Editor's Note: *This is the seventy-sixth in a series of review and tutorial papers on various aspects of acoustics.*

# Wallace C. Sabine, acoustical consultant

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Twenty-two correspondence files of Wallace C. Sabine, discovered recently at the Riverbank Laboratory, contain a rich supply of solutions to acoustics and noise control problems. Differing from his published papers [*Collected Papers on Acoustics*, edited by T. Lyman (Dover, New York, 1964)] and notebooks [J. Acoust. Soc. Am. 61, 629–639 (1977)], they are records of Sabine's extensive activities between 1909 and 1916 as an acoustical consultant. His projects covered auditorium acoustics, building noise transmission, the reduction of noise from industrial plants and from machines. Of interest also are Sabine's findings on a constant-power sound source, his part in the invention of acoustic tile, and his policies and ethical standards as an acoustical consultant.

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## I. THE BACKGROUND

The published papers[1] of Wallace Clement Sabine, the father of the science of architectural acoustics, reveal him as a physicist and meticulous experimenter of far-seeing vision. His biographer W. D. Orcutt[2] characterizes him as a man of gentle but firm character, with singleness and tenacity of purpose. He was known as a man of high principle and great modesty, possessing a far-ranging store of accurate knowledge, skilled at expressing himself and willing to extend help to anyone asking his advice (see Fig. 1).

Wallace Sabine was the first modern acoustical consultant. He is best known for his contribution to the design of Boston Symphony Hall—one of the country's finest concert halls, which was completed in 1900. During the rest of his life, he advised on hundreds of churches, cathedrals, auditoriums, theatres, and an opera house. His need for acoustical data over a wide range of frequencies on diverse building materials sent him back to the laboratory in successive bursts of intense activity in 1904–05, 1908–09, and 1914–15. In a technical paper published in 1906 he said, "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 . . . ."[1,3]

The present paper, a summary of some of Sabine's consulting experiences beginning in August 1909, results from an unexpected finding. In early 1979, the Illinois coauthor discovered in a dusty corner of a small closet in the Riverbank Acoustical Laboratory, twenty-two correspondence files of Wallace Sabine. This surprise discovery came on the heels of an earlier find in the same Laboratory of a dozen research notebooks of Sabine's, which have been indexed and placed in the Harvard University Archives for reference and preservation.[4] How did Sabine's notebooks and files come to be at the Riverbank Acoustical Laboratory?

FIG. 1. Sketch of Wallace Clement Sabine.

Sabine's untimely death in January 1919 at the age of 50 created a desperate situation for a Colonel George Fabyan, who lived on a 500-acre estate in Geneva, Illinois, which he had named Riverbank.[5] In addition to managing the Chicago office of his father's textile firm, Colonel Fabyan made a hobby of secret codes and ciphers. About 1909 an expert in his employ deciphered a supposed secret code that described an acoustical device that would demonstrate "levitation." Fabyan had a machine constructed after that description. When it failed in its purpose, he asked his Harvard Professor brother to help him find the "foremost acoustical consultant in the country" to advise him.[5] Probably from his brother, he learned of Sabine, whom he apparently


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induced to visit Riverbank, very likely in 1913, to see the machine. Through this visit, Fabyan became interested in Sabine's acoustical experiments at Harvard. Sabine told him of the difficulties of working in Cambridge where the laboratory was quiet only after the street cars had stopped running late at night and before the milkcarts started rolling over the cobblestones in the morning. Fabyan was impressed with Sabine's work and offered to build a laboratory "out in Illinois on the prairie where there just isn't any noise" to Sabine's design and for his use.[5] Sabine agreed, but there is no record that any conditions of use were actually imposed.

Working with Fabyan and a Chicago wookworker, B. E. Eisenhour, Sabine designed a building that was completed in 1918 shortly before his death. It was originally named the "Wallace Clement Sabine Laboratory of Acoustics," and its details were described in *The American Architect*.[6] This three-story building with basement contains several acoustic test chambers and experiment rooms, shops, and offices (see Fig. 2).

FIG. 2. Riverbank Acoustical Laboratory in 1918. It was originally known as the Wallace Clement Sabine Laboratory of Acoustics and the etched glass pane in the main entry door still bears that name.

After Sabine's death, Colonel Fabyan turned once again to Cambridge to seek a possible successor. He learned that among the students who had attended Professor Sabine's physics classes was a distant cousin of Wallace's, Paul E. Sabine, who had received a Ph.D. in physics at Harvard in 1915 in the field of spectroscopy, and who in early 1919 had just completed the calibration of a wind tunnel at the U.S. Navy Yard in Washington. Because World War I had only recently ended, Sabine was available, and he responded favorably to Fabyan's invitation to transfer his interests to the field for which the Riverbank Laboratory had been built. Paul Sabine served as its Director from the spring of 1919 to 1947 and created at Riverbank a highly respected national testing laboratory.

One can imagine how inadequate Paul Sabine must have felt when he accepted the challenge of directing this as yet untried laboratory. There is no evidence that he had ever worked in acoustics. He would have discovered from Wallace's published papers that plans had been made for completing a number of investigations and he would have suspected that Wallace's research notebooks might reveal the basic reasons behind many of the details of the Riverbank Laboratory.

Wallace Sabine's assistant after 1916 had been John Connors, who was engaged with him at the time of Sabine's death on the "Standardization of the Riverbank Organ Pipes, $C_1$ through $C_7$" (72 pipes).[4] Connors continued to work on that project until August 1919. Certainly Paul Sabine went to Harvard to inspect the organ pipes and to arrange for their shipment to Riverbank. He would have obtained and perhaps discussed with Connors the calibration data that were contained in the last one of the dozen notebooks previously described.[4] He probably was shown Sabine's files of correspondence, with their hundreds of letters relating to consulting projects. It is plausible that if Paul asked Connors for the notebooks and pertinent files, Connors, who had been very close to Professor Sabine, would have assented, believing that there could be no better disposition of them. As Professor Edwin H. Hall of Harvard later said, "John knew more about his (Wallace Sabine's) acoustic experiments and his plans for future work than did any member of the teaching staff."[2]

Several biographical questions remain unresolved by the discovery of Sabine's files. First, apparently neither Wallace Sabine's widow nor Professor Theodore Lyman, who edited the book of Sabine's *Collected Papers*, were aware of the existence of those notebooks and files. In the Preface to the *Collected Papers* Lyman wrote, "In addition to the papers already in print at the time of the author's death the only available material consisted of the manuscripts of two articles, one on echoes, the other on whispering galleries, and the full notes on four of the lectures on acoustics delivered at the Sorbonne in the spring of 1917." In 1939 Lyman told the Cambridge author that he had watched Sabine, toward the end of his life, burn a large stack of written materials, apparently as a consequence of "extreme self-criticism and repression."[1] If Lyman believed that no notebooks or files survived, he would not have asked Paul Sabine if there was any additional material. Certainly as late as 1939 Lyman was unaware of the existence of any notebooks or files of Wallace's. However, Paul had, some years earlier, mentioned "notes and unpublished papers" in a 1919 form letter that he had circulated widely (emphasis added). We quote:

> Having known the work of my cousin, the late Professor Wallace C. Sabine, on Architectural Acoustics it will, perhaps, be of interest to you to have the enclosed appreciative review of his life, written by Professor Hall of Harvard.[7]
>
> Prior to his death, Professor Sabine had planned to enlarge the scope of his researches [at] this laboratory ...
>
> It is our purpose to carry out, as fully as possible, in the scientific spirit in which it was planned, the program which had been laid out by

Professor Sabine, *making use of the notes and unpublished papers which he left.*

The Laboratory will welcome at any time inquiries and suggestions concerning practical problems in architectural acoustics.

Paul Sabine also made it known in other ways that there were unpublished data of Wallace's to which he had access. On p. 41 of his 1932 book[8] he wrote, "From his notes of the period it is possible to give the experimental details of the investigation (on the distribution of sound intensity in a room)." Again on p. 123 Paul wrote, "Pencilled notations in his notes of the period indicate that further work was contemplated." In 1936, Paul wrote,[9] "The notes of those first five years contain data . . . . Fragmentary notes of the period suggest the vast amount of labor involved . . . . It has to be said in passing that Professor Sabine's notebook is not a model of neatness and order . . . . We find a succession of pages of readings with no apparent meaning . . . . The picture presented is that of an extremely busy man with little time and no necessity for recording in detail the course of his experiments . . . . From his notes, we know that on the night of December 11th, 1918 . . . he was measuring . . . again on the 14th and for the last time on the 16th he was at work with only his faithful friend, John Connors . . . ." Those excerpts all refer to the notebooks now in the Harvard Archives.[4]

What Professor Lyman saw Sabine destroy could have included: Correspondence before 1909, the missing correspondence folders between 1909 and 1918, the over 200 pages of technical material produced between 1900 and 1904 that were excised from his notebooks, and the missing notebooks A, B, and C, that Sabine mentioned.[4]

A second interesting point is that the only surviving piece of evidence in Wallace Sabine's files of his acoustical work between 1900 and 1905 is a clipping of an article from the December 31, 1902, edition of the prestigious *Boston Evening Transcript*, entitled "Boston Symphony Hall—A Scientific Analysis of Its Acoustics—The Hall Said to Possess Wonderful Adaptation to the Transmission of Pure Notes to All Parts of the House—The Dissident Judgement of a Musical Critic."

This article by Frank Waldo, Ph.D., is a reprint from *The World in General* and quotes two sources, an article by Upham on "Acoustic Architecture" (circa 1852–53) and a 1900 article by Sabine.[10] Waldo endorsed the acoustical theories expressed in these two articles and commended the acoustics of Symphony Hall which was apparently under musical attack. Appended to the article is the following 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.

Apthorp's condemnation is surprising in the light of Symphony Hall's subsequent widespread acceptance by musicians and critics although no changes have ever been made in the Hall.

## II. THE CORRESPONDENCE FILES

The twenty-two correspondence folders of Wallace Sabine found at the Riverbank Laboratory cover the period August 1909 to June 1916, with a few items from late 1918 and early 1919. The folders are classified by subject or correspondent and are numbered. They appear to be part of a total of perhaps 380 that must have existed at one time. They reveal Wallace Sabine's expert knowledge of practical architectural acoustics and his skill at solving acoustical problems and in dealing with architects. The files have been assembled into a stack of typewritten pages by the Illinois author, of which one copy will be retained by the Riverbank Acoustical Laboratory [1512 Batavia Avenue, Geneva, Illinois 60134] and one will be sent to the Harvard Archives for preservation along with the dozen notebooks.

The folders themselves consist mainly of correspondence between Sabine and his clients. Copies of Sabine's letters are chiefly carbons on yellowish paper of typewritten originals. The clients' inquiries and replies are in their original form. Almost every file describes an acoustical problem along with the appropriate solution. The material fills in gaps in the previous history of this remarkable man, and none of it contradicts any information previously published. Of the greatest interest to acoustical consultants are Sabine's solutions to problems in architectural acoustics which still form valuable references for many special acoustical situations and which are the *raison d'être* for this paper.

## III. IMPROVING THE QUALITY OF SOUND IN THE AUDITORIUM

Wallace Sabine was first known to American architects through a series of articles, published in 1900.[10] After the completion of Symphony Hall in Boston, Sabine's next known acoustical consultation was on the New England Conservatory of Music (1902–04).[2,3] There he recommended the addition of sound-absorbing material to improve the listening conditions in a number of rooms. In 1903 he studied the echo in Colonel Astor's indoor tennis courts at Rhinebeck-on-the-Hudson. In 1904 he advised on the Pulitzer House in New York, and in 1905 on a proposed Catholic Cathedral for Los Angeles. From 1906 to 1908, he consulted on many structures including St. Paul's Cathedral in Detroit, the Congregational Church in Naugatuck, Connecticut, the Hall of the House of Representatives in the Rhode Island State Capitol Building, and the Century Theatre in New York.[11]

In 1908 and early 1909 his most important consultations were on the Chapel of Union Theological Seminary in New York, St. Mary's Church in Minneapolis, the Hall of the House of Representatives in Washington, D.C., the Middlesex County Court House in Cambridge, Massachusetts, the Boston Opera House, West Point Chapel, St. Thomas Church in New York, and the Halifax Cathedral in Nova Scotia.[4] The consulting files for these years are interspersed with discussions with architects and other exchanges of letters—some of which are merely requests for copies of his 1900 and 1906 papers.[10,3] Of the acoustic problems presented by these buildings, only two, the Congregational Church in Naugatuck, Connecticut, and St. Paul's Cathedral in Detroit, are discussed in print.[11]

By 1908 Sabine was recognized as the authority on architectural acoustics, without even a recognized competitor.

## IV. SINAI TEMPLE

In 1910 Wallace Sabine was asked by Alfred S. Alschuler, a Chicago architect, to consult on the proposed Sinai Temple. The most important letters are Alschuler's of November 11, 1909, which asks a series of twenty questions, and Sabine's responses of November 21 (in File No. 100). Here the questions and answers are alternated, with minor editing.

Sinai Temple was planned primarily for the use of a single speaker, and the organ and choir were to be secondary. It was to be constructed of reinforced concrete so as to be entirely fireproof, and the walls of the auditorium were to be plastered. The seats were to have three layers of flat cotton padding covered by "pantasote" leather, all seat woodwork was to be five-ply veneer. Unfortunately no drawings of the building or the seats are available.

Q.1: The method of constructing the floor of the platform. It will probably be of wood.

A: Your choice of wood is good. Should you cover the platform with carpet, it should be thin; it will then serve to deaden footsteps without perceptibly diminishing resonance.

Q.2 and 4: Effect of covering the cement floor throughout with carpet strips in the aisles and between seats.

A: (a) The aisles should be covered with thick carpet. All sound which reaches the plane of the audience should be absorbed. Any reflection from that plane is without further value but is ultimately, after reflection from other surfaces, a source of disturbance. (b) Carpet between seats is less necessary than in aisles and need not be so thick.

Q.3: Slope of risers throughout.

A: The slope of the risers (front edges of seating steps) should be left to considerations other than those of acoustics. Even if they are vertical, they will produce no acoustical effect since sound passing over the seats, be they in any form whatsoever, is broken in direction and very irregularly reflected.

Q.5: Wood paneling at the back of the platform.

A: This paneling should be thin and separated by an inch from the solid wall behind it in order to secure its best resonant effect.

Q.6: Effect of choir balcony and its position: Square corners around balcony or cove or curve in panel below it to throw the sound sideways.

A: The choir balcony is in the most effective position for the choir but it detracts in some small measure from the audibility of the speaker. Its floor level is not more than 2.5 feet above the speaker's head. The opening of this balcony is well designed to throw forward the voices of the choir. However, all that portion of the speaker's voice that comes within the balcony opening is absorbed by the clothing of the choir. I would suggest that the railing in front of the balcony be solid and not pierced. This will reflect the spoken voice, but will not absorb the voice of the choir when standing.

Q.7: Rounding or coving the lower face of platform.

A: The face of the platform is without acoustical effect since comparatively little sound will reach it if the speaker stands behind the pulpit. Moreover, any sound which did reach it would, after reflection, be absorbed by the clothing of the people in the front row, who sit about a foot higher than the surface of the platform.

Q.8 and 9: Method of deadening the surface directly over the speaker's head to remove the possibility of echoes.

A: It will not be necessary to deaden that surface because it is not at such a height or distance from the speaker as to produce a distinct echo, and its effect on the whole will be to strengthen the sound. It would be well, however, to *break* the surface in order that its distributing effect may be a maximum.

Q.10, 11, and 14: Best method of ventilation and general distribution of air currents. Should exhausts be placed at the rear of the building to draw the currents in that direction? Air inlets near speaker? Under seats?

A: From an acoustical standpoint, the best method of ventilation is that of distributed floor outlets. The greatest acoustic influence of ventilation arises from possible irregularities of temperature, particularly if they are columnar or in numerous layers. You will, on the whole, get the most uniform temperatures if you use distributed floor outlets and introduce warm air fairly high in the auditorium and in front of the windows. Air registers in front of the speaker and under the seats should be outlets and not inlets.

Q.12: Question of placing much relief decoration on the face of the platform rail and material of rail.

A. Neither adding decoration nor making the rail of wood rather than iron would alter the acoustical effect.

Q.13: Question of making the floor of projecting organ balcony in lattice form to allow air circulation.

A: As previously mentioned, it should not be in lattice form.

Q.15: Question of shape of large cornice under barrel vault.

A: The shape indicated for the large cornice under the barrel vault is good, but irregularities are recommended on the surface, to make the reflection general rather than in a narrow direction.

Q.16: Question of curving the ceiling over the balcony seats.

A: A great arching would be objectionable, but there is no acoustical objection to a moderate ceiling curvature.

Q.17: Question of section of large columns.

A: The columns should be fluted to some extent and not plain and unbroken.

Q.18: Question of plain flat organ pipes exposed over back of speaker's head or an architectural grill in this space.

A: The display pipes in front of an organ are always of the nature of grill work. In general, organ pipes are more closely spaced and form a better reflecting surface than would grill work, but an architectural grill having the same proportion of solid parts to open work would be acoustically its equal.

Q.19: Can any relief work or projections such as pilasters, etc., be placed at the back of platform?

A: A somewhat broken surface at the back of the speaker is desirable and an architect is at liberty to use pilasters and other irregularities of that sort. The object of this is for the speaker's voice to be mirrored from several small surfaces rather than from one large surface.

Q.20: Question of height of platform as affecting the height of the speaker's voice above the main floor.

A: The height of the platform must be determined acoustically from the dimensions of the auditorium and the inclination of the seats. For your expanse of auditorium, a somewhat higher platform than you have planned is recommended.

Q: How should plaster be applied to the various surfaces?

A: Where possible the plaster should be placed on wire lath rather than directly on tile or on brick. All modern advances (1909) in building material have been dictated by sanitary and fireproofing considerations. The result is harder and more impervious material. Both are in the wrong direction for good acoustics, and for that reason the buildings of today are less likely to be successful than the corresponding buildings of old.

> I have gone over your plans as a whole; the dimensions of the building, distribution of the seats, inclination of the floor of the auditorium, the wall surfaces above and beside the platform. I desire to express my general approval. Were I to offer any criticism it would be that the room is rather broad, but I do not urge this as a severe criticism.

On completion, Alfred S. Alschuler, the architect, won a competition for his design of the Sinai Temple.

## V. CATHEDRAL OF ST. JOHN THE DIVINE

Between January 1912 and May 1913, Sabine consulted on the Cathedral of St. John the Divine in New York and, somewhat later, on the Hall of the Synod House adjacent to it with the architects Cram, Goodhue, and Ferguson, of New York and Boston (File No. 189).

A letter to Mr. Cram in April 1912 discusses a sounding board:

> The purpose of a so-called sounding board is to reflect down upon the audience the voice which would otherwise rise to the ceiling and to the upper walls. The effect of this is two-fold: It somewhat strengthens the sound to the audience; it somewhat reduces the general reverberation. The effect of a sounding board is ordinarily not very great, but such (effect) as it has is dependent upon the angle which it subtends above the head of the speaker; in other words, upon its large area and low height. The sole considerations which should limit it in this respect are therefore architectural.
>
> The advantages of the thin concave, sometimes called parabolic, sounding board, are that it may be given a spread and be brought down closer to the head than would be tolerable under the ordinary canopy form.

In the middle of July 1912 Sabine submitted a report to Mr. Cram on the design of the Cathedral of St. John the Divine. Here, edited slightly to reduce redundency, it is virtually a textbook of Sabine's techniques of that time.

> I beg to submit the following report on the Cathedral of St. John the Divine. The report is based on the blueprints with which Dean Grosvenor supplied me, on three personal investigations of the building when not occupied, and on the experience of five services listened to from different parts of the floor.
>
> It is perhaps superfluous to say that hearing is unusually difficult, but it is not entirely superfluous to say that this condition arises not merely from the great height of the Cathedral but from the very rigid granitic material of which it is composed. Aside from the general reverberation thus produced, there is a distinct echo coming from the chancel and apse.
>
> Disregarding for the moment the chancel and apse effect, the acoustical difficulty in the Cathedral may

be regarded as practically that of general reverberation.

For a (512-Hz) note, the reverberation in St. John the Divine in its present condition, and with an audience occupying all the seats, is ten seconds. It is about twice as great as that of St. Paul's Cathedral in Detroit. It is half again greater than Halifax Cathedral with one-third audience. Twice as great as West Point Chapel with its normal attendance, and comparing it with European cathedrals, slightly greater than York (transept and nave, not the chancel to which services are ordinarily restricted) and not so great, at the present stage of the construction, as St. Paul's in London.

My first intention, on completing my computations of the changes which would have to be undertaken to make the result wholly satisfactory, was to make a negative report and to urge that nothing be done, because it would be structurally difficult and indeed impossible. I so reported to you orally. On your request I took it again under consideration with the end in view of recommending such changes as would produce the maximum effect with a minimum expenditure and with the least possible evidence visually.

Repeating that it will not give entire correction of the acoustical difficulties in the Cathedral, but that it will give a very pronounced relief, my recommendation is that all of the concrete surfaces on the side and rear walls of the nave and transept crossing be covered with two inches of clarified hair felt and this in turn covered by a porous fabric stretched and matching in color with the present surface. Even this is a considerable undertaking as it means covering some seven thousand square feet, with somewhat difficult conditions as to scaffolding.

The result of this treatment will be a reduction of the reverberation from ten to six seconds. I can perhaps give the best idea of the magnitude of this effect by saying that it is the equivalent of increasing the audience by the addition of fourteen hundred persons most effectively distributed. The cost of this would be approximately $4000. If the Cathedral is to be occupied in its present form for four or five years, the relief during that time would be well worth the expenditure. It would benefit not merely the spoken but the intoned and musical portion of the services as well.

Particularly interesting is a Sabine exchange with an architect (October 1912), who complained that addition of a felt material on the ceiling of a small church would ruin its appearance, and stated that the large amount of wood paneling used in its interior finish should insure good acoustics. Sabine answered:

I am afraid that the only thing that I can say with the data at hand is that wood sheathing does not insure good acoustics. Indeed, some of the poorest buildings I have known have had wood ceilings, and some have had wood ceilings and wood walls. Nor does the small size of an auditorium assure good acoustics. I could cite many illustrations of this.

Sabine consulted on many other religious buildings and auditoriums, including St. Bartholomew's, St. Thomas, and South Churches in New York, St. Paul's Cathedral in Boston, the Fourth Presbyterian Church of Chicago, and the Beth El Synagogue in Buffalo, but the letters give no details for these assignments, apparently because he made his recommendations by annotating blueprints supplied by the architects.

## VI. AUDITORIUMS

In 1912, 1913, and 1915,[11-13] Wallace Sabine published several articles based on recommendations he had made on theaters and auditoriums referred to him for acoustic improvement. These articles dealt specifically with the Hall of the Rhode Island House of Representatives, a lecture room at the Metropolitan Museum of Art (1913), the Century Theatre (also called the New Theatre) (1913), and the Little Theatre (1912), all three in New York City, the Harris Theatre in Minneapolis, the Old Howard Theatre in Scollay Square, and the Old South Meeting House (1914), both in Boston.

Sabine's recommendations in 1916 for the music room of the Cyrus H. K. Curtis house near Philadelphia (Baily and Bassett, Architects) deal with the acoustics of a chamber concert hall with organ (File No. 93).

The music room was to be 32 feet wide and 50 to 75 feet long with a ceiling 20 feet high, or higher or lower if advisable. A large organ was to be installed by Day and Klauder, voiced to fit the room. Sabine reported in a letter dated March 1916 to Baily and Bassett.

The general dimensions of the room, length, breath, and height are good. There is not the slightest objection to the curve or cove between the ceiling and the walls at the sides and ends of the room.

The organ is well-placed with the exception that the large pipes in the ceiling should be drawn back as far as possible toward the end of the room, if the full benefit from the echo organ is to be obtained. For the same reason, the grills in the ceiling should be near the organ.

The echo organ would be placed to best advantage as planned over the entrance hall. Its outlet to the main music room should be through grills in the ceiling cove and not down directly into the hallway. It will thus be better balanced to the musician at the console and will better preserve its echo character throughout the room at large.

I would recommend that the organ be placed back a foot from the grill which is to separate the organ chamber from the music room. A light cloth in combination with the grill work will not in any way whatever affect the free access of the sound to the room—I understand that you have in mind a light silk. The grill enclosing this opening, which I understand is to be three quarters clear and one quarter wood work will obstruct the sound far less than do the pipes ordinarily displayed in an organ front. In fact, the freedom is so great and the opening so low, even below the headline of a person sitting, that I am afraid the winding, which always accompanies the speaking of any pipe, will be too distinctly audible. I would suggest closing up the lower part of this opening to at least a height of two feet and compensating for this by an opening in the form of a grill in the cove above the cornice line. Freedom at this level, which is above the pipes, would give a better quality than too near the lips of the pipes.

Your main inquiry, however, was in regard to the acoustical quality of the music room itself. You brought to my attention two methods of finishing the wall, plaster on tile with panels of light silk, or an entirely wood finish below the cornice line with wood pilasters and wood panels.

In carrying out the scheme as shown in the plan and evaluation sent me, with plaster directly on the tile or brick work, it would be very well indeed to place one inch felt immediately behind the silk panels which you indicate. Provision for this can of course be made in the original construction of the panel. The felt should be at least a quarter of an inch behind the silk. I might add that it is an excellent plan to stretch cotton flannel before stretching the silk, the one to rest lightly against the other. The effect of this treatment will be to greatly soften and enrich the organ tones, which without such absorbing material on the walls of the room is more harsh than in a large room of church or cathedral dimensions.

If the room is to be finished in wood below the cornice line, either the wood should be a very light wood and in thin panels, or heavy curtains should be hung at the windows. Heavy wood work in a small room will not differ perceptibly from hard plaster.

## VII. SHELLS AND BANDSTANDS

From August 1910 to June 1912 Wallace Sabine advised the Olmsted Brothers, Landscape Architects, on the design of a bandstand for the Boston Common, which was built in 1912 and has stood unchanged to this day. The initial presentation was in a letter dated August 20, 1910, from Frederick Law Olmsted.

It is proposed to build a bandstand in Boston Common. The Music Commissioner is inclined that it be in the form of a "shell" in order to afford a sounding board directing the music toward an audience gathered entirely on one side of the stand. From my point of view, a bandshell is very undesirable if it can be avoided. Its form is of necessity a more massive, obstructive, and conspicuous object than what might be called the old fashioned, freestanding column and roof type of bandstand. It has distinct front and back sides, and the back side is generally far from agreeable. The form implies some approach to the general form of a theatre in the disposition of the slopes, the trees, and the other features of the space to be occupied by the audience and in the surroundings a recognition of the bilateral symmetry of the shell. I can find no place upon the Common where these conditions can be met satisfactorily.

On the other hand, I feel that for free popular band concerts in a place like the Common where people are bound to come and go, to linger for a number or part of a number and pass on, where to many the music is incidental to something else, there is something appropriate about the open, circular, bandstand around which people are free to gather and to circulate through 360 degrees. The shell seems more appropriate to concerts addressed to serious devotees of music who want to go and take their fixed places in the outdoor theatre and remain there throughout the performance.

Sabine's first two responses are dated August 24 and October 13, 1910 (edited for brevity).

In order to obtain the maximum effect from a bandstand open on all sides, the roof of the stand should extend considerably beyond the platform. Moreover, the ceiling should not be flat, for if it is, the different parts of the orchestra will seem of very different loudness, the audience hearing best that part of the band that is on it side. It is, however, possible to so design a roof as to greatly reduce this effect.

I return herewith the topographical map of the portion of the Common concerned with the position of the present bandstand marked with the letter A, the positions which you tentatively proposed for my consideration marked by the letters C and B. My understanding is that your proposal of B was in case a stand open on all sides was to be erected, and C in case the stand was to be of shell or parabolic form, and that if the position C is adopted, the shell bandstand is to be recessed in the knoll at C. By the letters D and E are indicated the positions which seem to me more favorable acoustically, and which I therefore hereby submit to you for consideration.

The present location of the bandstand A, in the center of a large triangle free from trees, raises the question whether the stand should be located in an open space or near or among trees. Trees trimmed high form a canopy which retains the sound, carrying it to a greater and greater distance. It is true that the trunks in some measure interfere with this transmission, but the interference offsets the advantage from the more closely woven canopy of leaves and branches. The positions D and E are preferable on this account.

If I have understood you correctly, you chose the position C, in part from the standpoint of landscape architecture, in part with the thought of utilizing the opposite hill, Monument Hill, as a slope. This position, however, is too remote from Monument Hill to make an effective use of its rising slopes. If the side of Monument Hill is to remain covered with trees as it is now, and the stand is to occupy position C, the lower branches and limbs and foliage would cut off all except the very lowest part of the slope. A nearer position of the bandstand would, of course, seem to have before it a freer sweep and larger angle of opening; might indeed be so chosen as to render effective the whole side of the hill, but for position C this would not be true. On the other hand, if the hill and space between were to be stripped of trees, the slope would be entirely available, though even then at a rather great distance. This arrangement of bandstand and audience would have the disadvantage that the circulation would be greatest near the foot of the hill, intermediate between that portion of the audience which was on the hillside and that portion which is nearer the bandstand; the latter of course, it would not disturb, the former such a circulation would disturb seriously. Indeed, the circulation at this point would be a great deal more of an annoyance than it would be if it were nearer the bandstand.

In open air, there is a great difference in volume and intensity at the near and at the more remote points, and for this reason the more remote parts of the audience are those to be more carefully protected against disturbances by noise. Nor is one so much offended by motion in the forward part of the audience. A circulation at mid-distance would be especially annoying to what would probably constitute the larger number of listeners.

A bandstand at D should be circular (or polygonal). The position which seems to me preferable to all others is E. It is well under the cover of trees, and the slope of Monument Hill begins almost immediately and is gradual. With the aid of a moderate amount of grading the whole formation could be made exceedingly efficient. To a certain extent, the choice of position E will depend upon the nature of the use to which it is proposed to put the bandstand. If the concerts are to be given on Sunday afternoons only or but once a week, D would on the whole be the more desirable position, for in this position the necessary changes would be but slight and no great provisions of seats would be necessary. On the other hand, if the concerts were to be given more frequently at the noon hour daily, as in some of the German cities, greater expenditure would be justified and in that case E could be made very much superior to D. This would involve grading, possibly terracing in part, and a liberal arrangement of seats.

It might not be out of place to make some suggestions even in this preliminary report in regard to the nature of the bandstand. In position D, a bandstand open on all sides would be preferable without question to a shell or parabolic form.

In position E, the relative advantages of the circular (or polygonal) and the other (or parabolic) form of bandstand are by no means so decided. If there are to be a comparatively small number of instruments in the band, there is no question whatever but that the shell form of bandstand is preferable. If, on the other hand, the number is to be large, especially in view of the overhanging trees, there would be no danger of weakness in volume and all the space to the east and the whole circle surrounding the stand could be served, and the number who could hear the music close at hand would be greatly increased.

The stand itself, above and including the floor, should be of as light construction as is consistent with strength. The floor should be wood, and not concrete. The roof should be wood of comparatively thin sheathing protected above at the distance of from a few inches to perhaps a foot or more by another water and weather proof covering. The upright supports of the roof should be as slight as is consistent with strength and appearance.

The ceiling, and that is a point of considerable importance, should extend out beyond the floor and it should be flat out to its edge and with as little of a drop at the edge as is consistent with good appearance. It should certainly not be spherically concave, though it might, without considerable disadvantage, slope to a somewhat elevated point at the center.

From the standpoint of acoustical considerations alone, and the more equal audibility of all the pieces in all directions, the floor would be better were it to slope downward toward the center. This, however, might offer certain difficulties to the conductor.

Position E is not disadvantageous from the standpoint of noise from Tremont Street, being very much better situated in this respect than most of the bandstands in Europe. The situation, from the standpoint of the Tremont Street noises, however, would be very greatly improved were there some slight wall or embankment between the bandstand and the street. Shrubbery could be so planted as to help, but a slight elevation of land or a wall near the street would be very much more effective.

The bandstand on the Boston Common is circular in design, with a roof supported on a dozen, one-foot diameter ionic columns. It was dedicated on June 23, 1912, and stands near Tremont Street.

## VIII. QUIETING THE OFFICE MACHINE

A letter from the Remington Typewriter Company of New York, dated December 23, 1915, solicited Sabine's help in quieting the noises produced by typewriters. In less than a month, Sabine presented a 9-page report, reproduced here, which is slightly edited (File No. 382). Like so many of Sabine's letters to clients, his response was a virtual textbook on the noise produced by lightweight impact machines.

The extent to which it is worthwhile pushing the reduction of noise in any one part of the mechanism depends on the success attained in the machine as a whole.

The solution of the problem of noise prevention is greatly advanced by realization of the fact that the production of sound consists of two very distinct processes, (a) the initial production of the vibration, (b) the communication of this vibration to the surrounding air.

When a vibrating body presents a small area to the surrounding air, it communicates but a small amount of motion to it. For a given area, the amount of sound communicated to the surrounding air is dependent on the pitch. The higher the pitch the more efficient the communication of sound.

In seeking to reduce the noise from typewriting machines, it is necessary to reduce both the initial disturbances, and the communication of these disturbances to large extended surfaces. In percussion machines, as distinquished from pressure machines, the so-called noiseless machines, the total elimination of vibration is impossible and therefore attention must also be directed to the second consideration, the reduction of vibrating areas.

The only goal which can be aimed at with percussion machines is the reduction, not the total elimination of noise.

### A. The initial production of the vibration

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.

(1) The noise of the space bar, aside from the motion of the carriage to be considered later is almost wholly eliminated by the cushions provided and is a negligible factor.

(2) The return of the typebars to their rest and of the keys to their normal position produce no inconsiderable noise. The rest against which the typebars return is cushioned, but as the typebars strike the cushion on a narrow edge the cushion has necesarily to be made of rather hard and durable material.

It would be a very simple matter, practically without expense in stamping out the typebars, to turn sidewise a lip which would give a greater resting surface. The receiving cushion could then be made of softer material.

While most of the key bars when at rest hang clear of the notch in which they slide, nevertheless in their free rebound they strike the metal of the machine. A turned lip on the key bar and a felt cushion would obviate this.

The motions of the space bar, of the keys, and of the returning typebars are not necessarily precise in their limits and therefore such ordinary means as felt can be adopted in checking them and in preventing noise. All the other motions of the machine, however, must be precise, —the lower to upper case shift, the letter spacing of the carriage, and the striking type.

(3) When a definite mechanical motion is too limited by stops these must be rigid, or nearly rigid, if the limits of the motion are to be definite and precise. The precision of the motion is determined by the rigidity of the stops. As precision is important in the typeshift, the use of felt or of any other soft material to deaden the noise produced by the check is impracticable.

Felt is rendered even more impractical by the fact that the limit is determined manually by a sustained pressure on the typeshift key. The use of felt sufficiently soft to prevent noise would admit of a varying amount of shift with varying strength of pressure in different operators.

It is possible to make rigid stops, with metal surfaces in contact, almost noiseless on impact by the air cushion which forms between two large flat surfaces. The impinging surfaces should be each an inch to an inch and a quarter in diameter. The effect can be enhanced by making the striking disks slightly indeed, concave, and still further by giving the device slightly the character of a piston.

(4) The noise produced by the carriage shift, its release and its check, are of two very different types. One is a high note, a metallic click, the other is a low thud, the check of a heavy body in motion. Both sounds are annoying. The high note can be stopped for it is not due to a motion which need be exceedingly precise. The low note, however, comes from a motion which is of all the motions of the typewriting machine the one which must be the most precise.

The low-pitched sound produced by the checking of the carriage is that which is most strongly transmitted from floor to floor or from room to room. The higher notes of the metallic contacts are air-carried sounds and most annoying in the room in which the machine is located.

The noise of the carriage check can be reduced either by an adaptation of the air cushion above referred to, or by a postitive mechanical shift.

(5) The free blow and rebound of the type on the paper is characteristic of practically all commercial instruments and is apparently essential to quick action.

Little can be gained by giving attention to the type and typebars. They are as light as is consistent with strength and durability. Aside from this, the impression of a letter, especially with multiple carbon work, is determined by the momentum of the type, so that a diminution in weight of the latter would have to be accomplished by an increase in its velocity. The blow, and hence the vibration and noise, would be in no wise decreased. Further, the type and typebars already present as small a vibrating area to the air as can be designed reasonably.

Since the condition in front of the paper is determined, any reduction in noise must be determined by the conditions behind the paper. It is fair to assume that the roller and its covering is a result of a fairly elaborate investigation to the end that it shall be durable and not injurious to the type. In other words, its hardness and rigidity are determined by other essential requirements.

Making the roller solid instead of hollow would slightly decrease the noise of the striking type, but on the other hand would increase the weight of the carriage. This would necessitate a stronger spring to letter space with equal rapidity and thus more rather than less noise.

While the vibration produced by the striking key originates at the point of impact, it is communicated to the air by all the extended surfaces of the machine, particularly by the cylinder itself.

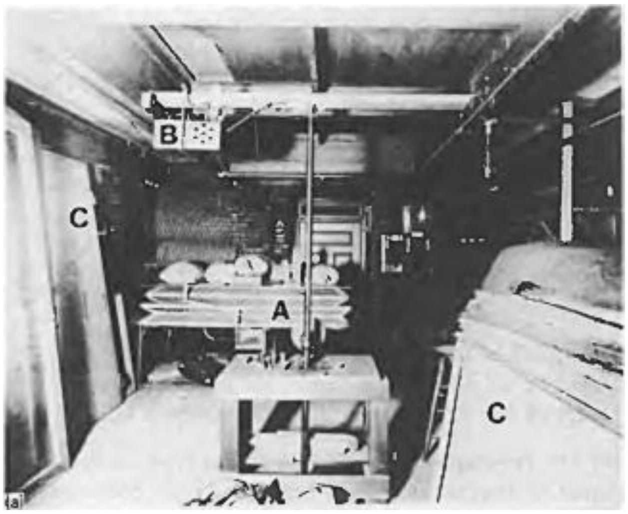
The best method of reducing the noise of the striking type is to reduce the area of the surface or surfaces which it sets in vibration.

### B. The communication of the vibration to the surrounding air

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 which 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.

(1) I am not at all sure that it is wise to undertake the reduction of the extended surfaces of the machine, the loss in appearance perhaps more than compensating for the gain in noiselessness.

(2) Very nearly one-half the noise of a typewriter comes from the table on which it is mounted. The machine may be insulated from the table in either one of two ways: (a) By the use of felt, but spreading the pressure over a much greater area; this could be done of course by a large circular disk; or better still by a disk of steel gauze kept taut by being soldered at its edge to a ring; (b) by cushioning the legs on air in hermetically sealed cells of



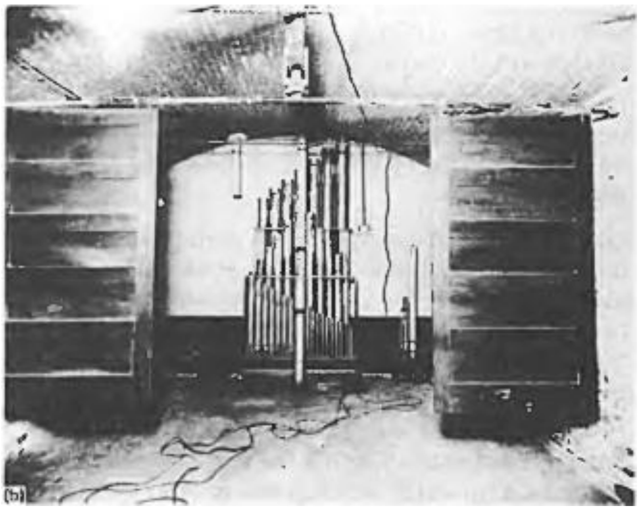





FIG. 3. Sabine's acoustical research facilities in the Jefferson Physical Laboratory at Harvard: (a) The control room above the reverberation chamber showing (A) the wind chest with sandbag loading to produce the exact pressure for the test organ pipes, (B) the motor drive for the transmission shaft to the reverberation chamber beneath (shown below), and (C) acoustic panels under test; (b) the reverberation chamber with rotating panels for sound diffusion and a bank of 36 organ pipes connected to the wind chest above; (c) the box in which the experimental subject sat neck deep so that his clothing was not exposed to the reverberant sound field. His task was first to turn on the air to an organ pipe, then, simultaneously, to turn it off and turn on an electric timer by remote switch, and, finally, to turn off the timer just as the reverberant sound became inaudible. Sabine always served as one of the two or three subjects used in each measurement of reverberation time.

thin metal in the form of disks. The latter device (b) is very much better than the former (a) when the pressure is great.

## IX. MEASUREMENT OF SOUND TRANSMISSION LOSS AND DESIGN OF A DOUBLE WALL

In 1915 Sabine wrote a paper to demonstrate the methods and apparatus needed to measure attenuation of sound transmitted through partitions.[14] These tests were so preliminary that they were made at only one frequency, 512 Hz. They involved 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 logarathmic scale—the forerunner of the decibel!

Sabine's Harvard Research facilities are shown in Fig.3, (a) to (c). In a sound transmission test, the door shown in (c) was sealed off by the panel under test and the test subject sat in a smaller room on the other side.

Between November 13, 1912, and June 7, 1916, Sabine, in correspondence with several lime and gypsum manufacturers, laid out a program of transmission loss measurements on plaster and block walls (Files Nos. 32, 95, 98, 194, and 339). Part of a letter Sabine addressed to one of these suppliers, dated May 26, 1916, reveals his plans:

> About a year ago I found that my plans to test for a few notes were insufficient and I undertook the installation and calibration of an organ of seventy-two notes. Obviously the problem has very greatly extended itself in the labor and time required for its completion, but I wish again to begin the tests shortly. It will take a year or two to complete them.
>
> However, it is not unsuitable that the specifications should be drawn by the Association of Lime Manufacturers in order that I may make sure that the constructions tested are standard. I should be very glad to receive any suggestions that you may make. The more definite and the more in the form of precise specifications the better.
>
> I shall test plastered walls, both of lime and gypsum plaster, applied on wire lath or perhaps the expanded metal as that seems more common, and on wood lath, probably on studding at different distances apart.
>
> I do not know whether your Association includes also the manufacturers of gypsum block. If so, I am undertaking to test this construction also and I should be glad to have similar suggestions, or better, formal specifications, for these tests. I propose to test blocks of two, three and four inches in thickness, and of the latter thickness I should be glad to test, if you wish, three varieties.

To a different manufacturer, he wrote on May 15, 1916:

> I have about completed the tests on doors and windows and hope to publish this some time this summer in the June or July number of the *Brickbuilder*.
>
> I have done some work on wall structures but this is by no means nearly so far advanced, for not merely do the tests take a great deal of time, but after constructing each wall I must allow the wall to season thoroughly if the test is to be really significant.
>
> I propose to test brick walls of different thickness unplastered and plastered; walls of terra cotta tile of two-, three-, and four-inch thickness, as well as walls of gypsum block unplastered; walls of plaster on wood lath and on expanded metal lath, on wood studding and on metal studding, in single thickness and in double with air space between; the latter tests will be made with both lime plaster and gypsum plaster, possibly also with the Keen cement plaster, for I have inquiries on this from the Pacific coast; I shall test the various wall deadeners separately and between walls; sawdust, sand and asbestos as wall filling; and finally, various wall boards like beaver board. I hope the final statement will amount to something.

These tests were not completed, as is attested by a letter that Paul Sabine wrote some two years after Wallace's death and his own assumption of the direction of the Riverbank Laboratory. The letter, dated October 2, 1921, was addressed to one of the companies that Wallace had corresponded with five years earlier.

> In 1913, you conducted some correspondence with the late Professor Wallace C. Sabine, relative to the sound absorbing and sound transmitting properties of lime plasters. These tests, I believe, were never completed. This Laboratory was established and built under Professor Sabine's direction for the purpose of conducting tests of this general configuration under as nearly ideal conditions as possible. Owing to Professor Sabine's death, the carrying out of the plan has been delayed. However, the work is now well under way, and I shall soon be ready to proceed with the tests on lime plaster.

Wallace Sabine's mastery of architectural acoustics and noise control is illustrated by the following letter, dated February 12, 1915, to the New York Electric Light and Power Company. Again he has written virtually a miniature text on the reduction of external plant noise:

> I beg to submit the following report in regard to the prevention of disturbing noises reaching neighboring property.
>
> It was a part of the original design to make the walls of this building independent of the walls of the adjoining building. Such design is not uncommon where good insulation is sought. On the other hand, such construction, as an accomplished fact, is ex-

ceedingly uncommon. Two such walls designed to be separate are almost invariably in contact at many points through the carelessness of workmen. This happens either through some irregularity in the laying of the brick, or through some extrusion of the cement. Such accidental contact is more probable in this case because of the very great irregularities in the wall of the building abutting your property on the north, this wall being not merely badly out of alignment, but has itself a more than usual amount of extrusion of mortar, and even at some points a considerable outsetting of single bricks from the general contour. These factors make it difficult for workmen to avoid all contact under ordinary methods of construction, even though they be warned to do so.

In order to insure the complete separation of the two walls, I beg to recommend that an apron be carried along having a thickness of at least three-eighths of an inch. I have found that a very good apron for this purpose can be made of two pieces of thin sheet iron with some form of sheathing quilt between them. The combination has the desired thickness and is flexible so that it follows the irregularities of the wall toward which you are constructing. A little oil will prevent it from rusting, and it can be moved readily as the work advances. The resulting air apace is better than it would be were it filled by any kind of deadening material.

I do not believe that without such precaution it will be possible for you to be sure of securing the desired separation of the two walls. One point of good contact will give an amount of telephoning as great, possibly even greater, than if the two walls formed a single wall of the combined thickness and thus of course of more than combined rigidity. There is of course communication between the two walls at the bottom of the foundation but the communication of vibration at this point from wall to wall is reduced by the earth acting as a great reservoir for the incident vibrations.

The discussion of interior details will be greater clarified by distinguishing between the vibrations of the air and the vibrations of the structure.

The vibration of the air, the sound which is heard within the building, is in some respects well taken care of by the present design. I refer to the unbroken rear wall, the use of the fire escape for the intake, and the front stairway for the outlet, both extending to the roof and turning toward the center. Along the same line, I would earnestly recommend that the windows on the front of the building be closed and locked, that the front door be provided with a vestibule, unless this in some way interferes with other features of the design, and that the outlets on the roof be provided with louvers extending horizontally and lined with felt on their under side.

There is another way now available for absorbing internal sounds. The R. Guastavino Company has made a light colored tile whose absorbing power is almost one-third that of the best-known felt. The use of this one the walls and ceiling of the front stairway and on the wall of the fire escape in the rear will render the use of felt louvers wholly unnecessary. Indeed, its use in the ceiling of the transformer room will greatly serve to quiet this room also.

The structural noises generated by the regulators, the static condensers, and the blowers, can be in a very large degree insulated by placing under the bed plates an insulator composed of alternate layers of cork and sheet iron. The iron should be of from a quarter to three-eighths of an inch in thickness and work in progressive layers one-half, three-quarters, and an inch. The cork should be of the degree of compression used in the insulation of refrigerating plants, not the much more compressed cork used as floor tiling. The bolts holding the machines to the floor should pass through the bed plates protected by cork washers and held down with cork washers one-half inch in thickness beneath the steel washers under the nuts or bolt heads. Such insulation is very much more effective than the more usual method of bedding the machine on sand or sawdust. To install such insulation, the opening through the concrete floor under both regulators and the static transformers will have to be a little but only a little, reduced. Such constriction will have very little effect on the flow of air, for in the apparatus the air passage is much more constricted and the drop in velocity potential through the floor opening is negligible in comparison with that through the apparatus.

I do not believe that any device for the insulation of sound can be safely carried out under the large rotary condensers. It is so important that this machinery be securely fastened and accurately level, important even as to the generation of sound, that I strongly recommend that no special endeavors at sound insulation be attempted and that instead the effort be devoted entirely to its rigid security, and level, and balances of the rotating parts.

Your plans very wisely show a separation between the street-level floor and the foundations of the rotary condensers. It will probably be convenient when the floor is being washed if this gap be spanned by heavy canvas tarred into place. Such closing of the gap will not in the least interfere with the insulation of sound between the foundation and the floor.

Sabine was asked in November 1911, by W. B. Ittner, a St. Louis architect, to consult on a fire- and sound-proof curtain for the 70-foot by 25-foot proscenium of a new high school auditorium. Sabine's reply, dated December 8, 1911, describes several examples of solid-borne noise control in buildings (edited slightly).

I am in receipt of your inquiry about the prevention of the transmission of sound in your new high school building in St. Louis. This is a subject on which I cannot claim a great deal of knowledge, but from experience I have learned that sound transmission is one of infinite detail and care, that the best of plans may fail because of careless execution or because of some essential incompleteness in the initial conception. Let me relate a few instances which have been brought to me for post mortem examination, or at least in a state of coma.

In New England Conservatory of Music, the class rooms were separated by four walls, two of plaster on wire lath, and two of tile, with three air spaces between them, two of the air spaces having sheathing quilt. The sound was transmitted from one room to another so loudly as to interfere with class work. In the Institute of Musical Arts in New York, two walls separated the class rooms made of gypsum block covered with plaster and separated by an air space of several inches with sheathing quilt in the air space. Here also there was a disturbing communication of sounds from class room to class room. In a private building in New York, the owner, exceedingly sensitive to sound, had had built for himself a separate house, separated from the main house by an eighteen inch wall not penetrated by any steam or water pipe and by only two doors. His library was arched in concrete. On top of this was three inches of sand, on top of this three inches of lignolith block, on this flooring and on this an inner wall of plaster on wire lath. If, on the other side of the eighteen inch wall and down two flights in the servant's room, one were to strike the wall the sound would be louder two flights up on the other side of the wall and in this sound proof room, than it was in the servant's room itself. In all three cases it was easy to discover the fundamental error which had been committed.

In an article published in 1915[14] Sabine discussed these rooms. In the New England Conservatory, he wrote, the plaster-on-wire-lath walls were too light, too flexible, and thus, too responsive to small forces. In the New York Institute of Musical Arts, transverse masonry webs in the floor–ceiling and inadequate insulation of the separate walls of the two classrooms at floor, ceiling, and edges caused the undesired noise transmission. In the Pulitzer House in New York, sound was transmitted along the 18-inch outer wall to the inner walls and ceiling through the iron angle bars installed between them for stability. In Ref. 14, Sabine asked himself many questions about sound insulation in structures of these kinds and proposed a series of investigations to answer them.

In March 1914, a Mr. E. C. Kane of Summit, New Jersey, wrote to Sabine to ask whether an exhaust fan inserted in a cone-shaped device could be used over an area of direct sound to draw in the air and the noise. Sabine's reply follows (File No. 194).

> Your proposal to draw out the sound with the air through a ventilating duct, or its equivalent, is an old one. It has taken various forms. It has been related not merely to auditoriums, but has even been proposed as a means of stopping the noise on the elevated railways, where one inventor proposed putting a hood over each truck and sucking the air with it up into a duct passing through the car vertically. I scarcely need say that the velocity of sound is such in comparison with any conceivable velocity of air as to render these methods of almost infinitesimal effect.
>
> I might add that the use of felt in ducts to prevent the transmission of sound from blowers and ventilating fans into a room is an old one and is very serviceable, but that is a very different proposition indeed from sucking the sound in the room out. In fact, the use of the felt in the duct is absolutely independent of the air.

## X. CONSTANT-POWER SOUND SOURCE

Modern standards laboratories are still searching for a loud portable source of sound with constant-power output. Sabine addressed this question in a letter, dated February 14, 1916, which he wrote to a candidate for a B.S. degree at the University of California:

> It is very unfortunate indeed that there are no standard sources of sound available for such experiments. It is necessary that the source of sound should be of such a nature that the energy it radiates represents a very large percentage of the actuating energy; in other words, that it be a source of high efficiency. Otherwise, the reaction of the sound in the room on the source will vary its output greatly, and a change of but a few feet in the position of the source will vary its output twenty or thirty fold. An organ pipe represents the type of source desired; a vibrating diaphragm, maintained perhaps in constant amplitude electrically, is an undesired type. It is for this reason that I chose an organ pipe as my source.
>
> The futility of many experiments on sound, not merely in regard to the reverberation but in regard to the transmission through walls, is due to failure to recognize the reaction of the sound in the room on the source.
>
> Organ pipes are not standard in character, their output depending on the depression of the languid and the cutting of the wedge which forms the upper part of the mouth.
>
> I know of no way to determine the loudness of your organ pipes except by calibrating them by the four organ pipe method described in my papers published in 1900.

In describing his experimental procedure for reverberation time as a function of frequency, Sabine published the "four organ pipe method."[3]

> The procedure consists first in the determination of the rate of emission of the sound of an organ pipe for each note to be investigated. This consists in determining the durations of audibility after the cessation of two sounds, one having a known multiple of the intensity of the other. Thus, if each of the four organ pipes develops the same loudness in the room, multiples of 2, 3, and 4 times that emis-

sion can be obtained by combinations of the four pipes. From these results it is possible to determine the rate of emission by the pipes, each in terms of the minimum audibility for that particular tone. The apparatus consists of four organ pipes, one at each organ station, separated a minimum of five meters apart, in order that they not interact, particularly at the low tones.

## XI. ARCHITECTS, CLIENTS, AND FEES

The problems faced by an acoustical consultant have changed more in detail than in kind since Wallace Sabine created the profession. The complexity of the field of acoustics has always left many unanswered questions about the behavior of building structures—how much reverberation is tolerable or desirable in various architectural spaces with possibly conflicting purposes, how original architectural designs with new materials will turn out acoustically, and not least, how sympathetically architects, clients, and building contractors will respond to acoustical dicta.

In addition to his teaching and scholarly research, Sabine consulted on building acoustics with architects, on the development of new products with manufacturers, and on the comparative testing of competing products. For the product testing, he refused to accept payment from the competing manufacturers, as he made clear in several letters. For example,

> I am conducting these tests entirely on my own initiative and responsibility and at my own expense. Though a number of firms have offered to bear the expense of the tests of their own materials, I have thought it best that comparative tests of commercial products should be free from any possible bias.

As requests for Sabine's assistance grew, he discussed with Univeristy officials the conflict that seemed to be arising between his primary interest as a university professor and investigator and his fees and royalties arising from his consulting activities. Harvard's President Charles W. Eliot stated[2]:

> He could not bring himself to charge proper fees for his own services, and his mind often misgave him as to the propriety of his spending time which belonged to the University on outside work. I repeatedly pointed out to him that Harvard gained much whenever its professors contributed to the public welfare, although their services were directly rendered to commercial or industrial bodies or individuals.

The increasing demands for Sabine's consulting services compelled him, in self-defense, to stipulate a nominal honorarium of $200, but, according to his biographer,[2] the honoraria were "always conscientiously used for apparatus or experiment."

Sabine's standard fee of $200 was well estabilished by 1908 and apparently remained unchanged, at least up to the time he began war research in 1916. For one large project he received $500 plus reimbursement for expenses.[4] His usual method of consulting on the design of a building was to write his recommendations directly on a set of blueprints, which he always tried to return within a week of receiving it.

Sabine insisted that the client and not the architect pay his fee. For the extensive work he did on the Cathedral of St. John the Divine in New York, he accepted no fee, in accordance with this policy, as a letter to Cram, Goodhue, and Ferguson, dated May 1913, explains (edited for brevity).

> I am in receipt... of your check for $200... for consultation on the acoustics.... I was under the impression that the clients had requested my services and that the expense would fall on them.... I am not, however, willing that it should be a charge against the architect... because I am anxious that the results should come into more general service, and... because I recognize that I am more of a nuisance than a help in the architect's essential problem. Please permit me, therefore, to return your check.

Sabine held to this policy throughout his consulting experience. He also objected to the practice of engaging two consultants to work independently of each other on the same project. An instance of this sort, in connection with the design of the Hill Auditorium at the University of Michigan in Ann Arbor, had proved embarrassing to him. Architect Albert Kahn of Detroit had written to Sabine on March 15, 1911, asking for a preliminary opinion on the feasibility of a 4000-seat auditorium. Sabine replied on March 20 that a smaller auditorium would have somewhat better acoustics and could be designed more easily. He proposed a consulting fee of $500 plus travel expenses. Sabine then learned that he had lost this assignment to a Mr. Tallant of New York, who was named Associate Architect after proposing to handle not only the acoustics but "any number of details regarding design, convenience, equipment, etc."

Some friction then arose between Tallant and Sabine, apparently about a general consulting arrangement that Sabine had made with the Johns-Manville Company. Sabine wrote to Architect Kahn on June 27th:

> Mr. Tallant sought to force for himself an alliance with the Johns-Manville Company. To this, I objected, I hope, properly.... My own connection with the Johns-Manville Company is that of developing, with the aid of their technical knowledge, architectural and structural materials which shall have good acoustical values.... I did not feel that in this work, the reward for which is the thought and perhaps the recognition of having made a scientific contribution, I should share with Mr. Tallant.... I am concerned, however, that the relations of the Johns-Manville Company with you and other architects may not be disturbed by Mr. Tallant's feeling of grievance with them... should their many relations with architects be affected by their consideration for me, I should regret it very much indeed.

In a letter dated September 12, 1911, addressed to

R. Markgraf, a Kansas City architect, Sabine described his relations with several industrial companies (edited slightly):

> The work of the past year has been especially interesting in that I have had an opportunity to do constructive work in the direction of developing new materials which shall not merely have the usual architectural desiderata but which shall also have desirable acoustic properties. So far my work has been in the direction of developing a suitable tile which has come out of my consultation over several Gothic buildings. In this work, the Guastavino Company is placing at my disposal all the technical skill of their factory. The work has progressed so far that we can reasonably look forward to satisfactory ultimate results. I expect to take up the question of plaster within a few months with the Johns-Manville Company and later possibly the question of the transmission and exclusion of sound through the structures of buildings with the technical assistance of some other firms that have offered their facilities. This is the type of work which I think ultimately will avail much. The work is satisfactory in that it has all come about on the suggestion of many architectural firms for whom I have from time to time done consulting work.

Orcutt in his biography quotes Rafael Guastavino, whose company pioneered the development of acoustic tile, as follows[2]:

> Up to the year 1911, the construction of vaults in our churches had a finish of ceramic tile which had practically no property of sound absorption—in fact, very little more than stone. Many of these churches were poor, acoustically. I had read in one or two of the architectural magazines articles on Architectural Acoustics by Professor Sabine, which interested me very much, and in view of the fact that at about that time Cram, Goodhue, and Ferguson, architects, were designing prominent Gothic churches, in which it was desired that the acoustics should be good, and, as the interiors had to be of a masonry material (for felts were not desired for acoustical correction), I decided to write Professor Sabine for an appointment. He kindly granted me an interview in March 1911.
>
> We went over the whole situation, and arrangements were made to carry on experiments, first on a ceramic tile. Experiments were made up to 1913, and by that time we were able to produce a rather efficient product, for which a patent was granted to us December 1, 1914. So far as we know, this was the first patent on an acoustical ceramic tile. For a while, further experiments were conducted, and it became apparent that the process was a rather difficult one....
>
> We then decided to look forward to making a nonceramic acoustical material of masonry character, or stone-like, that would not present the difficulties of a ceramic product. The first successful samples of this material were produced about September, 1915. These were improved upon from time to time, and a patent was issued to us September 12, 1916, and re-issue filed July 24, 1918, as coinventors. This material, owing to its high efficiency and economy in manufacture, has practically superceded the ceramic product. This nonceramic product has been used in a great many of the prominent buildings in the United States.
>
> The relation in the collaboration between Professor Sabine and myself was that of the scientist and the practical ceramic worker.

Bertram Goodhue, architect for St. Thomas Church in New York, revealed, in a letter to Sabine dated December 23, 1912, how the magazine *Architecture* viewed the collaboration of Guastavino and Sabine in developing the new tiles:

> The magazine called "Architecture" proposes to publish in their next issue some photographs showing St. Thomas Church in its present state. There will be an accompanying description, in which occurs the following passage: "At the architect's earnest solicitation, Mr. Raphael Guastavino placed thousands of dollars at the disposal of Prof. Wallace C. Sabine, the greatest of all experts on the problem of acoustics. Exhaustive experiments carried on for nearly a year have produced a tile, the acoustic properties of which are far superior not only to any tile which has so far been used, but also to any other building material except that most unarchitectural of materials, felt. Roughly speaking, the idex of absorption in ordinary tile is 5%, that of stone about 3% while that of the new tile is 26%. It is of this tile that the vaults are constructed."
>
> If this is incorrect or you have any suggestions to offer, may we ask you to telegraph as we understand that it goes to print at once.

Sabine's relations with his clients were always excellent, as is attested in a letter dated September 20, 1911:

> Dear Mr. Sabine:
>
> You may have original drawings, photographs, furniture, good will, money, personal services, or any other old thing you want to ask from this office, as we shall seize upon the opportunity with avidity. You do not seem to realize that you have put us everlastingly in your debt and that nothing we ever can do will be adequate compensation therefore. Very faithfully yours, Cram, Goodhue, & Ferguson.

Finally, in response to an architect's grumbling that acoustics sometimes interferes with a building's appearance, Sabine responded:

> In order not to feel myself an outcast in society, I have to stop every now and then and remind myself that whatever I may have done in architectural acoustics I did not invent the problem. Please exonerate me from being the cause of your troubles.

Hoping that nothing will be done, either in the correction of architectural acoustics or in initial design, which will interfere with architectural effects, I am....

## XII. CONCLUDING REMARKS

We stand amazed at the breadth and depth of Wallace Clement Sabine's accomplishments in so short a life. After his first laboratory researches and his consultation on Boston Symphony Hall, which ended in 1900, he immersed himself in his teaching at Harvard until 1906, when he was appointed Dean of the Graduate School of Applied Science (1906 to 1915). The years from 1916 to a month before his death in January 1919 found him deep in military aviation, both in Europe and in Washington, D. C. Beginning in March 1916 he served for 17 months as a civilian Chief of the Technical Section of the Air Service, A.E.F., in France, under the Assistant Chief of Staff of that Service. In the early fall of 1918 he returned to the U. S. to combine two days a week of teaching at Harvard[2] with five days as advisor to the U. S. Air Service in Washington, D. C. In June 1918 he was named Director of the (newly created) Department of Technical Information in the Bureau of Aircraft Production. Sabine could probably be called the first "Chief Scientist" of the U. S. Air Forces.

In September 1918 President Wilson appointed Sabine a member of the National Advisory Committee for Aeronautics (the predecessor agency to NASA). Sabine was personally responsible for a report issued on November 30, 1918, recommending that (1) after the War, NACA should deal with scientific and technical aeronautical research; (2) the Air Services' Division of Science and Research should be disbanded; (3) a permanent Technical Section of the Air Services should be established; and (4) the Chief of the Air Service and the Chief of the Technical Section should represent the Army on NACA.

Another distraction in Sabine's life occurred when, in 1911, a Pittsburgh engineer named Mazer nearly obtained a patent on Sabine's discoveries in room acoustics, based on Sabine's published papers and some explanatory letters that he had written to Mazer earlier. President Lowell of Harvard, on learning of this imposture, persuaded Senator Henry Cabot Lodge to protest to the Patent Commissioner. Lodge and other Senators talked to President Taft who asked the Secretary of the Interior to order the Commissioner to withhold the issuance of the patent pending an investigation. The word "Withdrawn" was then stamped over the printed word "Issued" on the patent. The case was subsequently tried before an examiner. Sabine testified, as did others, and Mazer's claims were shown to be audaciously fraudulent.[2]

In spite of those competing activities, we can observe from the recently discovered notebooks and files that Sabine's originality and depth of understanding of applied acoustics reveal an extraordinary mind. In 1914, on the occasion of awarding Sabine an Honorary Degree of Doctor of Science, President Lowell of Harvard described him as "a generous spirit, solicitous only for the public good, who has traced in science the waves of sound, with a mind attuned to nature and a soul in harmony with men."

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[1] W. C. Sabine, *Collected Papers on Acoustics*, edited by T. Lyman and first published in 1922 by the Harvard University Press, now available in paperback from Dover Publications, Inc., New York, NY (1964). Of the eleven collected papers, six are referenced below.

[2] W. D. Orcutt, *Wallace Clement Sabine—A Biography* (Plimpton, Norwood, MA, 1933) (out of print).

[3] W. C. Sabine, "Architectural Acoustics: I. The Accuracy of Musical Taste in Regard to Architectural Acoustics (Piano Music); and II. Variation in Reverberation with Variation in Pitch," Proc. Am. Acad. Arts Sci. 42 (2) (June 1906). (Contained in Ref. 1).

[4] L. L. Beranek, "The Notebooks of Wallace C. Sabine," J. Acoust. Soc. Am. **61**, 629–639 (1977).

[5] F. W. Kranz, "Early History of Riverbank Acoustical Laboratories," J. Acoust. Soc. Am. 49, 381–384 (1971).

[6] Paul E. Sabine, "The Wallace Clement Sabine Laboratory of Acoustics, Geneva, Illinois," Am. Arch. 60, 133–138 (July 1919).

[7] E. H. Hall, "Wallace Clement Sabine," Harvard Grad. Mag. (March 1919); see also, "Thirteenth Memoir," Nat. Acad. Sci. 21 (1924).

[8] P. E. Sabine, *Acoustics and Architecture* (McGraw–Hill, New York, 1932).

[9] P. E. Sabine, "The Beginnings of Architectural Acoustics," J. Acoust. Soc. Am. 7, 242–248 (1936).

[10] W. C. Sabine, "Architectural Acoustics: Reverberation," published in seven parts in 1900: "I. Introduction, April 7; II. Absorbing Power of Wall-Surfaces, April 21; III. Approximate Solution, May 5; IV. Rate of Decay of Residual Sound, May 12; V. Exact Solution, May 26; VI. The Absorbing Power of an Audience, and Other Data, June 9; and VII. Calculation in Advance of Construction, June 16," Am. Arch. Build. News 68 (1900). (These papers are contained in Ref. 1).

[11] W. C. Sabine, "Architectural Acoustics: Correction of Acoustical Difficulties," Arch. Q. Harvard Univ. (March 1912). (Contained in Ref. 1.)

[12] W. C. Sabine, "Theatre Acoustics," Am. Arch. **104**, 257 (1913). (Contained in Ref. 1.)

[13] W. C. Sabine, "Architectural Acoustics," J. Franklin Inst. (January 1915). (Contained in Ref. 1.)

[14] W. C. Sabine, "The Insulation of Sound," Brickbuilders 24 (February 1915). (Contained in Ref. 1.)