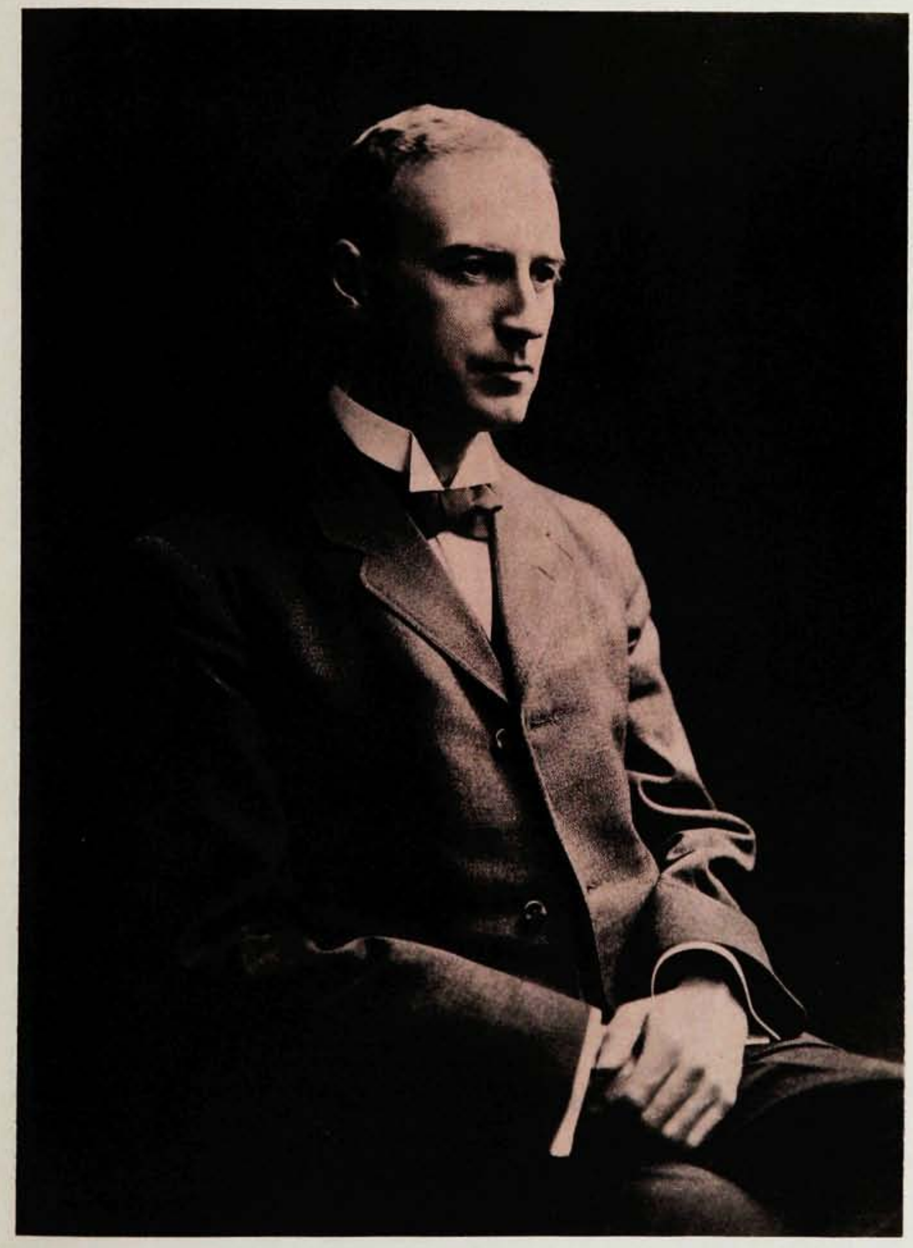
Using the resources of the Jefferson Physical Laboratory, Sabine changed architectural acoustics from an obscure body of knowledge to an experimental science.

Leo L. Beranek



Wallace C. Sabine, who founded the scientific discipline of architectural acoustics with investigations that began in Harvard University's Jefferson Laboratory and Fogg Art Museum. (Photo courtesy AIP Niels Bohr Library.)

best be attained through its connection with the universities."

A new science

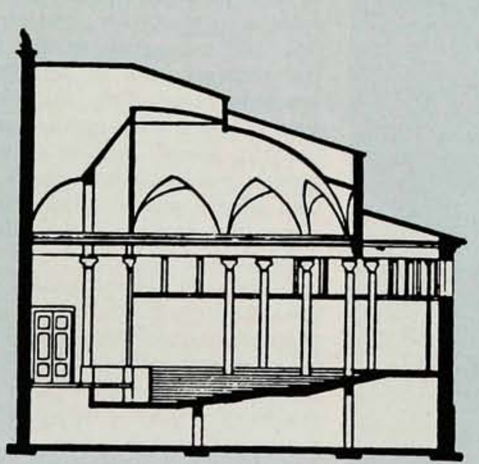
Sabine's acoustical contributions had their beginning when the auditorium in the Fogg Art Museum, which was opened in 1895 (later renamed Hunt Hall when the Fogg museum moved to a new building) was found to be unsuitable for lectures. The drawings on page 46 show the plan and the centerline cross section of the lecture room that Sabine included in his paper.[2,3]

In an effort to salvage the disastrous lecture hall, Eliot turned to Trowbridge for advice and, on receiving his recommendation, asked the newly appointed assistant professor Sabine for help. After some thought and consultation with his mentor at Ohio State, Mendenhall, Sabine accepted the assignment to try to correct the poor acoustics.

Although Eliot sought only to correct a defect in a single auditorium, Sabine was determined to discover by scientific experiment the secrets of an age-old baffling subject: architectural acoustics. His colleagues warned him that the problem was so complex as to preclude satisfactory solution. They even referred to his new assignment as "a grim joke." Sabine realized that success would have to come from his own efforts and, courageously he ignored the amused incredulity of his colleagues.

At the time of Sabine's investigation, the literature of architectural acoustics showed no consensus on the dimensions for an acoustically acceptable room, or the materials of which to build it, or the means to correct existing defects. Sabine recognized that, broadly speaking, only the size and shape and the interior materials, including both the furnishings and the audience, constituted the prime variables in the acoustics of rooms. In most repair work, only the materials could be varied. It was obvious that the reverberation of the

Lecture room in Hunt Hall (then called the Fogg Art Museum) at Harvard University: **a** floor plan, **b** cross section.



Fogg lecture room was too long for spoken words to come through clearly, and that sound-absorbing materials would have to be added. Sabine concluded that his first task would be to determine the relative absorbing power of the substances that might be used in correction. To do this, he needed to be able to measure the rate of decay of sound in the room as he introduced various kinds and amounts of materials.

Sabine groped for a suitable way to measure the decay of sound intensity in a room and concluded that the two known optical methods for measuring the intensity of sound, that is, observing a sensitive manometric gas flame either by a micrometer telescope or by photography, were unsatisfactory. He then chose the measuring setup shown in the figure on page 48. The sound source was a 512-Hz organ pipe, blown from a double tank, water-sealed and noiseless. The air supply was turned on and off by an electro-pneumatic valve. The electric current required for this purpose also produced a mark on the cylinder of a chronograph that measured intervals of time between half a second and 10 seconds with an accuracy of about one hundredth of a second. As sound detector, Sabine used the ears of a human observer whose only duties were to turn the air supply to the organ pipe on and off and to squeeze a hand bulb to produce a mark on the cylinder of the chronograph whenever the reverberation in the room became inaudible.

At the outset, Sabine tested many features of his apparatus in both the unfinished lecture room of the Boston Public Library and the reverberant lobby of the old Fogg Art Museum. In particular, he determined how long a time the organ pipes had to sound before the sound field reached a steady state. He also determined that the viscosity of the air in the rooms had a negligible effect on the reverberation at 512 Hz. Other observers have since found that at higher frequencies viscous sound absorption is in fact significant.

Sabine's early measurements yielded

some interesting results; for example:

- ▶ Measurements in Steinert Hall (Boston) showed that the duration of audibility is nearly the same in all parts of an auditorium
- ▶ In the large lecture hall of Jefferson, he found that the duration of audibility is independent of the position of the source
- ▶ In the Fogg lecture room, the efficiency of an absorber proved to be largely independent of its position
- ▶ Also in Fogg, Sabine found that over a period of time different experienced observers recorded nearly identical durations of audibility for a given stimulus and condition.

With these preliminaries out of the way, Sabine began his research in earnest in the Fogg lecture room during the late fall of 1895. He obtained permission to transport more than 400 seat cushions (filled with hair, covered with canvas and light damask) from Sanders Theater across the wide street to the lobby of the Fogg museum, provided only that they were returned to Sanders within a few days. Introducing these seat cushions into the lecture room a few at a time, he measured the duration of the sound decay at 500 Hz as a function of linear meters of seat cushions. To avoid interference from street noises, he made his measurements after midnight. Next he made similar measurements for curtains, cloth, canvas, hair-felt and oriental rugs. He also made extensive measurements of the same type in Sanders Theater, where moving the cushions from the lobby to the hall was easier.

Over the next five years, the Sanders seat cushions were lugged repeatedly to and from the Fogg and various other rooms, generally after classes were done at the end of the day, and returned to Sanders before classes assembled again the next morning. With two laboratory assistants, Sabine moved the cushions and made his measurements between midnight and 5 am, on either three consecutive or three alternate nights per week. The amount of work involved was prodigious, but, according to his biographer, W. D. Orcutt, Sabine scarcely missed a daytime class except when illness confined him to bed.

Sabine made another significant measurement, essential to his understanding of the lecture room in the summer of 1897. One day, at the close of a lecture, he determined the duration of the residual sound before and immediately after half the audience had left, and then after all of it had gone, thus achieving a measure of "audience absorption"—both per person and per square meter of floor space occupied. He repeated this experiment under better controlled conditions in the large lecture room at Jefferson three years later.

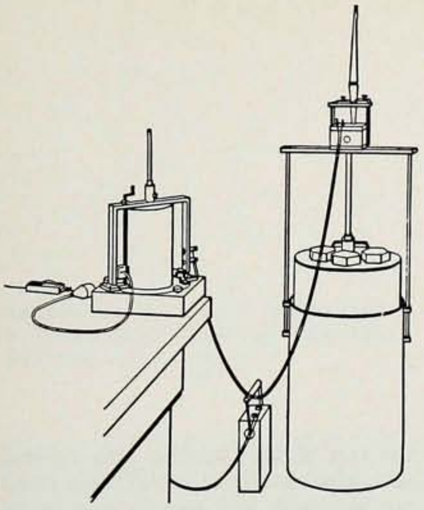
During the first two years after Sabine undertook his research at the Fogg lecture room, Eliot encouraged the acoustical experiments. But then he became exasperated with the delay and issued a reprimand that Sabine could not ignore. In early 1898, Sabine prepared a paper that contained a drawing and specifications for recommended treatment of the Fogg lecture room. That paper served as a guide for the renovation and became the first of 13 articles that Sabine published on architectural acoustics. It describes the placement of hair-felt blankets, 0.75 and 1.05 inch in thickness, on 21 surfaces of the room, and the covering of the platform with a thick carpet. The lecture room was returned to use in October 1898, and although its circular shape prevented it from ever being fully satisfactory, it remained in use for 75 years, until the building was torn down to make room for Canaday Hall. The University paid Sabine an honorarium of $500 for his efforts and, in addition, covered the costs of the experimentation, including the two assistants.

In about 1898, Sabine began to use the constant temperature room in the basement at the west end of Jefferson as a reverberation chamber. (See the figure on page 49.) This room appealed to him for two reasons: first, because it and the rooms extending above it to the roof were separated structurally from the rest of the building, thus normal activities elsewhere in Jefferson could not be heard; and, second, because its walls were constructed of brick and cement, making it highly resistant to excitation by sound. It was here that Sabine first measured the sound absorption at 512 Hz of brick and concrete, both painted and unpainted.

The new Boston Symphony Hall

Sometime early in 1898, Major Henry Lee Higginson, the founder and benefactor of the Boston Symphony Orchestra, having learned that the City of Boston was determined to destroy the old Music Hall to make way for a street, revived plans for a new hall for his orchestra. Apparently Higginson discussed those plans and also some apprehensions he had about the acoustics of the new hall with Eliot. Eliot, who had been pleased with Sabine's recommendations for the Fogg lecture room, convinced Higginson that the architects for the new hall, McKim, Mead and White, could benefit from Sabine's experience. With Higginson's permission, Eliot asked Sabine whether he would consider consulting with the architects. Sabine hesitated before responding. What troubled him was that he had not yet determined a generalized formula that would allow him to extrapolate from his measured results to the plans for an unbuilt structure.

Believing that there must be such a generalized formula, Sabine devoted the next fortnight to a feverish restudy of the seat-cushion data at 512 Hz that he had taken in a dozen or so rooms of various sizes and reverberances around Harvard. On Saturday evening, 29 October 1898, the answer came to him. He turned to his mother who was nearby and said, "I have found it at last! It's a hyperbola!" (See the figure on page 50.) The very next day he wrote to Eliot: "You may be interested to know that the curve in which the duration of the residual sound is plotted against the absorbing material is a rectangular hyperbola with displaced origin; that the displacement of the



Acoustical setup for controlling the sounding of an organ pipe and accurately measuring intervals of time.

origin is the absorbing power of the walls of the room; and that the parameter of the hyperbola is very nearly a linear function of the volume of the room. . . . 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." The formula, known as the Sabine formula, is:

$$T = KV/S_t\overline{\alpha}$$

$$\overline{\alpha} = (S_1\alpha_1 + S_2\alpha_2 + \ldots\ldots)/S_t$$

where T is the time in seconds it takes for sound to decay 60 decibels in the hall; K is nearly a constant, inversely proportional to the speed of sound; V is the room volume; S_t is the total area of all surfaces in the room; and $\overline{\alpha}$ is the average sound absorption coefficient of the surfaces in the room, each of which has area S_n and sound absorption coefficient α_n.

Eliot, reinforced by Sabine's new confidence, wrote forthwith to Higginson to tell him of the kind of help he thought Sabine could give the architects. The encouragement and resources of Harvard during Sabine's previous three years of study now bore fruit, and his findings were about to be subjected to practical test.

Over the next eight months Sabine frantically collected the new data he thought necessary. He studied the effect of organ-pipe intensity on the accuracy of his data. He assembled measurements comparing the absorbing power of carpets, cheesecloth, cretonne cloth, cork, open windows, and seats of several kinds. He conducted tests in various university rooms, including the lecture hall, the constant temperature room and room 41 in Jefferson; the faculty room, clerk's room and dean's room in Harvard's University Hall; and five rooms at the Harvard Botanic Gardens. He also returned to the two rooms he had experimented in at the Boston Public Library.

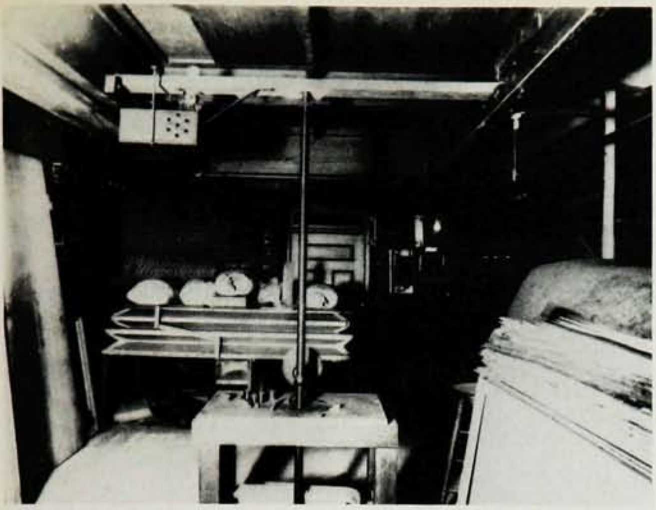
Following the initiation of the Boston Symphony Hall project, McKim, Mead and White had worked with Higginson's building committee to choose a suitable shape and size for the hall. Acting primarily on the advice of musicians and a few lay observers who had heard music in a number of European halls, they decided to model the design after the Neues Gewandhaus in Leipzig, Germany, but to increase the seating capacity by about 70% over the Gewandhaus's 1560 seats. Sabine later wrote, "At this stage calculation was first applied . . . which, proportions being preserved, would have doubled the volume . . . resulting in a [calculated] reverberation time of 3.02 seconds." That time is half again as much as he had calculated for the Gewandhaus. Sabine continued, "This would have differed from the chosen result by an amount that would have been very noticeable." Today we know that the proposed hall would have been completely unacceptable.

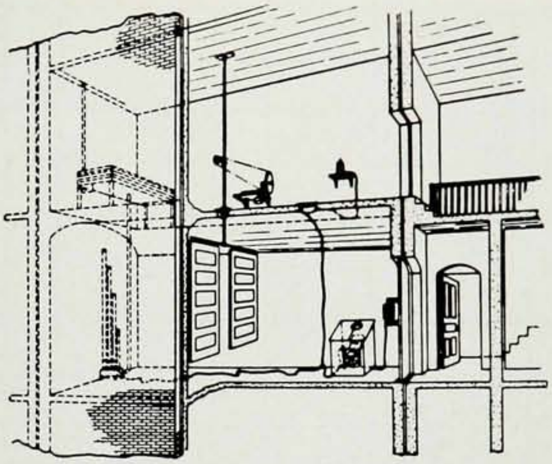
Sabine and the architects agreed that the hall should not be significantly greater in length than the Gewandhaus. Attention then turned to the existing Boston Music Hall, which Boston audiences found quite satisfactory. The Music Hall was rectangular in shape, of nearly the same length, and had a calculated reverberation time only slightly longer than in the Gewandhaus. It accommodated the desired larger audience by having two balconies instead of one, whose floors lay parallel to the sloping main floor. Sabine wrote that, "the real discussion was based on only two buildings—the present Boston Music Hall and the Leipzig Gewandhaus; one was familiar to all and immediately accessible, the other familiar to a number of those in consultation. . . . It should, perhaps, be added immediately that neither hall served as a model architecturally, but that both were used rather as definitions and starting points on the acoustical side of the discussion."

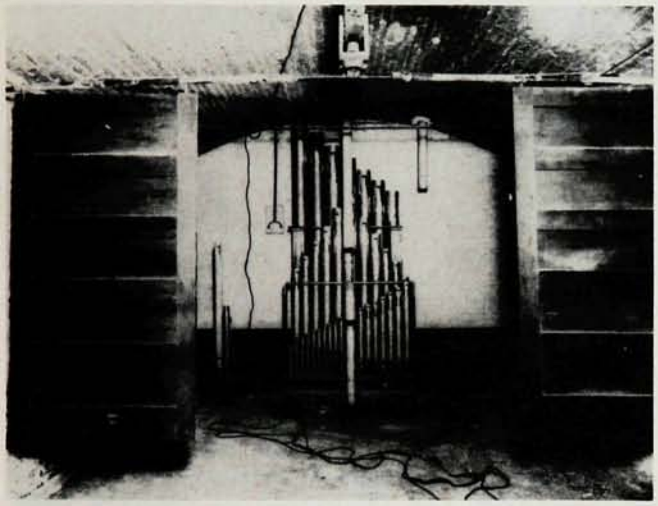
In addition to reverberation time, Sabine also advised the architects on other points, described after the fact in a letter to Higginson in February 1899. These included such recommendations as eliminating the balcony seating along the sides of the stage, narrowing the stage and splaying its sides. The effect of this, he said, will be to "increase the loudness or volume of the sound, and at the same time . . . better the 'attack.' The reflected sound and the sound coming directly [to the listeners] will more accurately unite. . . . In respect to loudness, I do not think that the new hall will, on the whole, be at a disadvantage in comparison with the old. . . . In respect to reverberation, the two halls will be very nearly the same. . . . "

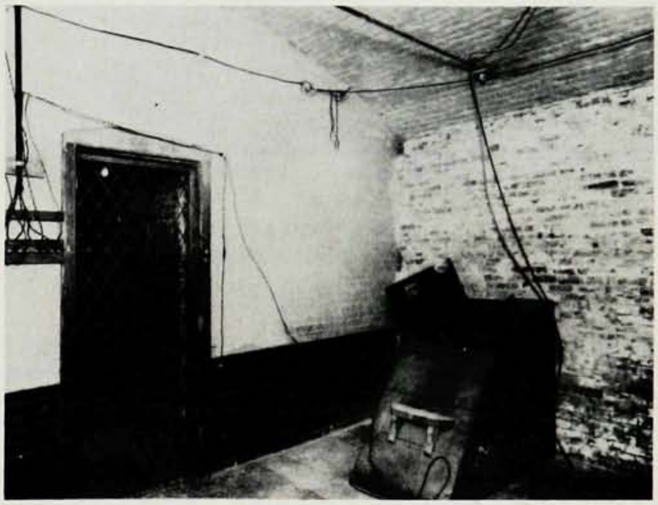
Although Sabine makes no mention of it, the ornate interior of Boston Symphony Hall, with its coffered ceiling and sidewall niches and statues, contributes significantly to its good acoustics. Sabine paid particular attention to eliminating ventilation noise, writing: "Transmission of disturbing noises through ventilation ducts . . . is practically a legitimate and necessary part of the subject. . . . [Ventilation] is best secured by a system . . . known as 'distributed floor outlets.' It has the additional merit of being, perhaps, the most efficient system of ventilation."

Sabine was to suffer bitter disappointment following the opening of Symphony Hall on 15 October 1900. Musicians and critics from around the world who heard the hall in its early









Constant temperature room in the Jefferson Physical Laboratory. On the left of the cutaway view is shown the control room with the wind chest feeding the organ pipes and the motor-driven rotating shaft connected to the sound-diffusing panels in the room below. Below left is a view of the organ pipes and the rotating sound-diffusing panels. The rotating panels greatly reduced the fluctuations in intensity of the decaying reverberating sound, making it possible for the observer to determine more accurately when the reverberation became inaudible. Below right shows the box in which the observer was enclosed to eliminate the sound-absorbing effect of his clothing. The photos were taken around 1919. (Photos courtesy of Riverbank Acoustical Laboratories, Geneva, Illinois.)

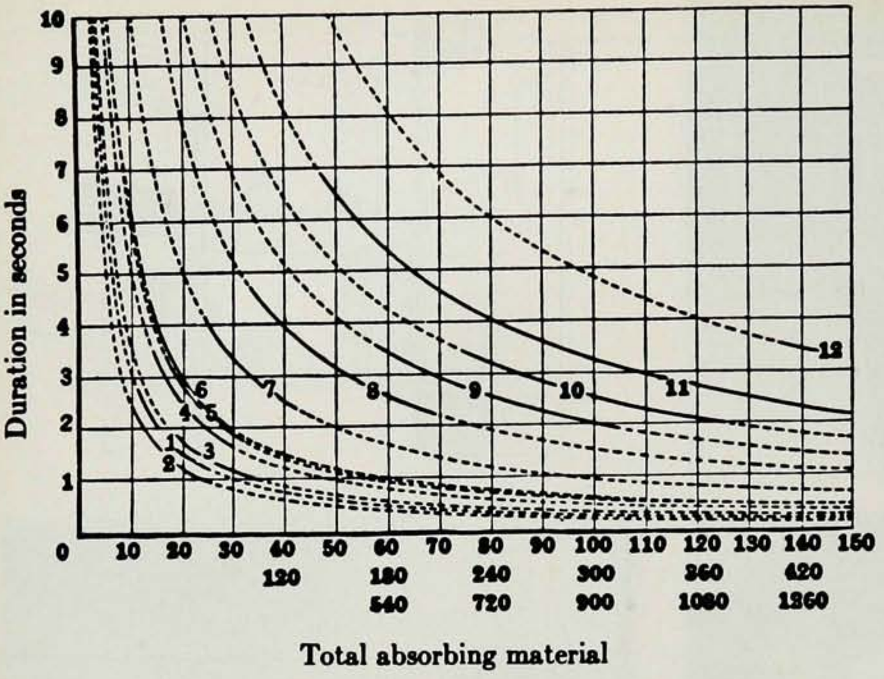
years compared it unfavorably with the better halls of Europe. Two years after it opened, an article appeared in the 31 December 1902 edition[4,5] of the prestigious *Boston Evening Transcript*, entitled "Boston Symphony Hall—a Scientific Analysis of its Acoustics—The Hall Said to Possess Wonderful Adaption to the Transmission of Pure Notes to All Parts of the House—The Dissident Judgement of a Music Critic." The article, signed by Frank Waldo, PhD, praises the hall and quotes from articles by a Dr J. B. Upham and Sabine. Appended to the article was a note, in square brackets, by the *Transcript*'s respected music critic, William Foster Apthorp:

> This is all very well; but, like many essays on musical subjects by scientists, it arrives at conclusions with which most musicians find it difficult to agree. To begin with, neither the late Dr. Upham nor Mr. Sabine can be rightly deemed competent to express a musical opinion of any weight whatever; both come musically in the amateur class. And, to conclude with, we have not yet met the musician who did not call Symphony Hall a bad hall for music. Expert condemnations of the Hall differ, as far as we have been able to discover, only in degrees of violence.
>
> —W.F.A.

Boston Symphony Hall, unchanged today, is rated the greatest hall in the western hemisphere and, for its size, one of the greatest in the world. One explanation for its poor initial reception may have been its size; it seats 2625 persons, almost twice the 1400 seats typical of European halls. Thus, with an orchestra of 90 or so—the usual number of musicians in 1900—the music sounded thin in Symphony Hall. With today's complement of 104 musicians, the sound is fuller and louder.

A second disappointment came to Sabine when the reverberation time of the completed Symphony Hall was measured at half a second shorter than he predicted in his published paper of 1900 (calculated as 2.3 seconds versus 1.8 seconds actual). The reason for the discrepancy was that he had understated the absorbing power of the audience by calculating it on a "per person" rather than a "per square meter" basis. His earlier measured data were published both ways, but his choice of the per-person prediction of the reverberation time was unfortunate because the area per person was greater in Symphony Hall than in the Jefferson lecture hall, where the earlier measurements were conducted. So unhappy was Sabine that in no paper after 1900 did he mention Symphony Hall, and when questioned about it he would only say that the real test of his work must come with actual use of the hall for the exact purpose of its erection.

I hasten to add that the effect of



Plot of the audible duration of sound at 512 Hz as determined by a listener from the instant the organ pipe was cut off. The graph, reproduced from Sabine's original paper, shows curves for 12 rooms. The solid portion of each curve shows the measured data as a function of the number of square feet of Sanders Theater seat cushions introduced into the room. Room No. 11 is the Fogg lecture room and No. 12 is Sanders Theater. The dashed portions of the curves are hyperbolas fitted by Sabine to the measured (solid line) portions.

Sabine's choice of predictions in the design of the volume and shape of the new hall was of no consequence. His primary concern was to compare his calculations for the new Symphony Hall with those for the Boston Music Hall. Because the volumes and areas per seat were nearly equal, his calculations for both halls were about equally high. The Boston Music Hall, now called the Orpheum Theater, is still standing, although renovations have completely changed the interior.

Back to teaching

One can imagine that those five years of intensive nightly measurements would have aroused questions and comments among his teaching colleagues. Perhaps they got the impression that he was apathetic toward his academic work, because his only opportunity to sleep was during the day. Another irritant to his colleagues may have been his preemption for his project of laboratory assistants, who were, consequently, of little help to other faculty members because they too had to sleep during the day. Still remembered in 1900 were the stories that circulated about Sabine and his assistants dragging hundreds of seat cushions from Sanders Theater to various Harvard buildings late in the day and dragging them back in the early morning. Whether he was impelled by this collegial reaction or by other disappointments, without apparent reason Sabine threw himself wholly into teaching in the academic years 1900 to 1904.

In 1900 Sabine asked to be assigned direct responsibility for "Physics C," an introductory experimental physics course, as well as for three other courses covering light, heat, thermodynamics and physical optics—courses that were open to both graduates and undergraduates. But it was the undergraduate Physics C that interested him most. Eliot had noted in his annual report for 1899–1900 that enrollment was much higher in chemistry courses than in physics—a fact he thought most curious. After all, he commented, physics was broader in scope than chemistry, and there was considerable demand for competent teachers trained in heat, light and electricity. Eliot's prescience was rewarded: In the three years following Sabine's embarking on Physics C, the attendance jumped from 69 to 236, prompting Trowbridge to write in his report of 1902–03: "The marked success of this elective is due to Professor Sabine." A year later Trowbridge added: "Physics C now occupies three large laboratories in Jefferson. The success is due to the constant effort of Professor Sabine to increase its instrumental appliances and to raise its intellectual level."

Strangely, Sabine went without promotion for ten years, despite the high quality of both his teaching and research. Theodore Lyman once intimated to me that Sabine may have been neglected in the wake of the adverse criticism of Symphony Hall. Furthermore, Higginson paid him no consulting fee, even though Eliot had set a precedent for doing so at the Fogg.

Recognition

In 1904, Sabine began to accept commissions from architects to advise on the acoustics of churches, cathedrals, auditoriums and theaters by the dozens, and the Boston Opera House (now demolished to make room for a parking lot). His need for reverberation data over a wide range of frequencies on diverse building materials sent him back to his laboratory in Jefferson's constant temperature room in successive bursts of intense all-night, three-nights-a-week activity in 1904–05, 1908–09, and again in 1914–15. In 1906, he wrote, "Each problem has been taken up as it has been brought to the writer's attention by an architect in consultation either over plans or in regard to a completed building. This method is slow, but it has the advantage of making the work practical. . . ." His papers, the last of which was published in 1915, and his consultations established his fame.

Sabine worried constantly about the propriety of accepting fees or royalties for his work in acoustics. Early in his Harvard career he raised the question with Eliot, who later wrote, "I repeatedly pointed out to him that Harvard University gained much whenever its professors contributed to the public welfare, . . . and, further, that no sharp and fixed line can be drawn between Pure and Applied Science, since what is pure today may easily have valuable

Interior of the Boston Symphony Hall. (Courtesy of Boston Symphony Orchestra.)

applications tomorrow."

Finally, in 1905, Sabine's promotion came—a double advancement to full professor, which his biographer says caused Sabine real embarrassment and mystified his family and friends. Eliot later commented on this delayed promotion, but offered no explanation: "Sabine served five years as instructor in physics and ten years as assistant professor at Harvard University before he reached the position of full professor, in spite of the fact that he quickly proved himself an admirable teacher and a highly successful investigator." As a full professor, his salary was raised to the standard professorial $4000 and it remained the same for the next 10 years.[6]

Soon after his promotion, Sabine again surprised his colleagues when, after many years of not participating in faculty meetings, he proposed, early in 1906, a radical reorganization of graduate study in applied science at Harvard. This proposal, and the sudden death of Dean Nathaniel S. Shaler, elevated Sabine to the post of dean of the graduate school of applied science, which he held for nine years with an annual supplement to his professorial salary of $500. His biographer says that he took the position of dean reluctantly, and only after persuasion by Eliot, because his primary interest continued to be research and teaching.

William F. Osgood has commented on Sabine's success at discovering and attracting to Harvard promising young scientists—among them Percy W. Bridgman, Edwin C. Kemble, Francis Wheeler Loomis, and Theodore Lyman. In 1976, Kemble, the last link between Sabine and ourselves, wrote[4] to me, "Sabine was personally responsible for my coming to Harvard for graduate work. My undergraduate patron, Dayton C. Miller, who was also an acoustics man, wrote to Sabine and Harvard offered me a fellowship which Sabine paid for out of his personal pocket. I took Sabine's Optics the first year and liked him exceedingly. He had me at his Marlborough Street home for dinner and I remember once lunching with him to talk over a personal problem. But in the spring of 1917 he was off to war . . . two years later he was gone."

In July 1915, Sabine was appointed "Hollis Professor of Mathematics and Natural Philosophy," though he hardly had an opportunity to enjoy his new status. He was completely absorbed with the dismal prospect of World War I and, taking a leave of absence, he served the allied war effort. First he prepared in Switzerland a planning report for the International Tuberculosis Commission. Then, in 1917, he visited the battlefield twice on scientific missions, returning to the US in September. Thereafter, until the war ended in November 1918, he spent four days of each week in Washington advising on aircraft design and production and from Tuesday to Thursday he met his classes in Cambridge. It might be said that *de facto* he was the first chief scientist of the US Air Force.

On 7 January 1919, he underwent an operation to remove a malignant kidney. His death followed three days later. The obituary "minute" prepared by his colleagues for presentation to the Harvard faculty contains a fitting conclusion, "He succeeded by reason of a combination of qualities among which were unending patience and untiring energy."

* * *

I am deeply grateful to Geraldine Stevens for her invaluable editorial help in the preparation of this article. The article is based on a talk given on 4 May 1984, at the centennial celebration of the Jefferson Physical Laboratory.

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