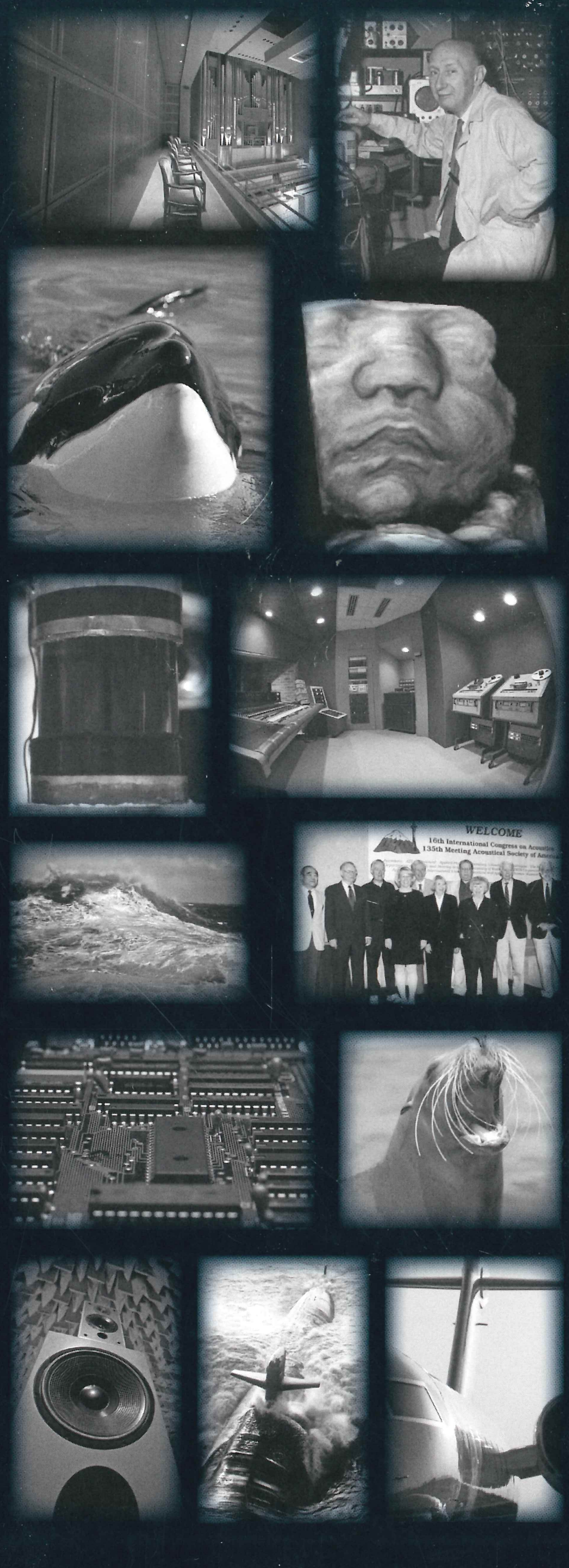
ASA at 75

A snapshot of the Acoustical Society of America on its 75th Anniversary... diffusing knowledge in acoustics and promoting its practical applications for three quarters of a century

Acoustical Oceanography
Animal Bioacoustics
Architectural Acoustics
Biomedical Ultrasound/
Bioresponse to Vibration
Engineering Acoustics
Musical Acoustics
Noise
Physical Acoustics
Psychological and
Physiological Acoustics
Signal Processing in Acoustics
Speech Communication
Structural Acoustics and Vibration
Underwater Acoustics



Henry E. Bass & William J. Cavanaugh, Editors
The Acoustical Society of America
Committee on Archives & History

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Published by the Acoustical Society of America [http://asa.aip.org]
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Dedication

To the thousands of past, present and future members of the Acoustical Society of America who have and will continue to diffuse knowledge in acoustics and to promote its practical applications for the betterment of mankind.

"The history of the science of sound in the 20th century is yet to be written; the material for such a history is accumulating at a remarkable rate, and it is certain that the achievements of the members of The Acoustical Society of America will bring honor to the world of science."

> *Dayton C. Miller*
> *Anecdotal History of the Science of Sound*
> *The MacMillan Company 1935*

Preface

Acoustical Society of America 75th Anniversary Book

Ilene J. Busch-Vishniac, President 2003-2004

Sound the trumpets! Raise the flags! Start the party! In this year, 2004, the Acoustical Society of America turns 75 years old! We will mark the occasion with special events at our spring meeting in New York City, and with this celebration book.

Is it so unusual for a professional society to make it to its 75th year? No, not really. But then, the Acoustical Society of America isn't like most professional societies. As with most societies, we were created to serve our members and to help inform and guide the public on matters related to our expertise. But unlike many professional organizations, we are more like an extended family of people (some of whom are a bit eccentric) who share a love of all things related to sound and a general fondness for one another.

Seventy five years in any family brings a significant number of births, deaths, marriages, and accomplishments. So it is as well in the Acoustical Society of America. We have seen new subspecialities of acoustics born while others have withered, sometimes to reemerge later. We've seen a convergence of formerly separate branches of acoustics, and many, many acoustic products created for the world to use and enjoy.

What has sustained the Acoustical Society of America for its seventy-five years has been a steadfast focus on serving all of the community of professionals working in areas related to sound. Technical disciplines have been marked by increasing pressures to specialize for the last several decades, and this trend has been accompanied by an explosion of professional societies with narrow focus. The Acoustical Society of America has resisted this pressure to specialize and instead put out the welcome mat for any group working to further our understanding and appreciation of acoustics. Through this attitude of inclusion, the Acoustical Society of America has broadened over the years from emphasis on the physical sciences related to sound, and the physiological and psychological reactions to and consequences of sound, to include the intersections of sound and biology, both in terms of biomedical applications and in the study of sounds made by animals in their natural habitat. Our members now include physicists, biologists, engineers, architects, consultants, audiologists, musicians, and entertainment professionals.

Just as the technical breadth included in the Acoustical Society of America has grown, so too has our geographic reach. Originally envisioned as a society serving members in North America, the ASA now boasts roughly 10% of its members from foreign countries throughout the world. Similarly, about 15% of the publications appearing in our world renowned journal are by authors outside of North America. In recognition of this universal appeal, the ASA now schedules international venues for its meetings with fair regularity. In the last five years, for instance, we have had meetings in Berlin and in Cancun, in both cases partnering our society with sister organizations in the area.

The heart of the Acoustical Society of America is the work of its members to expand the body of knowledge in acoustics, and to apply acoustics in the creation of new products. This is particularly visible through the advances that have come since the society's founding, largely due to the work of its members, including cochlear implants to restore hearing to the deaf, a large set of amazing facilities for musical performance, sonar for acoustical observation under water, automatic speech recognition devices, active noise control devices which add sound to noise in order to produce relative quiet, a large repertoire of fine instruments for musical performance, and recently, acoustic refrigerators with no moving parts and new standards for classroom acoustics so that all children may learn.

This celebration book chronicles the history of the Acoustical Society of America, describes the accomplishments over the years in each of our major subspecialties, and considers the future. What is clear is that the future in acoustics is bright for we still have many difficult problems to solve. We have far too many people rendered deaf permanently from exposure to intense sounds, far too few products about to reliably synthesize and recognize speech, far too much noise in our increasingly urban society.

So don your party duds, warm up that singing voice, and prepare for the party. Read this book and enjoy–celebrate the accomplishments of the people who make up the Acoustical Society of America, and look ahead to all of the new reasons to celebrate we will have at our 100th birthday!!

Acknowledgments

Henry E. Bass and William J. Cavanaugh, co-editors

First we graciously acknowledge the history lecturers without whose enormous contributions both in delivering lectures and preparing manuscripts on each of the thirteen technical areas which form the basis for this volume, the publication of this book would not have been possible. Actually, the idea of this commemorative book originated and germinated in meetings of the ASA Committee on Archives and History more than eight years ago. In true Acoustical Society fashion, the book was first conceived as a work of one or more knowledgeable "volunteers." But, lacking any candidates eager to take on this gigantic undertaking alone, we went to "plan B" which was to solicit volunteers to take on bite-sized pieces of recounting and recording the story of the Society's first seventy-five years. What better way than to enlist the help of each of the current thirteen technical committees in recruiting the history lecturers as well as in editing the individual technical area chapters that would form the heart and soul of the book.

Accordingly we must next acknowledge the invaluable help of the technical committee chairs, some of whose terms expired or overlapped others during the six year period of the history lecture series, in selecting the history lecturers and coaxing manuscripts from them and, in reviewing and editing the individual book chapters. We also thank the authors of the front and back end chapters: Ilene Busch-Vishniac for the Preface essay, Charles Schmid and Elaine Moran for Chapter 1, "Short History of the Society's First Seventy Five Years," Allan Pierce for Chapter 2, "History of the Society's Publications," Anthony Atchley for Chapter 3, "Development of the Technical Council," Thomas Rossing and Uwe Hansen for Chapter 17, "Acoustics Education and the ASA," Tony Embleton, Paul Schomer and Susan Blaeser for Chapter 18, "The Role and Future of Standards in Acoustics," and, William Kuperman for the Afterword essay, "A Vision for the Society's Next 75 Years."

A special thanks to Elaine Moran and the tremendously helpful staff at the ASA office in Melville. As with so many activities, publications and other undertakings of the Society, "We could not have done it without you Elaine." We keep asking ourselves, how can any one person keep track of so many simultaneously occurring activities and do it with such calm and grace? And the answer keeps coming back "Ask Elaine!"

We are more than indebted and grateful also to George Atkins at "Ole Miss." Hank Bass' office at the University of Mississippi won the toss, so to speak, to serve as the main collection point for manuscripts and overall headquarters for the 75th Anniversary Book and George served as the "commander" of field operations. Although a successful outcome appeared dim at times she persevered admirably and always cheerfully to help produce this remarkable account of the Society's seventy-five years.

Lastly, we are extremely grateful to Anthony Rosa of Trend Multimedia who produced a memorable graphic layout and design for the book and to Joseph Stampone of Major Printing Company who saw to it that the book was printed and delivered on time, and on budget, for our May 2004 celebration in New York City exactly seventy five years after our forebearers gathered for the very first of the 147 meetings of the Society to be held since then.

We hope you like the results of these remarkable efforts of so many of your colleagues and friends of the Society. While the editors have tried valiantly to catch all typos, corrections, omissions, etc. in our final reviews, we may not have succeeded in achieving the perfection we sought. We assume full responsibility for any and all of these and will appreciate hearing about any we may have missed."

"Although the history of science was long neglected by professional historians, this unhappy situation is now being rectified through an awareness of the significant influence the growth of science has had on the development of civilization.
The question has indeed been raised whether knowledge of the history of science has any value for the practicing scientist. It appears to the present writer that the weight of the historical evidence itself is in favor of the affirmative view in this matter. A knowledge of the evolution of the concepts basic to a given branch of science can often suggest useful ways of approaching current experience, and actually has done so in numerous instances."

R. Bruce Lindsay
excerpted from the Introduction to "The Story of Acoustics"
Journal of the Acoustical Society of America 39, 629-644 (April 1966)

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Chapter 1

Short History of the Society's First Seventy Five Years

Charles E. Schmid & Elaine Moran

Short History of the Society's First Seventy Five Years

Charles E. Schmid, Executive Director & Elaine Moran, Office Manager

A lot can happen in 75 years, whether it be to a person's life or the life of a Society. In fact much of the history of the Acoustical Society of America was built upon the professional lives of its members. Since there was no one source of information for writing this historical account of the Society, information from ASA correspondence files, from personal recollections, and from the Journal of the Acoustical Society of America (JASA) and other articles have been gathered together to write this informal history. To make it easier to read about the entire 75 years—or just segments of those years—this history has been organized into six chronological time segments:

- **1928-May 1929**
The Formation of the Acoustical Society
- **June 1929-1940**
The Organizational Years/Great Depression
- **1941-1948**
World War II and Immediate Post-War Years
- **1949-1954**
20th and 25th Anniversary Celebrations
- **1955-1990**
Expanding Publications - Inside and Outside the Society
- **1991-2004**
Building Diversity

Of course these are somewhat artificial categories which have been used to help organize the history of the Society into manageable sections. There is indeed overlap, and many topics do not neatly fit under these six headings. In addition, the histories of the technical fields, ASA standards, and education in acoustics have been, for the most part, omitted since they are well covered in the various sections in this 75th Anniversary book.

1. The Formation of the Acoustical Society, 1928-May 1929

The idea for forming a society which was specifically devoted to acoustics had its beginnings on July 30th, 1928 when Floyd R. Watson (1873-1974), Vern O. Knudsen (1893-1974) and Wallace Waterfall (1890-1974) met at a Santa Monica beach club near Los Angeles, California. They originally envisioned an organization for engineers working in architectural acoustics. In the fall of 1928, they sent letters to men who were working in acoustics proposing the formation of an "American Society of Acoustical Engineers."

Looking back there were a number of reasons why the idea for a new society on acoustics emerged at that particular time. First, other societies were not fulfilling the needs of acousticians. In 1929 Harvey Fletcher had just published his book *Speech and Hearing* which set the foundation for the field of airborne acoustics to accompany all the new devices which were being invented. He noted that presenting his papers at the meetings of the American Physical Society had been less than stimulating because there were so few people there interested in the work he was doing. A second reason is given by Dayton Miller in his 1935 book *Anecdotal History of the Science of Sound to the Beginning of the 20th Century.* He observed that there were many events occurring in the world of sound leading up to the concept of forming a society dedicated to acoustics, including rapid advancements in the field at this period. He stated that "More progress has been made in the realm of sound in the first third of the 20th century than in all the preceding centuries." He attributed much of this to the use of underwater sound during World War I, along with sound being transmitted by radio and telephone, amplified for hearing aids, and recorded and reproduced with gramophones and later for the movies. The section on Structural Acoustics and Vibration in Miller's book noted that Warren Mason was working on filtering of waves and that Floyd Firestone introduced an analogy between electrical circuits and mechanical systems. Other events included the showing of the first movie with full audio in 1927. (The motion picture industry participated in the early years of the Society since the acoustics of rooms was of particular importance.) Also, earlier in the 20th century, many new electroacoustic sound sources and receiving equipment had been invented which previously were not available to the earlier experimenters. The section on Engineering Acoustics in Miller's book describes a classic paper written in 1925 by Rice and Kellogg of General Electric on "a new type of hornless loud speaker" which used electromagnetics. Acousticians, along with the general public, were making good use of these new sources and receivers. This was acknowledged by noting that Thomas Edison, who created the groundwork for constructing much of this equipment, was named the Acoustical Society's first honorary fellow in 1929.

There was important work in acoustics before the 20th century began to which today's acousticians still refer. Philip Morse (1903-1985), president of the Society from 1950-51, remarked in 1955 that "it behoves all of us physicists to read Rayleigh's *Science of Sound* regularly."

And to place the pre-1900 efforts in acoustics in historical perspective, Dayton Miller recalled that when he received his D.Sc. from Princeton in 1890, the four greats in the science of acoustics–Helmholtz (1821-1894), Koenig (1832-1901), Rayleigh (1842-1919) and Tyndall (1820-1893)–were all still alive. Professor Miller's life bridged this time between these 19th century original thinkers who wrote treatises on acoustics, and the new breed of scientists and engineers who were applying acoustics to practical applications for consumers and for defense during the first third of the 20th century. Also spanning the gap was Wallace Clement Sabine (1868-1919) who published a number of papers on the new science of acoustics of auditoriums around the turn of the century. He died in 1919 while serving as vice president of the American Physical Society.

Returning to the formation of the Acoustical Society, a second letter from Knudsen, Watson and Waterfall was sent on December 10th, 1928 to 16 people, mostly at universities, in which they described the need for a new organization. The letter asked recipients to alert their colleagues of an upcoming organizational meeting which was to be held on December 27, 1928 at the Bell Telephone Laboratories located at 463 West Street in New York City where Harvey Fletcher was director of the now famous Acoustics Research Department. Forty men attended this organizational meeting, most of whom were from New York and from commercial organizations (see Figure 1). Various names were suggested for the new organization, starting with American Acoustic Society (parallelling the grammar of the American Physical Society) and the Acoustic Society of America. But eventually F. R.Watson made a motion for the "Acoustical Society of America" which was adopted with one dissenting vote. In his recounting of that meeting years later at the 25th Anniversary celebration, Harvey Fletcher said that speeches were made by several of the people who attended the organizing meeting, and "So you see our meeting started out as a talking Society and it has continued ever since through the years. Fifty years from now, this little gather-

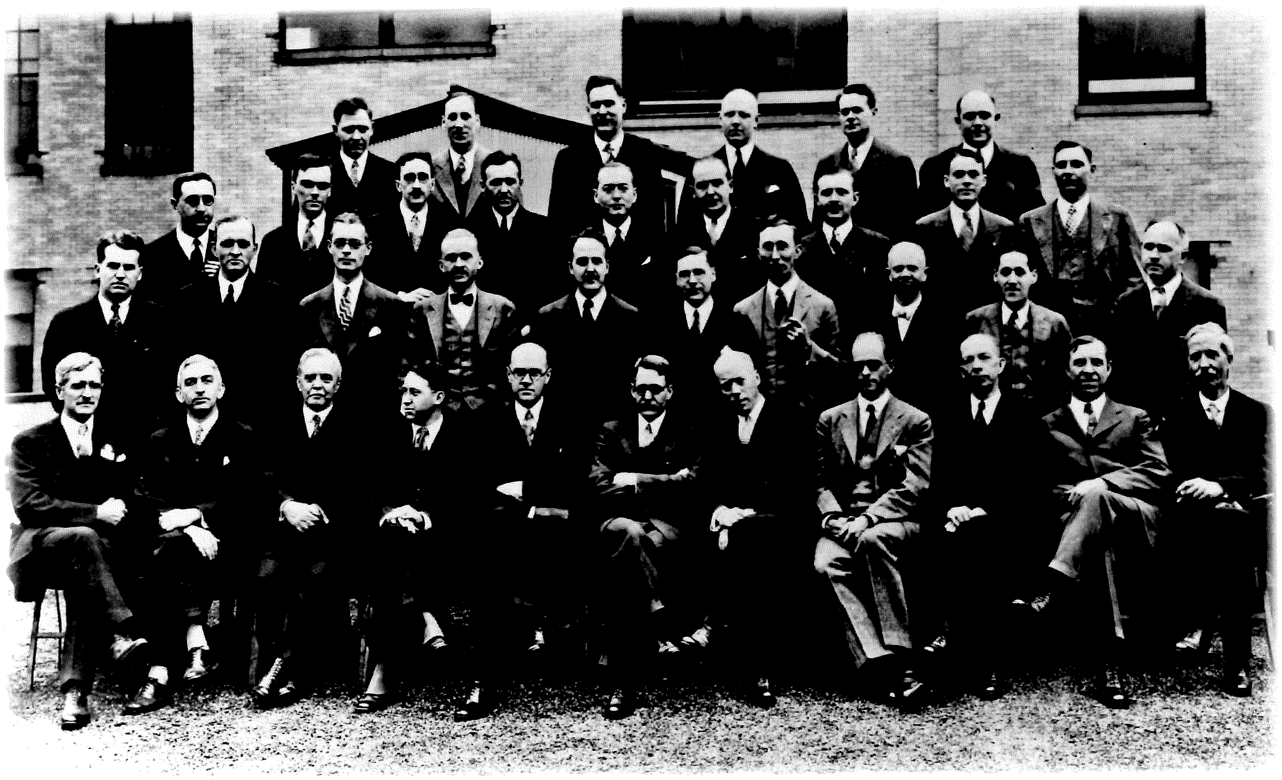

Figure 1. Part of the group of organizers of the Acoustical Society, Bell Telephone Laboratories, December 1928
Bottom row, left to right: F.A. Saunders, R.V. Parsons, D. C. Miller, W. Waterfall, V. O. Knudsen, H. Fletcher, C. F. Stoddard, J. P. Maxfield, F. R. Watson, F. K. Richtmyer, G. R. Anderson. Second row from bottom, left to right: H. A. Erf, H. C. Harrison, J. B. Kelly, R. L. Wegel, H. A. Frederick, N. R. French, C. W. Hewlett, A. T. Jones, I. Wolff, J. B. Taylor. Third row from bottom, left to right: L. J. Sivian, E. L. Norton, W. A. MacNair, R. F. Mallina, L. Green, Jr., R. H. Schroeter, H. W. Lamson, C. N. Hickman, D. G. Blattner.
Top row, left to right: W. P. Mason, J. C. Steinberg, V. L. Chrisler, E. J. Schroeter, E. C. Wente, W. C. Jones.
Ohter attenders not in photo: D. MacKenzie, J.H. Bolen, B. Graham and H. D. Arnold.

ing will be referred to as the First Meeting of the Acoustical Society of America."

The Society was formally organized during its next meeting which was held May 9th to 11th, 1929 at Bell Telephone Labs in New York City. The first day of the technical portion of the meeting was a joint session with the Society of Motion Picture Engineers. There were 183 members who registered at the first meeting. The program included two symposia, one on methods of measuring absorption coefficients and the second on speech. There was a total of 22 papers which were presented consecutively, two panel discussions, and one demonstration lecture on the science of musical sounds by Dayton Miller. By October 1929, the organization grew to 416 Charter members and 76 regular members.

The minutes of the first official meeting held on May 10th, 1929 can be found in the first issue of the *Journal* (Volume 1, No. 1, October 1929). Dayton Miller proposed that the organization include not just acoustic engineering but widened to include ". . .the study of the ear, hearing, othology, matters of speech, speaking...if we could get those various groups together and work together then I think there would be every reason in the world for the organization of the society." Harvey Fletcher (1884-1981) and Dayton Miller (1866-1941) had stressed earlier the desirability to include a more diverse set of technical fields than just architectural acoustics in order to create a stable institution. Even then, there was some concern expressed that the proposed society would be too small to stand alone because of the narrow interest on sound. A proposal was then made that the group organize as a subcommittee of an already existing organization or that if it were formed, to contribute to another organization to have papers published in an already existing journal.

Finally the group decided on a purpose of the new society: "to increase and diffuse the knowledge of acoustics and promote its practical applications." They then elected a set of temporary officers and discussed publications, a plan for further development of the organization, establishing a journal, standards, membership qualifications, finances, and most importantly, the scope of the organization. The first official actions by the Council at its 10 May 1929 meeting were to appoint a Publication Committee which was charged with publishing the proceedings for the first meeting and to investigate the possibility of starting a journal, appoint a Membership Committee that was given the charge to put into execution a plan to increase the membership of the Society, and approve the site of the next meeting and appointment of a local committee and Program Committee. The Acoustical Society of America had officially started its operations!

The Society was international in scope from its very beginning with 17 members residing in Australia, Belgium, Canada, Denmark, England, France, Japan, Norway, and Wales. There was one woman Charter member. The membership was comprised of people working in architectural acoustics firms, piano and other musical instrument companies, universities and at least one aircraft company. All of the major movie studios were represented including Paramount, Warner Brothers, Columbia, RKO, United Artists and Fox.

2. The Organizational Years/Great Depression, June 1929-1940

In 1929 Wallace Waterfall was given some manuscripts and he later recalled that he "asked the Council what I was supposed to do with them and I got the answer; 'Go publish them.' I said we had no money and they said that was my problem. I was with Celotex then, so I hit my own company for a sizeable contribution and other companies chipped in to get us started. We set up an Editorial Committee and I held the job of Managing Editor for 4 years." The first issue of the *Journal* was published in October 1929, the same month as the stock market crashed. It contained 8 papers in its 163 pages. On its cover was the 1929 logo which Wallace Waterfall had designed, later fondly remembering that: "A printer and I got together with a compass and we spent a lot of time, had a lot of fun, drawing that thing."

The Executive Council met on December 12th 1929 to appoint an editorial board, elect Fellows, and to incorporate the Society, which was approved on February 4, 1930. By March 1931, the membership comprised of 632 members, 128 fellows, 10 sustaining members and one honorary member. The membership grew to 800 in the mid-1930s, but dropped back below 700 by 1939, reflecting effects of the depression.

During the depression years the Council made various decisions on business matters, on how to provide outreach to the public, on standards issues, and to appoint standing committees to handle special subjects that required deeper deliberations. They established the membership category of "Fellowship" and encouraged "foreign" membership in the Society. Decisions on JASA operations included appointment of an Editorial Board, approving advertising, setting prices for single copies and the subscription rate for libraries and establishing a $2 page charge for authors of articles published in the *Journal.* (The first complaint about this charge was received soon thereafter!) The Council considered working with CBS TV to develop educational broadcasts about acoustics and adopted a resolution advocating more liberal appropriations for the U.S. Bureau of Standards. Committees were appointed to prepare a brochure to be distributed to mayors of U.S. cities about what could be done to reduce noise, and to cooperate with the Academy of Motion Picture Arts and Sciences which was doing research in developing standards for acoustical measurements in theatres. Emeritus membership and the Biennial Award were established in April 1940, and at the same time donations of JASA were made to three libraries in China where many reference libraries had been destroyed. Finally, a Patent Review section was begun, and the first technical committee – on musical acoustics – was appointed.

ASA's minutes for the Society's December 31, 1930 meeting show that Professor K.T. Compton from the American Physical Society spoke to the Council about APS' financial problems and relying on wealthy benefactors for publishing *Physical Review*. The Council approved entering into a cooperative agreement with the American Physical Society and the Optical Society of America for publishing journals. In 1931 the Acoustical Society, along with three other professional societies joined together to create the American Institute of Physics (AIP) with the primary purpose of providing facilities for publishing and other common activities. In May 1932 the Executive Council voted to transfer publication of the *Journal* to AIP. ASA's relationship with AIP continues today with the Institute providing a wide variety of services to the Acoustical Society.

Financial conditions during the depression are not very evident except for the fact that expenses were kept very low. In May 1931 the treasurer reported that "the business conditions continue, although there seem to be signs of improvement beginning some time in the latter part of the present year. In endeavoring to foresee business conditions of the Council, in the Treasurer's judgement, should not lay too much weight on the prevailing deep pessimism in New York and the East generally." In November of the following year, he felt that they didn't need to ask for additional funds from industry, noting that "our best information is that no important improvement in business can be expected until several months after the inauguration of President Roosevelt." After those inserts not much was mentioned about financial difficulties even though they must have been ever present for the Society. An increasing reliance was placed on member dues and less on contributions from corporations, and some members were kept on even though they were three years in arrears in dues. Annual expenses for the Society were only in the $3,000 to $5,000 range, mainly because no labor expenses were allocated to the Society. The Society kept about this same amount of expenses in reserves, although the American Institute of Physics was in debt in the latter part of the 1930s. By the time of the November 15, 1940 meeting foreign subscriptions were dropping because of world conditions.

3. *The War and Post-War Years, 1941-1948*

As with the rest of the world, World War II had its effect on the Society. Only one meeting per year was held in the spring of 1942, 1943, 1944 and 1945. During the same time, the number of pages in JASA dipped from 550 in 1940, to 220 pages in 1944. However membership increased over this same period by about 6% per year. Obviously the war-time effort and security measures were taking its toll on the publication output and ability to organize meetings, but members felt it was still important to maintain their membership in the Society during these war years.

Many members were involved in the applications of acoustics to the war. Frederick V. (Ted) Hunt organized and directed the Underwater Sound Laboratory at Harvard University (HUSL) during the war years 1941-1945. At the end of the war a portion of the Laboratory was moved to Penn State and is now still very active in acoustics as the Applied Research Laboratory (ARL). Leo Beranek was director of the Electro-Acoustic Laboratory at Harvard University. Other laboratories and research centers began carrying out military, industrial and academic acoustics, including the University of Texas at Austin.

The years just after the war marked the increase in research in all fields of acoustics. In 1946 the Society found the need to reorganize its membership structure to allow for "a wide and active participation, without meaningless stratification, of all persons having legitimate connection with the field which would be appropriate for the advancement of acoustics." Also at this time the grade of Associate Membership was established.

An article in JASA published shortly after the war was over noted that "A large fraction of the membership was engaged during the recent war in the development of new weapons utilizing acoustical principles, particularly the development of equipment utilizing underwater sound." It ended by predicting "The outlook for the future of the Society is bright. The war has spotlighted physics in general and acoustics in particular. Our future meetings will bring forth many interesting papers and our journal will continue to record the accelerated history of the development of acoustics." This came to be true as membership in the Society grew from around 1000 members in 1945 to 6500 in 1990. From 1945 to 1965 it grew at a rate of almost at 20% per year. The number of papers published in JASA increased at about the same rate. The nature of the Society also changed during these years. In 1966 Wallace Waterfall reported that 26% of ASA's members held doctoral degrees; in 2002 this percentage had grown to 67%. He also reported that 27% of the members were employed by academia and 45% by industry. By 2002 this had switched, with about 40% with academia and only 16% from industry.

A tremendous amount of work related to defense was done in acoustics during the war but was never published in the open literature. Articles on the research conducted in underwater acoustics, acoustical oceanography, transducers, hearing aids, acoustical measurements and speech communication were published in a huge collection under the auspices of the National Defence Research Council (NDRC). Hundreds of scientific and publications people were involved in this project which began in March 1945 and ended in May 1948. The project was authorized by Vannevar Bush, and administered by none other than Wallace Waterfall!

4. 20th/25th Anniversary Celebration, 1949-1954

After the depression and WWII, the Acoustical Society was celebrating its peacetime growth along with the rest of the nation. The Twentieth Anniversary meeting in 1949 held at the Hotel Statler in New York had an attendance of 417, and the membership had reached 1400 members. The theme for the meeting, "Acoustics and Man," seemed to indicate an interest in non-military applications of acoustics. A "founders' luncheon" was held and attended by 21 of the original founding members (see figure 2) who assembled for a photo mirroring the one shown in figure 1.

But one problem which resulted from this growth was expressed in Floyd Firestone's report of the 1951 Chicago meeting: "The growth of the Acoustical Society has brought with it the necessary evil, the programming of papers into simultaneous sessions, so that the member has to decide which papers he will miss, with the result that he may just stand out in the hall and visit. By contrast one can recall an announced meeting at Ann Arbor about a decade ago when only four papers had been received by the deadline date and it was necessary to stir up some progress reports in order to fill out the program." The growth of society had changed some of its character.

Although both membership and attendance at meetings were growing, the financial benefits were waiting in the wings for the 1950's boom to begin. Wallace Waterfall had been using 70 pound paper for JASA, but in 1948 decided to drop down to 55 pound paper to save money. This decision probably was promoted by Treasurer Nixon pointing out that the Society had only $16,000

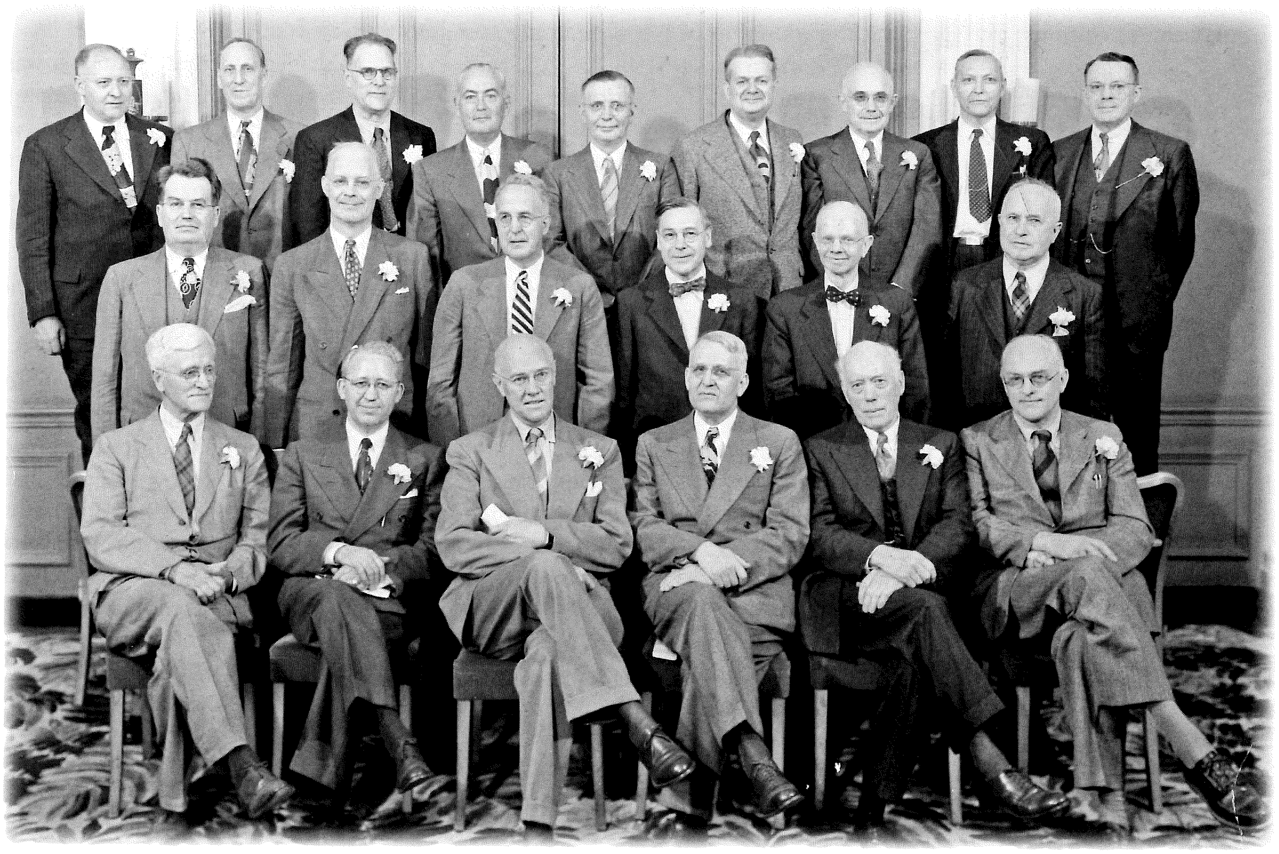

Figure 2. Participants in Founders' Luncheon at 20th Anniversary Meeting
Bottom row (left to right): F. A. Saunders, Wallace Waterfall, Vern O. Knudsen, Harvey Fletcher, C. F. Stoddard, J. P. Maxfield. Middle row (left to right): H. A. Erf, J. B. Kelly, H. A. Frederick, N. R. French, A. T. Jones, J. B. Taylor. Top row (left to right): W. P. Mason, J. C. Steinberg, V. L. Chrisler, L. Green, Jr., H. Lamson, E. C. Wente, W. C. Jones, D. C. Blattner, C. N. Hickman.

in the bank, but estimated that the publication of JASA would cost $25,000 to publish in the coming year. The Society actually operated in the red for three years, and in 1950, they decided to accept advertising in JASA. The Society also initiated a meeting registration fee of $2.00 for meetings, increased page charges from $4.00 to $8.00 per page, and promoted a program to obtain more sustaining members.

There was also considerable reorganization of the leadership structure during this time period as well. In 1948 the Executive Council decided that a president-elect should be chosen so that person could be better prepared to take on the responsibility of president. In the same year it was decided that the Acoustical Society should have its own standards committees rather than originating standards under the American Standards Association. A year earlier the Council had established a formal Standards Committee in 1947 with the explicit goal to keep the Executive Council better informed about standards activities. Later, in 1968, the Executive Council had established the position of vice president-elect, and assigned the vice president the duty of serving as chair of the technical council.

Regional Chapters were also established in the early 1950s in response to interest by members in forming local groups, and by 1954 four chapters had been organized. This program has expanded and contracted over the years in response to the needs and desires of local groups.

The 25th Anniversary meeting in May 1954 was very well recorded for posterity. A film of the four-hour 25th Anniversary banquet was taken, and the transcript of the film is reprinted in JASA. A "Parade of Acoustical Personalities" was the title of the presentations by all the living Presidents—gathered either in person or by recorded messages. There were several acousticians who attended from countries outside the United States including Belgium, England, Germany, India, Italy, and Japan. The Society's first Gold Medal was awarded at that meeting to Wallace Waterfall. The basic design of the medal was executed by Richard Bolt, with a drawing of a tuning fork based on an actual one made by Rudolf Koenig and borrowed from the collection of Dayton Miller.

The film of the banquet was intended for viewing at future anniversary meetings and will in fact be shown at the 75th Anniversary. A special "Time Capsule Custodial Committee" was appointed shortly after the celebration meeting to arrange for the film's care and safe-keeping. It was with this confidence of the survival of the Society and cold war worries that the members of ASA's "Time Capsule Custodial Committee" placed the 16 mm film in the Iron Mountain Atomic Storage Corporation located in upstate New York. They also kept one copy at the University of Michigan in Ann Arbor as a precaution against a widespread disaster, which the Committee noted "could conceivably not wipe out both of these locations." Even though the intent of the Committee was for the transmission to "our hundredth Anniversary Celebration," the film was eventually removed from Iron Mountain in 1976, and a film and negative are now stored at the American Institute of Physics Center for the History of Physics in College Park, Maryland.

5. Expanding Publications-Inside and Outside the Society, 1955-1990

The official theme of the 51st meeting held at the Massachusetts Institute of Technology and Harvard University in June 1956 was "Sound and Man," and covered three areas: 1) Bioacoustics and Noise Control, including Speech and Hearing, 2) Architectural and Musical Acoustics, and 3) Physical Acoustics and Sonics. It was also the occasion of the 2nd International Congress on Acoustics, and the first held in the United States with 1230 registrants.

The Society also began increasing its publications. The total number of pages in JASA went from 1279 in 1955 to about 7000 in 1990. In 1957 JASA went from being published bimonthly to twelve times a year. Two years before, in January 1955, the first issue of the Society's publication *NOISE Control* appeared with Lewis Goodfriend as editor. In his introduction to the magazine, then-president Leo Beranek said that "The magazine is directed to the reader who needs to know about noise control–whether he is an engineer, the manager of a factory, an audiologist, or an architect." It was meant to provide helpful information on the practical application of acoustics, current "Noise in the News," noise legislation and products. It also included ads. The magazine was replaced in 1962 with *Sound Its Uses and Control*. The reason for this change was given in the first editorial, namely that "the scope of *NOISE Control* has clearly been too narrow, and the time has come to provide a broader coverage and give a grasp of the meaning of sound, its uses and control in all aspects to a much wider audience." The editorial goes on to state that one objective is "to provide practical information on the uses and control of sound unencumbered by the heavy mathematical analysis of the conventional research paper." The magazine contained patents, book reviews, calendars, new products and articles which every reader could understand. Robert Fehr (1911-1998), an Associate Editor of *Sound*, elucidated upon this point in the final issue of the magazine when it was hastily, and sadly, terminated by the Executive Council in December 1963: "It is no mean task to bring people together where some are science-oriented and others are thinking in terms of hardware – and in dollars and cents." A small note was inserted in this issue noting the demise of the magazine, and that subscription payments would be refunded.

After WWII there are many examples of societies splitting off from the Acoustical Society. Although no official complaints are to be found associated with these events, minutes and recorded oral interviews allude to concerns expressed by the leadership of ASA about losing these technical fields and membership. In 1948 the Audio Engineering Society began as the hi-fi revolution took off. The report of ASA's Committee on the Development and Promotion of the Society noted the recent appearance of the publication of *Transactions in Audio and Ultrasonic Engineering* and the *Journal of the Audio Engineering Society* which the committee noted "suggest that there are areas, particularly in the area of applications of acoustics, which are not being adequately covered by the *Journal* or by the more recent Society publication, *NOISE Control*." In response to these new fields and publications, the Committee made several recommendations including forming new technical committees.

In 1971, following an Acoustical Society Workshop on Noise Control at Arden House in Harriman, New York, the Institute of Noise Control Engineering (INCE) was formed. Many acousticians are members of both ASA and INCE-USA, and thus the two organizations have held several joint meetings. Also the field of aeroacoustics shifted over to the American Institute of Aeronautics and Astronautics (AIAA), and many Society members helped start the Association of Research in Otolaryngology (ARO). The Society eventually accepted the splitting off of new societies, noting that the creation of new organizations in specialties in acoustics was part of a natural evolution, and the best approach is to avoid conflicts of meetings, and encouraged joint or cosponsored meetings.

Concerns about the future of the Society prompted studies which began with the aforementioned Committee on Development and Promotion of the Society which had been appointed in 1956. That Committee made a number of suggestions for revamping the Society's operations–primarily as they affected technical operations. As a result the Society's present day Technical Council/Technical Committee structure was established. During the oral history interview of Wallace Waterfall, he mentioned a significant development in the Society's structure in 1960. Waterfall recounted the growing sentiment that members wanted an expanded role in conducting the activities of the ASA. In response, the current Technical Committee structure, and later the Technical Council were formed. Wallace felt that it gave the ASA a "House of Representatives" with a large committee representation which could influence the direction of the Society–not only in administrative affairs, but the conduct of meetings and the Journal. Wallace commented that "I feel that a kind of grassroots representation has been very healthy. It certainly saved the Society from being broken up into actual sections...And it prevented the establishment of divisions." A more detailed description of the history of the Society's technical committees can be found in Chapter 3 of this book. In addition the history of each of the current technical committees can be found in the individual chapters of this book, a long with the histories of publications and standards.

A special committee to study the publication policies of the Society was established in 1957. The October 1957 issue of JASA (Vol. 29, No. 10) carries an editorial titled "What sort of journal do we want?" and questions were posed as to how the *Journal* could be improved to better serve the acoustics community. Another poll of the membership was taken in 1966 and reported in JASA in 1968. Members were asked about the publication format and if the technical areas were being served well. The members felt considerable pride and satisfaction for the quality of the content of JASA, but favored some sort of subdivision of the *Journal*. A survey of 42 scientific and engineering societies in 1992 placed JASA among the top three ranked best by members. Splitting JASA into two sections (Physical Sciences and Life Sciences) once again became a source of deep discussion in the early 1990s. However the solution to this question was essentially answered by electronic publishing whereby readers could choose their own topic of interest without receiving a huge or split journal in the mail.

In 1972 the Society hosted the Conference on Acoustics and Societal problems at Arden House in New York. John Johnson, the Conference Chair, began the report on the conference by stating: "The pervading and ascending influence of science and technology on our society has become a cause of public concern. While impressed by such triumphs as moon landings, the public has become increasingly critical of the scientific community for its seeming apathy toward many of society's everyday problems." The technical areas focused on the effects of noise and improvements to biomedical acoustics. Also improvements to the organization were mentioned such as better relationships with other technical societies and government. Thirty-two years later most of their findings are still applicable today. The need to apply technical solutions to everyday needs of society seems to be a perpetual concern.

All three of the founding fathers died in 1974. Wallace Waterfall served as Secretary of the Society from 1929 to 1969 when Betty Goodfriend, his assistant, assumed his responsibilities. Wallace Waterfall continued to serve as treasurer. Betty Goodfriend served until 1987, when Murray Strasberg, a long-time member of the Society and a past president, was appointed Secretary. In 1990 Charles Schmid became the first executive director of the Society and the position of Secretary was retired. Elaine Moran serves as division manager for the headquarters office, and began working for the Society in 1970.

6. Building Diversity, 1991-2004

Diversity emerged in many forms in the Society in the 1990s. The printed page started giving way to electronic publications, and members began submitting papers over the internet. The Society, through its meetings, authors and membership, became much more international in scope, and the members elected African-Americans and women to leadership positions. Along with these changes, the role of students and public relations became much more prominent in the Society.

The methods by which information was delivered and accepted from members changed drastically as a result of the internet revolution. Up until the mid-1990's ASA's communications were primarily at meetings or through the printed page. The decade which followed was truly a revolution in communicating with members. E-mail, CD ROMs, online publications, electronic submission of abstracts, manuscript management, the world wide press room, and ASA's web pages showed how many diverse ways the Society could communicate with its members and the public at-large. Before recalling the origins of these forms of Society communications, it might be of interest to note that two of the Society's past presidents had prominent roles in the founding of the internet! While most engineers and scientists in the emerging computer age were philosophizing how man and machine were going to communicate, past president J.C.R. Licklider (1915-1990) was working on a system in the early 1960s where man was communicating with man via computer – the internet. Earlier in his life he had received the Biennial Award (now the R. Bruce Lindsay Award) in 1950, and had been lauded as "one who enjoys the life of a pioneer who swings his not too precise machete through a jungle of inconsistent and contradictory data," praising his work in psychoacoustics. He also served as president of the Society in 1958-59 when he was working with Leo Beranek at Bolt, Beranek and Newman. Shortly after that he wrote a seminal paper "On-Line Man Computer Communication" and went on to join DARPA (Defense Advanced Research Project Agency) to work on the first communication systems which sent human messages between computers. Later, at Licklider's instigation, ARPA supported university scientists in their work to make computers smaller, cheaper and more available and above all, able to communicate over some sort of electronic nervous system.

However it took the world and the Acoustical Society until the early 1990s to begin extensive communications electronically. In 1994 the Society began placing past volumes of JASA on CD ROM so that members could have quick access to past issues and at the same time gain shelf space in their homes and offices. In 1995, then President-Elect Robert Apfel (1943-2002) led the effort to provide on-line submission of abstracts which was initiated for the fall meeting in that year. In 1996 he made the motion to publish the current issue of the *Journal* on CD ROM and give members the option to receive it every two months, with students automatically receiving JASA in CD ROM format. Robert Apfel also initiated *Acoustics Research Letters Online (ARLO)* which began online-only publication in 1999. This unique journal had its own electronic manuscript managing system, and is available only online without charge to anyone with a browser. Bob Apfel carried on the visionary approach for the Society that J.C.R. Licklider did thirty years earlier for the world!

Another form of communication with members is to poll the membership about the Society – to find out if members are satisfied with the products and services they receive, or more importantly how the Society can improve. In 1992 the Society entered into a survey with 42 other prominent scientific and engineering societies. The result was that the Acoustical Society was rated in the top three in: 1) overall satisfaction, 2) technical publications, and 3) standards activities. However members felt the Society could improve in its outreach to the public informing them about acoustics and acousticians, and was not doing enough with careers in acoustics. This was followed by the Re-creation Process–rethinking the ASA–which began in 1994 and concluded with a summary report in JASA which contained many suggestions for new and modified ASA programs. Another less formal survey was later carried out with a focus group comprised of graduate students in acoustics at the University of Washington. A strong suggestion from them was the need for a student council. The ASA Student Council was appointed in 1999 and now meets semi-annually at Acoustical Society meetings. They have already established a mentoring award, and a web page which provides information explicitly for students.

Based on the 1992 poll the Society took steps to increase its dissemination of information to its members and also improve public outreach. In 1995 the Society set up its own web page with the help of ASA volunteers Paul Baxley and Carr Everbach. Paul Baxley developed an idea to post lay papers from ASA meetings on the web for the public and the press to read, naming it the World Wide Press Room. This novel approach has been adopted by other societies, and along with the aid of the press room set up by the American Institute of Physics, has led to many stories in the public press about acoustics. The World Wide Press Room was later incorporated in a separate web page for the general public <acoustics.org>.

The need for some sort of publication to supplement JASA was apparent ever since the demise of *Sound* in 1963. An often heard complaint of members is that they would like something more readable. One of Charles Schmid's first tasks as executive director was to begin the publication of *ECHOES* with Alice Suter as managing editor. It began in Spring 1991, adopting the name of a newsletter once published by the executive director's previous employer. *ECHOES* is sent four times a year to all ASA members, the press and regional chapter members who are not members of the Society. Tom Rossing took over as editor of *ECHOES* in 1997.

The 1990s also saw the membership grow in diversity. As you probably noted in the photo above showing the 40 founding members of the Society—all were men. For that matter the photo of the 25th anniversary banquet had the caption "Council members and Past presidents *and their ladies*" (italics original). Even earlier notes from the meeting in 1948 in Washington, DC discussed the "Ladies Program:" "On Friday afternoon the ladies were graciously received at the White House by Mrs. Harry S. Truman in an affair including handsome Naval aides in gold braid and a military orchestra in red uniforms." It was fifty years later when Patricia K. Kuhl was elected as the Society's first woman president in 1998. Since that time, two women have been elected president. And Patricia Kuhl can be seen on the cover of the Summer 1997 *ECHOES* being greeted at the White House by President Clinton when she was invited by Mrs. Clinton to give a paper on early childhood development and learning. James E. West, the first African-American president, was elected in 1997. Although the leadership has become more diverse in gender and race, it should be pointed out that today only 13% of the Society's members are women and the number of under represented minorities is still very small. These issues have been addressed by the Committee on Women in Acoustics, which was formed in 1995, and the establishment of the Minority Scholarship in 1992.

Another aspect of diversity has been an increase in participation by international members and organizations. The percentage of members who are from outside the US or Canada went from 16% in 1990 to 26% in 2002. Likewise about half of the manuscripts submitted to JASA originate outside of North America. One approach the Society has taken to recognize this increased representation of non-US members has been to hold meetings in Ottawa, Canada (1968, 1981 and 1993), and to hold joint meetings with the Acoustical Society of Japan in Honolulu, Hawaii (1978, 1988, 1996). In addition, the Acoustical Society has hosted two joint meetings of the International Congress on Acoustics (ICA) in Cambridge, Massachusetts (2nd ICA 1956) and Seattle, Washington (16th ICA 1998). In the process of increasing its interaction with the International Commission on Acoustics, the Acoustical Society has become more involved with their activities, including jointly funding international travel grants and technical meetings, and scheduling conferences on acoustics. The first joint meeting with the European Acoustics Association (EAA) was held in Berlin (1999), which was also the first meeting that the ASA held in Europe. With 2,263 attending, it had the largest attendance to date of a meeting on acoustics. In 2002 the ASA met in Cancun, Mexico with the Iberoamerican Federation of Acoustics (FIA) and the Mexican Institute of Acoustics (IMA) for the first Pan American/Iberian Meeting on Acoustics. Another method to increase international participation with the Society was by offering electronic associate membership beginning in 2002. A special aspect of this membership was a corresponding electronic associate which allows acousticians in certain countries to join the Society at a low fee. Also the Regional Chapters program was "internationalized" with the establishment of chapters in Madras, India in 1995 and in Mexico City in 2001.

The fact that acoustics is such a diverse topic has led to concerns that specialty fields within acoustics are not addressed at Society meetings to the depth members would like. This problem was referred to above in section 5 (1955-1990) when it was noted that new journals and new societies were being formed which focused on one aspect of acoustics. Acknowledging this problem the Society decided to organize and cosponsor smaller workshops and symposia which are dedicated to one subject. There have been a number of these, including the Physical Acoustics Summer School (PASS) held every two years beginning in 1992, International Symposium on Musical Acoustics (1998), Themed Entertainment Workshop (1999), the first International Workshop on Thermoacoustics (2001), and the first International Conference on Acoustic Communication by Animals (2003).

Creating new technical committees was another approach towards providing a platform for acousticians in special and emerging fields. After the Cold War ended, the Society saw the emergence in the mid-1990s of three new technical committees which represented very diverse technical fields: 1) Acoustical Oceanography, 2) Animal Bioacoustics, and 3) Signal Processing in Acoustics. In addition Bioresponse to Vibration added Biomedical Ultrasound to address the important developments in health-related acoustics. The history of these fields, as well as the other technical committees, are covered in the ensuing chapters of this book. In addition to adding three technical committees, the Technical Council took an increasingly active role in polling its membership at meetings to better report the needs and desires of the members to the Executive Council. Wallace Waterfall would have approved of this function; as mentioned earlier, he felt that the technical committees gave the ASA a "House of Representatives" which could influence the direction of the Society.

Although not noticeable to the average member, finances are a very important responsibility with which the Society's leadership must concern itself. And although the Society had kept enough reserves to maintain its operations during economic downturns, it became apparent in the early 1990s that the Society needed endowment funds if it wanted to increase its outreach efforts, including supporting prizes and special fellowships. A Development Committee was appointed in 1990, after which it was decided that the best approach for fund-raising was to form a separate not-for-profit organization which would provide funding to the Acoustical Society of America. Hence in 1996 the Acoustical Society Foundation was incorporated as a separate organization with William W. Lang as General Secretary and Paul B. Ostergaard at its first president. Also during this time period the Executive Council organized itself into three Administrative Councils to carry out its business more efficiently: 1) Internal Affairs, 2) External Affairs and 3) Financial Affairs. This was first implemented at the Austin meeting in the fall of 1994. It also initiated meetings of Officers and Managers in 1995 to carry out administrative issues between its semi-annual meetings.

Parting Personal Thoughts

Seventy five years is about the average lifetime for human beings. This accounts for the fact that none of the founding members are alive today, and hence the story of how of our Society began is now handed down to us. It is interesting to note that a number of the Acoustical Society's active members, including past presidents and the editor of *ECHOES*, happened to be born in 1929, and will be attending the 75th anniversary celebration of the Society. Since we naturally foresee the Society transcending our life spans, the message is clear. In order to retain our history for those who follow, especially for younger acousticians, we need to record the present which will turn into its history. The founders must have been keenly aware of this when they placed the 25th Anniversary film in Iron Mountain Atomic Storage. We are confident the founders would be proud to know that we are in turn recording important events which have shaped the Society during our lifetimes. Besides videotaping recollections of past presidents, there will be a video taken of the 75th anniversary celebration itself.

Additional sources for information designated by the Archives and History Committee are the three sites for storing historical items and papers in certain fields: 1) Architectural Acoustics: Riverbank Labs, IL; 2) Physical Acoustics, National Center for Physical Acoustics, MS; and 3) Musical Acoustics: The Catgut Acoustic Society Library (CASL), web pages in the Musical Acoustics Research Library (MARL), and at the Stanford University Center for Computer Research in Music and Acoustics (CCRMA). In addition, the History Center of the American Institute of Physics in College Park MD retains historical information, including oral histories from members of the Acoustical Society. A list of those whose interviews have been completed is given at the end of this section.

Anyone reading all or parts of this history should come to the conclusion that there would be no 75th celebration had not a lot of members volunteered their valuable time and creative ideas over the years to improve the Society – and the field of acoustics in general. In turn, they too have benefitted in both their personal and their professional lives. Carrying on this tradition will most certainly allow our Society to live many human lifetimes.

In parting we note that the paragraph above is the easy way out to predict the future, namely the past is prologue. Perhaps we took a hint to avoid any stronger predictions from a JASA article entitled "Thoughts on the future of acoustics" moderated by Walter Rosenblith, with panelists James Barger, Lois Elliott, Tony Embleton and Robert Apfel. It was based on a session of the same name held at the 50th anniversary meeting. Lois Elliott was "willing to wager that when the Society celebrates its 100th anniversary, there will be people in the audience wearing and benefiting from implanted prostheses!" She would have been right even for the 75th anniversary.

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Collected by the Archives and History Committee, Acoustical Society of America

Laurence Batchelder
Leo L. Beranek
Robert T. Beyer
Per V. Bruel
Hallowell Davis
Tony F. W. Embleton
Robert S. Gales
Louis S. Goodfriend
David M. Green
Robert Green
Katherine S. Harris
Ira J. Hirsh
Richard H. Lyon
Daniel W. Martin
Harry B. Miller
Louis C. Sutherland
Eric E. Ungar
Robert W. Young

Collected by the History Center, American Institute of Physics

Harvey Fletcher
Frederick V. Hunt
Vern O. Knudsen
R. Bruce Lindsay
Wallace Waterfall
A. B. Wood

Present and Past Officers of the Acoustical Society of America

Presidents

Harvey C. Fletcher	1929-31
Dayton C. Miller	1931-33
Vern O. Knudsen	1933-35
Paul E. Sabine	1935-37
Frederick A. Saunders	1937-39
Floyd R. Watson	1939-41
E. C. Wente	1941-43
Floyd A. Firestone	1943-45
Hugh S. Knowles	1945-47
John C. Steinberg	1947-49
Richard H. Bolt	1949-50
Philip M. Morse	1950-51
Frederick V. Hunt	1951-52
Harry F. Olson	1952-53
Hallowell Davis	1953-54
Leo L. Beranek	1954-55
Warren P. Mason	1955-56
R. Bruce Lindsay	1956-57
Richard K. Cook	1957-58
Joseph C.R. Licklider	1958-59
Hale J. Sabine	1959-60
Robert W. Young	1960-61
Laurence Batchelder	1961-62
Robert W. Leonard	1962-63
C. Paul Boner	1963-64
Cyril M. Harris	1964-65
Robert W. Morse	1965-66
Martin Greenspan	1966-67
Ira J. Hirsh	1967-68
Robert T. Beyer	1968-69
Isadore Rudnick	1969-70
Vincent Salmon	1970-71
John C. Johnson	1971-72
Karl D. Kryter	1972-73
Edgar A. G. Shaw	1973-74
Murray Strasberg	1974-75
Robert S. Gales	1975-76
Kenneth N. Stevens	1976-77
John C. Snowdon	1977-78
James L. Flanagan	1978-79
Henning E. von Gierke	1979-80
Tony F.W. Embleton	1980-81
David M. Green	1981-82
David T. Blackstock	1982-83
Frederick H. Fisher	1983-84
Daniel W. Martin	1984-85
Floyd Dunn	1985-86
Ira Dyer	1986-87
Chester M. McKinney	1987-88
W. Dixon Ward	1988-89
Harvey H. Hubbard	1989-90
Alan Powell	1990-91
Eric E. Ungar	1991-92
Herman Medwin	1992-93
Richard H. Lyon	1993-94
Jiri Tichy	1994-95
Robert E. Apfel	1995-96
Stanley L. Ehrlich	1996-97
Lawrence A. Crum	1997-98
James E. West	1998-99
Patricia K. Kuhl	1999-2000
Katherine S. Harris	2000-01
William M.Hartmann	2001-02
Richard Stern	2002-03
Ilene J. Busch-Vishniac	2003-

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Vern O. Knudsen	1929–31
C. W. Hewlett	1931–32
H. A. Frederick	1932–34
R. F. Norris	1934–36
V. L. Chrisler	1936–38
Floyd A. Firestone	1938–40
C. R. Hanna	1940–42
Harry F. Olson	1942–44
John C. Steinberg	1944–46
Philip M. Morse	1946–48
Benjamin Olney	1948–49
Leo L. Beranek	1949–50
Carl F. Eyring	1950–51
R. Bruce Lindsay	1951–52
Richard D. Fay	1952–53
Robert W. Young	1953–54
Richard K. Cook	1954–55
Hale J. Sabine	1955–56
Leo P. Delsasso	1956–57
William Jack	1957–58
Arnold Peterson	1958–59
Robert W. Leonard	1959–60
Cyril M. Harris	1960–61
Robert T. Beyer	1961–62
Isadore Rudnick	1962–63
Martin Greenspan	1963–64
Vincent Salmon	1964–65
Harold L. Saxton	1965–66
Gordon E. Peterson	1966–67
Ernest Yeager	1967–68
Edgar A. G. Shaw	1968–70
John V. Bouyoucos	1970–71
Kenneth N. Stevens	1971–72
Robert S. Gales	1972–73
Ira Dyer	1973–74

Arthur H. Benade	1974–75
William S. Cramer	1975–76
James L. Flanagan	1976–77
Tony F. W. Embleton	1977–78
David T. Blackstock	1978–79
Edith L. R. Corliss	1979–80
Frederick H. Fisher	1980–81
Floyd Dunn	1981–82
Alan Powell	1982–83
William J. Galloway	1983–84
Chester M. McKinney	1984–85
Harvey H. Hubbard	1985–86
W. Dixon Ward	1986–87
Herman Medwin	1987–88
Eric E. Ungar	1988–89
Richard H. Lyon	1989–90
Katherine S. Harris	1990–91
Robert E. Apfel	1991–92
Jiri Tichy	1992–93
Stanley L. Ehrlich	1993–94
Lawrence R. Rabiner	1994–95
Lawrence A. Crum	1995–96
Patricia K. Kuhl	1996–97
Ilene J. Busch-Vishniac	1997–98
William M. Hartmann	1998–99
Mauro Pierucci	1999–00
Gilles A. Daigle	2000–01
Janet M. Weisenberger	2001–02
William A. Yost	2002-03
Anthony A. Atchley	2003-

Editor-in-Chief

Wallace Waterfall	1929-33
Floyd R. Watson	1933-39
Floyd A. Firestone	1939-57
R. Bruce Lindsay	1957-85
Daniel W. Martin	1985-99
Allan D. Pierce	1999-

Treasurer

Charles Fuller Stoddard	1929-30
E. E. Free	1930-34
G. T. Stanton	1934-39
C.C. Potwin	1939-41
Lonsdale Green, Jr.	1941-47
George M. Nixon	1947-50
Herbert A. Erf	1950-67
Wallace Waterfall	1967-74
Robert T. Beyer	1974-94
William W. Lang	1994-99
Paul B. Ostergaard	1999-00
David Feit	2000-

Secretary

Wallace Waterfall	1929-69
Betty H. Goodfriend	1969-87
Murray Strasberg	1987-90

Executive Director

Charles E. Schmid	1990-

Standards Director

Henning E. von Gierke	1978-79
William J. Galloway	1979-83
William Melnick	1983-87
Kenneth M. Eldred	1987-93
Tony F.W. Embleton	1993-97
Daniel L. Johnson	1997-02
Paul D. Schomer	2002-

Recipients of the Gold Medal

1954 - Wallace Waterfall
1955 - Floyd A. Firestone
1957 - Harvey Fletcher
1959 - Edward C. Wente

1961 - Georg von Békésy - For his deft proficiency in the experimental art which has laid open the ear and resolved the mysteries of its inner workings. (Abstracted)

1963 - R. Bruce Lindsay - For major contributions to the knowledge of physical acoustics through research and authorship; for teaching and training acousticians; and for sustained service to the Society as an officer and Editor-in-Chief of its publications. (Abstracted)

1965 - Hallowell Davis - For his many contributions to our understanding of the workings of the hearing mechanism; for his versatile concern with bioacoustics, psychoacoustics, audiology, physiology, and otolaryngology; and for his service to the Society. (Abstracted)

1967 - Vern Oliver Knudsen - For his research into the propagation of acoustical waves through the air and the sea; for his contributions to the understanding of the communication of speech and music and his expert application of this knowledge in the field of hearing and architectural acoustics; and for his service to the Society as founder and officer. (Abstracted)

1969 - Frederick V. Hunt - For his extensive contributions to the science and technology of acoustics in the fields of architecture, engineering, and signal processing; for his creative leadership in underwater sound and its application to the security of our nation; and for his service to the Society. (Abstracted)

1971 - Warren P. Mason - For his electromechanical filters which are the keystone of carrier-frequency telephony; investigations of piezoelectric crystals, ceramics and the properties of materials. (Abstracted)

1973 - Philip M. Morse - For his preeminent accomplishments in the field of vibration.

1975 - Leo L. Beranek - For leadership in developing, in the United States and abroad, the desire and the capability for achieving good acoustics in communications, workplaces, concert halls, and communities.

1977 - Raymond W. B. Stephens - For extensive contributions to the advancement of acoustics in his own and many other countries: as a physics teacher and experimentalist; as an author and editor; as a founder and leader of acoustical societies; and above all as a research supervisor who has taught and inspired a generation of acoustics students and guided them in the attainment of excellence.

1979 - Richard H. Bolt - For outstanding contributions to acoustics through research, teaching, and professional leadership, and for distinguished administrative and advisory service to science, engineering, and government.

1981 - Harry F. Olson - For his innovative and lasting contributions in acoustic transduction, sound reproduction, electronic music and speech synthesis, and his service to the Society.

1982 - Isadore Rudnick - For his ingenious and masterly contributions to acoustical research and teaching, and for his distinguished leadership and service to the Society.

1983 - Martin Greenspan - For wide ranging and superlative contributions to experimental and theoretical physical acoustics, including ultrasonically induced cavitation in liquids and sound propagation in solids, liquids, and gases.

1984 - Robert T. Beyer - For contributions to acoustics through his teaching, research, and translations and for his dedicated service to the Acoustical Society of America.

1985 - Laurence Batchelder - For significant contributions to underwater acoustics, to acoustical standards, and to the Acoustical Society of America as Fellow, officer, and patent reviewer.

1986 - James L. Flanagan - For contributions to and leadership in digital speech communications.

1987 - Cyril M. Harris - For service to the Society; for improved understanding of absorption of sound in gases; and for contributions to the science and practice of architectural acoustics.

1988 - Arthur H. Benade (posthumously) - For pioneering work in the science and art of musical acoustics, emphasizing the interactions among performer, instrument, and listener.

1988 - Richard K. Cook - For outstanding seminal contributions to diverse areas of acoustics and to standardization.

1989 - Lothar W. Cremer - For identifying and solving key problems in acoustics and acoustical engineering and for the impact of his teachings and writings.

1990 - Eugen J. Skudrzyk (posthumously) - For his extensive contributions to the advancement of acoustics, particularly structural and underwater acoustics, as a researcher, author and educator.

1991 - Manfred R. Schroeder - For theoretical and practical contributions to human communication through innovative application of mathematics to speech, hearing, and concert hall acoustics.

1992 - Ira J. Hirsh - For contributions to the understanding of the auditory process.

1993 - David T. Blackstock - For contributions to the understanding of finite-amplitude sound propagation and worldwide leadership in nonlinear acoustics.

1994 - David M. Green - For contributions to knowledge, theory, and methodology in audition.

1995 - Kenneth M. Stevens - For leadership and outstanding contributions to the acoustics of speech production and perception.

1996 - Ira Dyer - For contributions to ocean acoustics, structural acoustics, and aeroacoustics, and for dedicated service to the Society.

1997 - K. Uno Ingard - For contributions to and teaching of physical acoustics and noise control.

1998 - Floyd Dunn - For creative contributions to fundamental knowledge of ultrasonic propagation in, and interactions with, biological media.

1999 - Henning E. von Gierke - For contributions to bioacoustics, psychoacoustics, vibrations, and for leadership in national and international acoustical standards.

2000 - Murray Strasberg - For contributions to hydroacoustics, acoustic cavitation and turbulence noise, and for dedicated service to the Society.

2001 - Herman Medwin - For innovative research in ocean acoustics and leadership and service to the Society.

2002 - Robert E. Apfel - For fundamental contributions to physical acoustics and biomedical ultrasound and for innovative leadership in electronic publishing.

2002 - Tony F.W. Embleton - For fundamental contributions to understanding outdoor sound propagation and noise control and for leadership in the Society.

2003 - Richard H. Lyon - For sustained leadership and extensive contributions in the application of statistical concepts to structural acoustics and noise.

2004 - Chester M. McKinney - For pioneering research and leadership in underwater acoustics and high resolution sonar, and for dedicated service to the Society.

Recipients of Honorary Fellowship

1929 - Thomas A. Edison
1949 - Harvey Fletcher
1954 - Vern O. Knudsen
1954 - Paul E. Sabine
1954 - Frederick A. Saunders
1954 - Floyd R. Watson
1960 - Harvey C. Hayes
1971 - Walter G. Cady
1980 - Elfyn J. Richards
1983 - Maurice A. Biot
1988 - Henrik A. S. Nodtvedt
1994 - Leo L. Beranek
1997 - Robert W. Young
1998 - Carleen M. Hutchins
1999 - Leonid M. Brekhovskikh
2002 - Michael Longuet-Higgins

Recipients of the R. Bruce Lindsay Award (formerly Biennial Award)

1942 - Richard H. Bolt
1944 - Leo L. Beranek
1946 - Vincent Salmon
1948 - Isadore Rudnick
1950 - J. C. R. Licklider
1952 - Osman K. Mawardi
1954 - K. Uno Ingard
1956 - Ernest Yeager
1956 - Ira J. Hirsh
1958 - Bruce P. Bogert
1960 - Ira Dyer

1962 - Alan Powell - In recognition of his outstanding contributions to acoustics, through research and publication on edge tones, random vibrations, boundary layer phenomena, and the noise made by jet flow and turbulence.

1964 - Tony F. W. Embleton - For his original contributions to radiation pressure of curved wave fronts, his work on precision microphone calibration, and especially for the varied work, both theoretical and experimental in the field of noise control.

1966 - David M. Green - In recognition of his many contributions to the body of knowledge of psychological acoustics, stressing the importance of the analytic model in understanding the basic processes of audition; with particular recognition of his major role in demonstrating the relationships between detection theory and auditory perception.

1968 - Emmanuel P. Papadakis - For important contributions to the theoretical and experimental understanding of the propagation, attenuation, diffraction, and refraction of elastic waves in crystalline and polycrystalline solids.

1970 - Logan E. Hargrove - For research in ultrasonics, including especially his contributions to the understanding of diffraction of light by ultrasonic waves and his demonstration of mode-locking in lasers.

1972 - Robert D. Finch - For research in ultrasonics; specifically for contributions toward the understanding of cavitation nucleation.

1974 - Lawrence R. Rabiner - For exceptional research contributions in speech communications, hearing and digital-signal processing.

1976 - Robert E. Apfel - For his contributions to physical acoustics, especially for research in acoustic cavitation and the strength of liquids.

1978 - Henry E. Bass - For theoretical and experimental research on the effects of molecular relaxation on sound propagation in multicomponent gases.

1980 - Peter H. Rogers - For research accomplishments in theoretical linear and nonlinear acoustics as related to acoustic radiation, transduction, and shock waves.

1982 - Ralph N. Baer - For important contributions toward a better understanding of the propagation of sound in the ocean and, in particular, the effects of Rossby waves and eddies.

1984 - Peter N. Mikhalevsky - For significant contributions to understanding the propagation of sound in the ocean and the role of fluctuations in signal detection modeling.

1986 - William E. Cooper - For his explorations of the mechanisms for processing the phonetic attributes of speech; for his pioneering research in the role of prosody and intonation in sentence processing and sentence planning; and for his contributions to basic research on speech and language disorders subsequent to brain damage.

1987 - Ilene J. Busch-Vishniac - For outstanding contributions to developing an improved understanding of the dynamic response of electret transducers and noise propagation in urban environments.

1988 - Gilles A. Daigle - For theoretical and experimental studies of the effects of micrometeorology and of the contours and acoustical properties of the ground on sound propagation outdoors.

1989 - Mark F. Hamilton - For contributions to nonlinear acoustics, particularly parametric arrays, intense sound beams, and waveguides.

1990 - Thomas J. Hofler - For the development of thermoacoustic heat pumps and for the design and calibration of optoacoustic transducers.

1991 - Yves H. Berthelot - For experimental and theoretical contributions to the use of lasers in acoustics and to the measurement of propagation of sound over irregular terrain.

1991 - Joseph M. Cuschieri - For contributions to theory and measurement of power flow in vibrating structures.

1992 - Anthony A. Atchley - For contributions to the understanding of acoustic cavitation and thermoacoustics.

1993 - Michael D. Collins - For exceptional contributions to numerical modeling of complex acoustical phenomena and nonlinear inversion methods.

1994 - Robert P. Carlyon - For contributions to knowledge concerning the auditory processing of spectrally and temporally complex sound.

1995 - Beverly A. Wright - For contributions to the understanding of auditory processing of complex signals.

1996 - Victor W. Sparrow - For contributions to nonlinear acoustics, outdoor sound propagation, and structural acoustics.

1997 - D. Keith Wilson - For contributions to atmospheric acoustics, and for applying acoustical tomography to the turbulent atmosphere.

1998 - Robert L. Clark - For contributions to adaptive noise control.

1999 - Paul E. Barbone - For developing novel theoretical and computational acoustics techniques.

2000 - Robin O. Cleveland - For contributions to nonlinear acoustics, particularly to shock wave lithotripsy.

2001 - Andrew J. Oxenham - For contributions to the measurement of peripheral auditory nonlinearity, and to understanding its effects in normal and hearing-impaired listeners.

2002 - James J. Finneran - For contributions to the understanding of auditory mechanisms and transduction in teleost fish and of hearing by dolphins.

2002 - Thomas J. Royston - For contributions to the nonlinear characterization and control of vibration and for acoustical outreach to inner city youth.

2003 - Dani Byrd - For research in motor control and timing in speech production.

2004 - Michael R. Bailey - For contributions to the understanding of shock wave lithotripsy and nonlinear acoustics

Recipients of the Distinguished Service Citation

1972 - Laurence Batchelder
1973 - Robert W. Young
1973 - Betty H. Goodfriend
1974 - Gerald J. Franz
1978 - Robert T. Beyer
1978 - Henning E. von Gierke
1981 - R. Bruce Lindsay
1984 - William S. Cramer
1986 - Stanley L. Ehrlich
1986 - Samuel F. Lybarger
1987 - Frederick E. White
1989 - Daniel W. Martin
1990 - Murray Strasberg
1996 - John C. Burgess
1994 - William J. Cavanaugh
1997 - Alice H. Suter
1999 - Elaine Moran
2000 - F. Avril Brenig
2000 - John V. Bouyoucos

Recipients of the Minority Fellowship

1993 - Brian Scott
1997 - J. Sean Allen
1999 - Guillermo E. Aldana
2001 - Vernecia S. McKay
2002 - David T. Bradley
2003 - Gaylon C. Hollis

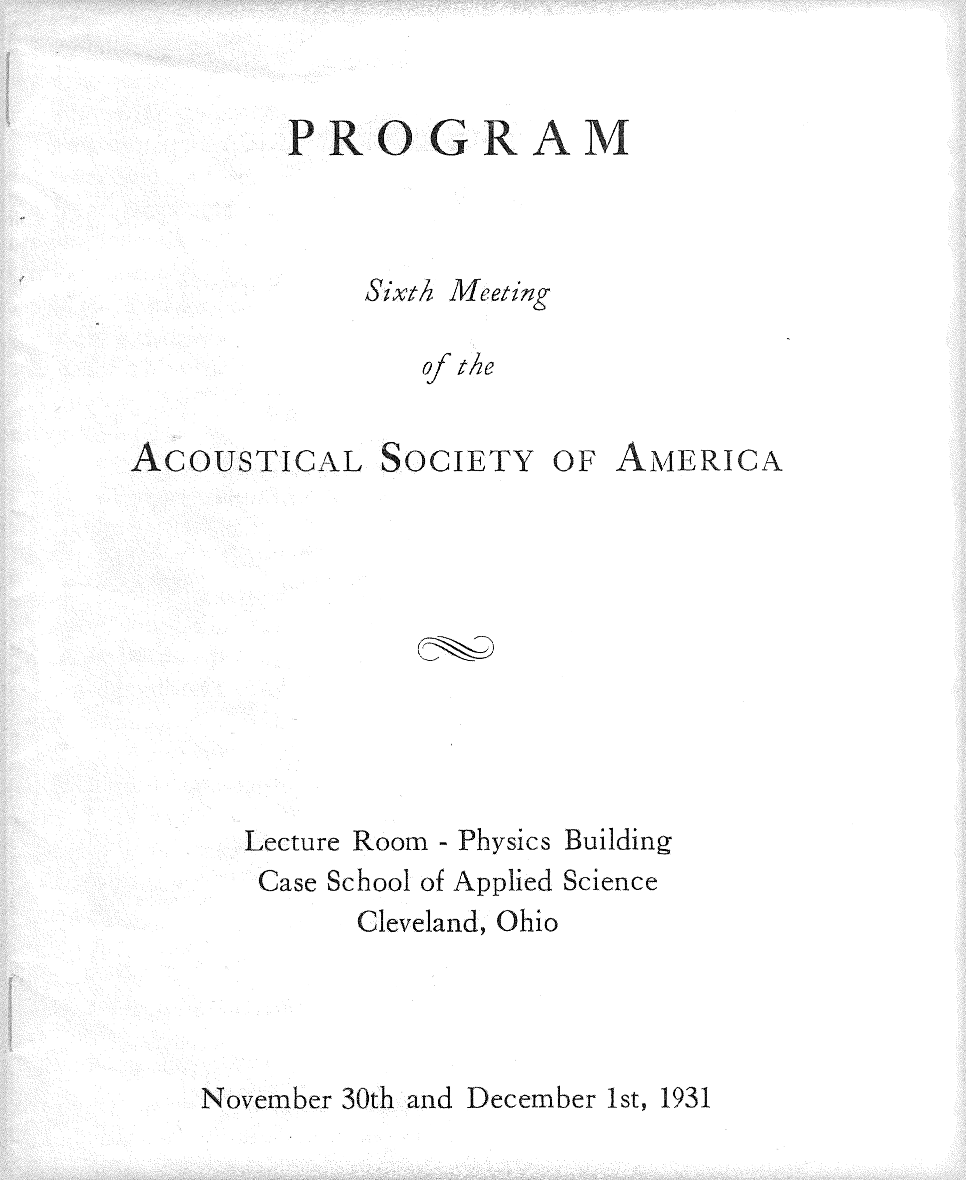
Recipients of the Frederick V. Hunt Postdoctoral Research Fellowship in Acoustics

1978-79 - Steven L. Garrett
1979-80 - Mary J. Osberger
1980-81 - Cynthia A. Prosen
1981-82 - Daniel Rugar
1982-83 - Wesley N. Cobb
1983-84 - Mark F. Hamilton
1984-85 - Christine H. Shadle
1985-86 - Anthony A. Atchley
1986-87 - M. Christian Brown
1987-88 - Ian M. Lindevald
1988-89 - Elizabeth C. Oesterle
1989-90 - E. Carr Everbach
1990-91 - Kenneth A. Cunefare
1991-92 - Gregory J. Sandell
1992-93 - Quan Qi
1993-94 - Charles E. Bradley
1994-95 - T. Douglas Mast
1995-96 - Robin O. Cleveland
1996-97 - Mark A. Hasegawa-Johnson
1997-98 - James J. Finneran
1998-99 - Lily Wang
1999-00 - Penelope Menounou
2000-01 - James C. Lacefield
2001-02 - Chao-Yang Lee
2002-03 - Constantin C. Coussios
2003-04 - Tyrone M. Porter

Chapter 2

History of the Society's Publications

Allan D. Pierce, Editor-in-Chief



PROGRAM

Sixth Meeting

of the

ACOUSTICAL SOCIETY OF AMERICA

* * *

Lecture Room - Physics Building
Case School of Applied Science
Cleveland, Ohio

November 30th and December 1st, 1931

History of the Society's Publications

Allan D. Pierce, Editor-in-Chief

The purpose of the Acoustical Society of America is to increase and diffuse the knowledge of acoustics and promote its practical applications, and the publications of the Society are intended to help fulfill this purpose. In addition to the *Journal of the Acoustical Society*, which has been published continuously for the past 75 years, the Society has engaged in a number of other publications activities, including the publication of a second periodical, the publication of a newsletter, and the publication of a number of books, videos, and compact discs. The Society has also recently began to publish material on the Internet, and it is anticipated that this activity will increase substantially in the future.

In the present chapter, an attempt is made to summarize the history of these publishing activities.

Origin of The Journal

At the historic organizational meeting on December 27, 1928, when the launching of the Acoustical Society of America was planned, the subject of a possible journal was discussed. According to a later account, there was some concern that such a journal would not be a success, as there would not be a long term guarantee of enough new publishable material to sustain the journal. But optimism prevailed, and the available records suggest that the principal founders carried out a fund-raising campaign to make the publication of the journal possible.

The Society held its first meeting on May 9-11, 1929, and at this meeting, the newly elected President, Harvey Fletcher, called for a meeting of the newly elected Executive Council for the same day. "There are a large number of questions to be considered, one being the question of the publication of a journal. I feel sure that we have sufficent financial support already so that we can promise you that the proceedings of this meeting will come out as the first publication of the Society. What the future plans will be, of course, will be put in the hands of a committee." At the subsequent Executive Council meeting, a publication committee consisting of Wallace Waterfall (Chair), Floyd R. Watson, Paul E. Sabine, and Charles F. Stoddard was appointed to supervise the publication of a journal. (All of these persons were members of the Executive Council; Stoddard was the Society's first Treasurer; Waterfall was its first Secretary.)

The first issue of the *Journal* was dated October 1929. The cover (designed by Wallace Waterfall) was yellow-tannish and the size was 6.5 by 9.5 in., and there were 163 pages. The now-familiar logo appeared on the cover for the first time, with the letter S in the center of a set of alternately shaded concentric circles supported on its two lower corners by two A's and on the upper right and left by the numbers 19 and 29, respectively. At the bottom of the cover, there was the statement: "Published Quarterly at Menasha, Wisconsin, by the Acoustical Society of America." On the inside front cover was a stating of the membership of the "publication committee" and statements that the subscription price was $4 to members and $6 to nonmembers.

Much of this historic issue was devoted to the archiving of the creation of the Society, and to publishing the abstracts of papers presented at the first meeting, but there were eight technical articles. These were somewhat interdisciplinary, but a gross classification yields one on architectural acoustics, three on speech, two on instrumentation, and one on psychoacoustics. One of the speech papers was also concerned with architectural acoustics, another overlapped with physical acoustics; one of the instrumentation papers was concerned with musical acoustics, the other with noise. In any event, the first issue set the tone for a journal that was relating strongly to practical problems of the day.

The Society held its second meeting in December 1929, only two months after the appearance of the first issue of the Journal. At that meeting, the Executive Council again took up the subject of the *Journal.* Floyd R. Watson, who was then a member of the Council, was appointed Chair of an Editorial Board, who in turn selected E. C. Wente, Paul E. Sabine, H. W. Lamson, Frederick A. Saunders, and Wallace Waterfall as the other members of the Board.

The *Journal* was initially a quarterly, with issues appearing in July (No. 1), October (No. 2), January (No. 3), and October (No. 4). The first volume, because the first issue appeared in October, had only three issues. The first issue of Volume 2 was in July 1930. A typical issue had of the order of 100 pages, these appearing in a single column format during the first four years. There were of the order of 8 to 10 technical articles in a typical issue. Several of the issues had a part 1 and a part 2. The second parts were sometimes numbered separately, and sometimes had technical articles. The text of the *Journal* is unclear as to the reason for the two parts and as to whether there was a clear-cut distinction between the nature of the technical articles that appeared in the two parts. However, most of the papers that did appear in the second parts were authored by people affiliated with the Bell Telephone Laboratories, and some had been published previously in other journals.

Apparently, there were no financial problems with publication in these early years, and there were no advertisements in the *Journal.* Wallace Waterfall, who was the managing editor, carried out many tasks that in the present day are carried out on behalf of the Society by the American Institute of Physics. Waterfall prepared papers for the printer; he was responsible for the printing of the *Journal*, for its mailing, and for the collection of bills.

The membership of the Editorial Board changed frequently over the successive years, but Floyd Watson remained as its Chair until June 30, 1939. Among those who later served were C. R. Hanna, F. A. Firestone, John S. Parkinson, and Irving Wolff. Watson sought to appoint Board members who represented "as far as possible the various interests in acoustics." There was no standard definition as to what these interests were, and individual members were likely to have relatively wide interests.

In those idyllic years, the "selection" of papers for publication in the *Journal* was anything but passive. A primary source of papers for publication was the Society's semi-annual meetings. There were typically of the order of 20 to 30 technical talks at each such meeting, and there were no parallel sessions. The members of the Editorial Board attended the meetings and presumably each member heard a considerable percentage of the presentations. The Board met immediately after the Society's meeting, discussed the talks presented at the meeting, and made decisions as to what papers were to be solicited for publication. They apparently were proactive in inviting persons to present papers at the meetings and to subsequently publish written versions in the *Journal*.

Unsolicited papers were not precluded, and peer review then was far less rigid than is the common practice today. Papers by eminent senior persons, especially those by well-recognized authorities in other countries, generally sailed through with only a cursory review. The Editorial Board evidently took the "diffuse and increase the knowledge" clause of the *Purpose Statement* very seriously. A guiding principle was that "the Acoustical Society was formed to stimulate activities in acoustics, even those abroad." In those cases where an author was perceived as either inexperienced or as not well-known, the submitted paper was read by a member of the Editorial Board, who suggested any changes that appeared necessary. Watson also strongly felt that one of the functions of the Editorial Board was to encourage young investigators and to help them get started in their work. Reviewers from outside the Board were occasionally consulted, but this was typically informal. Wente, for example, drew extensively on the advice of his immediate colleagues at the Bell Telephone Laboratories.

Affiliation With the AIP

The American Institute of Physics (AIP) was established in 1931, and the Acoustical Society of America was one of its four original founding member societies. The other three were the American Physical Society (founded 1899), the Optical Society of America (founded 1916), and the Society of Rheology (founded 1929). The AIP was originally intended as a service organization, much in the same spirit as a farm cooperative to which various farmers might have belonged. The principal service that the AIP offered was the management of the publication of scientific journals. The member societies would of course have to pay for any services at a cost commensurate with the magnitude of the services that were provided. The Executive Council at the time found the affiliation to be attactive because it solved the problem of the management of the publication of the *Journal* at a reasonable cost. As a consequence all the publication management functions that had originally been undertaken by Wallace Waterfall were taken over by the American Institute of Physics.

Beginning with Volume 5 (first issue was that of July 1933), the *Journal* displayed the statement — *published for the Acoustical Society of America by the American Institute of Physics*. The format of the *Journal* also changed with this issue; one noticeable feature was that the technical articles were published with two columns on each page rather than one column. The cover continued to have the design, but the size increased to 8 by 10.5 in.

Instituting the Office of Editor

More or less simultaneously with the transferring of the task of publication to the AIP, the Society formally created the office of Editor. At the May 1933 meeting, amendments were passed to the Constitution and By-Laws that made the Editor of the *Journal* an elected officer of the Society and a member of the Executive Council. The Editor was empowered to select an Editorial Board consisting of five members, with the membership subject to approval by the Executive Council. At that time all of the officers were elected officers, including the Secretary and the Treasurer. The office of Editor differed somewhat from the others in that the term was three years rather than one year. The amendment that created the office of Editor was the first amendment to the Society's Constitution.

In the first four years of the *Journal*, Floyd Watson had been functioning as the editor in the sense that the term is used today. He was a voting member of the Executive Council for the first three years of the Society's existence and the By-Laws stipulated that he was ineligible for immediate reelection. The problem thus arose that the de-facto editor of the *Journal*, who had been on the Executive Council from the very beginning, was suddenly no longer on the Executive Council. A plausible hypothesis for the impetus in the creation of the amendment is consequently that the Executive Council felt that much of their deliberations concerned the *Journal* and that they needed the editor's presence at their meetings. Given this line of reasoning, it is not surprising that the Executive Council did not wait on the electoral process to fill the office of Editor. They made use of their constitutional prerogative to appoint Watson for a term that would expire with the beginning of the first elected term. Watson was subsequently elected Editor for a term that began July 1, 1934.

Chronology of Changes in the Journal

The *Journal* continued to grow, and various changes in its appearance occurred with the passing years. Starting with Volume 19, January 1947, the *Journal* became a bimonthly (6 issues a year), each volume corresponding to a calendar year. Beginning with the May 1950 issue (Volume 22, Number 3), the format of the cover changed, so that the table of contents was on the cover. Advertisements also appeared in the front pages and end pages of the *Journal*. There were 18 ads in this issue.

The six issues per year frequency ended in 1956. Beginning with January 1957 (Volume 29), the *Journal* was published with 12 issues per year. In 1969, the number of volumes per year increased to two, January through June was Volume 45, and July through December was Volume 46. This practice of publishing two volumes per year continues to the present time.

The second half of 1969 was the occasion of the initialization of an effort to split the *Journal* along disciplinary lines (with respect to content). An editorial by the Editor-in-Chief, R. Bruce Lindsay, appeared in part 1 of the July 1969 issue, and in which the rationale for a split was described. Each month, the *Journal* would be issued in two parts. The first part was to contain items expected to be of interest to all the readers, which the second part, in successive months, would deal, alternately, with topics related to the physical sciences and to the biological sciences. Lindsay's editorial labeled this activity as an experiment, and apparently the experiment failed. The previous system of one issue per month with broad coverage was reinstated in January 1973. An editorial by Lindsay stated, "With this issue the *Journal* abandons the subdivision plan which has been in effect since July 1969 and reverts to the single cover per issue containing papers in all branches of acoustics."

In 1971, the *Journal* ceased to publish advertisements. Nostalgic reading is the ad in the front matter of part 1 of the December 1970 issue signed by James W. Day of B & K Instruments. "To the professional in acoustics: this is our last ad in JASA . . . not because we want it that way, but because of JASA's new policy. This ends a period of 20 successive years in our JASA ad program — and a grand 20 years it has been." The *Meetings Programs*, in the form in which they were distributed at the Society's semiannual meetings, started to carry ads in 1971. Before then, they had no ads. (More is said about the *Meeting Programs* further below.)

Another small change that occurred during this era was the ceasing of references appearing as footnotes on the pages where they were first cited. In the two parts of the February 1970 issues, such footnotes appeared in some profusion; in the March and subsequent issues, they were nonexistent.

Instead, they were all collected and printed at the end of the article. There is no announcement in the *Journal* as to why this change occurred, but the most likely explanation is that this was done to make the task of compiling citations easier for the organizations that publish lists of subsequent papers that cite archived publications.

While the big S within concentric circles logo has, for the most part, been a regular feature on the front cover of JASA, there was a ten year period, between September 1954 (Volume 26, Number 5) and December 1964 (Volume 36, Number 12) in which the tuning fork logo appeared on the cover. The September 1954 issue was tagged as the first of two issues chronicling the Twenty-fifth Anniversary Celebration of the ASA. The tuning fork logo was designed by Richard Bolt for the gold medal of the Society. Then, starting with the January 1965 issue (Volume 41, Number 1), there was no logo on the cover. There was only the journal title and a table of contents. This absence of logo continued up through the end of 1991. Then, in the January 1992 issue (Volume 91, Number 1), the old and original big S within concentric circles logo reappeared, and it has continued to be on the front cover up to the present time.

The publication of the complete table of contents on the cover continued from May 1950 up through 1972. But with the January 1973 issue, when the two parts per month experiment was abandoned, it became necessary to only put a part of the table of contents on the front cover, with the remaining items being continued on the back cover. But the size of the *Journal* was then growing rapidly, so that with the August 1974 issue (Volume 56, Number 2), the continuation of the table of contents continued to two additional inside pages, and the back cover was used to give particulars concerning the officers of the Society, the Editorial Board, and the prices of subscriptions to the *Journal*. The placing of the initial portion of the Table of Contents on the front cover ceased with the end of 1995. With the January 1996 (Volume 99, Number 1) issue, the front cover took on a less crowded appearance, with the big S within concentric circles displayed prominently and with a listing of a few items within the Journal that had been selected by the Editor-in-Chief as being worthy of prominence. This cover design continued until the end of the first half of 2001. But beginning with the July 2001 issue (Volume 110, Number 1), a condensed version of the complete table of contents appeared on the front cover. Abbreviated short titles were listed along with the page numbers at which the corresponding articles began, and authors names were omitted. Although some of the abbreviated titles were somewhat cryptic, the display was sufficient to give a person a general overview of the nature of the articles within the issue. It was found that the complete table of contents in this form could be easily fitted into a two-column format on the cover. This cover style has continued to be used up until the present.

At the beginning of 1974, two other changes took place. The size of the journal pages increased from the previous 8 by 10.5 inches to 8.25 by 11.25 inches, and the previously used monotype composition was replaced by typewriter composition. The result in regard to the latter was a decrease in the attractiveness of the printed pages, but did not significantly change the legibility. The reason for the two changes was explained in an editorial by R. Bruce Lindsay as follows: "The changes mentioned are largely dictated by the need to meet the steadily increasing cost of publication of the *Journal* without imposing an undue burden on the membership of the Society." (To put the matter in perspective, the price of a nonmember (typically, libraries) subscription to the *Journal* at the time was $65 for subscribers in North America. Membership dues at that time were $35, and the members received the *Journal* as part of the benefits of membership. At the present time, the nonmember subscription price is $1425, and the membership dues for those who receive the print version of the *Journal* is $120.) The unattractive typewriter composition format was dropped at the end of the first half of 1982, although the size of the printed pages remains the same. From July 1982 (Volume 72, Number 1) till the present, the printed pages in the *Journal* have had an attractive appearance consistent with that of the other leading archival journals in the sciences.

Electronic Publication of JASA

The Journal of the Acoustical Society of America began to be simultaneously published as an online journal (JASA-O) in 1997. Online browsing of the table of contents is available to anyone, and those who are subscribers are able to view or download specific articles in PDF (portable document format). A easy way to access the online site is to open the ASA home page at http://asa.aip.org/ and then just click on JASA-O. Use of online journals has become fairly common in recent years, and many modern researchers prefer to browse online journals rather than those on display in print version in their local libraries. Simultaneously with the publication of the online journal, the Acoustical Society offered a membership option where the members could receive a CD-ROM disc every two months which would contain all of the issues of the *Journal* that had been published up to the date of the CD-ROM. Thus, there were six CD-ROM's per year, and the last of the year would contain all of the contents for the entire year. With the proliferation of the use of personal computers, this option was very attractive, as members could store all of the issues since 1997 on their hard disks and be able to read whatever they wished without the necessity of having internet access.

In a similar vein, the Society sponsored an effort, with the leadership of Richard Stern, to place all of the back issues on CD-ROM. The January 1995 issue (Volume 97, Number 1) had a CD-ROM inserted into the issue which contained the first 16 volumes (1929-1945) of the *Journal*. This was a demonstration disc, and the Society offered, for a modest fee, a three CD-ROM set that contained the first 27 years of the *Journal*. By the Fall of 1996, the Society was offering a subsequent two CD-ROM set which covered the years 1956-1961. However, as Richard Stern states in a "read-me" file in a subsequently published CD-ROM set, "although this was a good start, the technology available [in 1995] was indequate for the scope of the project [of getting all of JASA on CD-ROM's]. New efforts with newer technology resulted in a 10 CD-ROM set published in 2000 which covered all of JASA from 1929 up through 1996 (the year before the creation of JASA-O and of the option for CD-ROM subscriptions to the *Journal*).

The Meetings Programs

With the exception of a few years during World War II, the Society has always held two general meetings per year. (There were no Fall meetings in 1942, 1943, 1944, and 1945.) The programs of these meetings have typically been published in the *Journal*, and there has also been a publication distributed to the attendees at the meeting. The cover of one of the early programs (the sixth meeting, which took place in Fall 1931) is included in this chapter. The program of the very first meeting (May 1929) appeared in the first issue of the *Journal*, and abstracts were printed for each of the 21 papers that were presented. This tradition of archiving all of the abstracts has, for the most part, been carried on throughout the life of the Society.

The *Programs* as such were somewhat distinct from what was printed in the *Journal* until Spring 1974. The program for the 86th Meeting (Fall 1973) appears as part of the February 1974 issue of the *Journal*, and the separately published *Program*, which was mailed separately to the members and given to the attendees had a whimsical cover illustration and about 30 pages of material (partly advertisements) that were not reproduced in the *Journal*. (Advertisements were a regular feature of the meeting programs after 1971.)

A little note on page 3 of the Fall 1973 Program states that *programs of Society meetings [were] available to nonmembers on subscription for $5 a year*. There is no indication, however, that these programs were regarded as a copyrighted publication, and one would undoubtedly be hard-pressed to find them in any institutional library. The change that occurred with the Spring 1974 program was that the entire program document, with all the front matter that had previously not been included in the *Journal* became an official Society publication, labeled as "Supplements" to the *Journal*, but not carrying specific dates. Thus, for example, the *Program* for the April 1974 meeting was published as *The Journal of the Acoustical Society of America, Vol. 55, Supplement, Spring 1974.* This "Supplement" was separately paginated, with the archival material (the abstracts and the index) appearing on the pages S1 through S93. Attendees at the meeting would receive this supplement issue and subscribers to the *Journal* would receive exactly the same document.

The reason why the Society went to this system for publishing the meeting programs was undoubtedly to reduce costs. One big printing would cover all purposes. *The References to Contemporary Papers in Acoustics*, which had previously been an integral part of *Journal* was also published as a supplement. If there were more than one supplement to a given volume, these were issued as Supplement 1, Supplement 2, etc.

This system of publishing meeting programs as supplements ceased with the Spring 1991 meeting. The program for this meeting and for subsequent meeting became a more tangible part of the *Journal* with the simple device of having monthly issues with two parts. Thus the Spring 1991 program appeared as Part 2 of Volume 89, Number 4, April 1991. Paginations for the programs were the continuations of the paginations of the rest of the *Journal.* The present writer does not remember the reasons for this latter change, but believes it was primarily to make sure that there would be no ambiguity as to whether these meeting programs were a part of the *Journal.* The Society is rather unique among the AIP member societies in that the abstracts of papers presented at meetings are an integral part of it principal publication.

Soundings and the Offprint

Beginning with the July 1995 (Volume 98, Number 1) issue, all of the material that had hitherto appeared in the back of the *Journal* was moved to the front. This included editorials, the news reports, book reviews, reviews of patents, and all other items that were other than the published research and technical papers. In the subsequent issue, the Editor-in-Chief, Daniel W. Martin, published an Editorial which announced that this front matter would be published additionally as an offprint of the *Journal.* Those who wished could receive this offprint publication which would be identical to the Journal, but which would be substantially thinner because of the absence of the technical articles. The rationale for this new publication, as expressed in the editorial, was that some members would find a less bulky publication more manageable. (Currently, a full year of JASA occupies about 15 inches of shelf space.) This option in lieu of receiving the full *Journal* began in 1996, which was before the creation of the online version of the *Journal* and the offering of a bimonthly CD-ROM subscription rather than a monthly print version subscription.

In subsequent years, this offprint publication was given the name "Soundings" and the section of the *Journal* which went into the offprint became known as the *Soundings* section. The Editor-in-Chief had some leeway in deciding just what would be included in this section, and for a brief while, one or more selected regular research articles would be given special prominence, because of their perceivable broad interest to the readership, by being moved to the "Soundings" section. Largely because of the perception that the CD-ROM member subscribers should receive some publication every month, rather than only every other month, it was decided to send the offprint to those subscribers also. This practice has continued to the present time.

Short-lived Magazines

There had been for some time a desire among the membership for an additional periodical publication, the contents of which would be readily comprehensible to persons other than those who were already experts in the subfields of the individual articles. At the Fall 1953 meeting of the Executive Council, a " New Magazine Committee" was appointed, with Leo L. Beranek to serve as chair. The result of the committee action was the creation of a new bimonthly magazine, titled *NOISE Control*, with an editorial board having Floyd Firestone (the then current Editor of JASA) as chairman and Leo Beranek as vice-chairman. The nature of this new magazine required the employment of an Editor, and Lewis Goodfriend agreed to take on the task. Concurrent with this action, the bylaws of the Society were amended so that the Editor of the *Journal* was promoted to Editor-in-Chief, with the charge that the holder of the office be responsible for all of the Society's publications.

NOISE Control was published for seven years, starting with Volume 1 in 1955 and ending with Volume 7 in 1961. It can be found in various university libraries, such as that of the Pennsylvania State University (call number TA365.N6). The present writer, at the time of this writing, does not have the volumes in front of him, so a description of the contents is omitted here. However, a brief description in the inside back cover of the September 1957 issue of the *Journal* lists that it is a bimonthly, designed for readers with practical noise control problems, and that it covered all phases of noise, its measurement, and control. The subscription price for members was $5 and for nonmembers was $8 (the nonmember subscription price for JASA at that time was $16.) The *Journal* at that time tended to run a "house ad" from the American Institute of Physics, which listed all of the journals published by the AIP and its member societies. *NOISE Control* is listed for the first time in the March 1955 issue, with Lewis Goodfriend as editor, who continued to be listed as such through the end of 1957. The listing in the January 1958 issue names Preston W. Smith, Jr., as the Editor, and this continued through to the December 1959 issue, wherein Herbert A. Erf is listed as "Managing Editor." (One should note that Herbert Erf was the Treasurer of the Society from 1950 to 1967.) Erf continued to be listed until the end of the publication of *NOISE Control*.

Because a magazine with a wider scope was desired, one with a different name replaced *NOISE Control* in 1962. At the business meeting of the Society in November 1961, a transition was announced from *NOISE Control* to a new magazine titled *Sound: Its Uses and Control*. The Editor-in-Chief, R. Bruce Lindsay, took on the editorship of this magazine, and one finds *Sound* listed in the AIP listing with R. Bruce Lindsay as editor, beginning with the January 1962 issue of the *Journal*, and this listing continued to appear through November 1963. Sound was a bimonthly and it was published for only two years. Lindsay, in an editorial published in the first issue of *Sound* justifies its launching as follows: "The obligation . . . of the Acoustical Society of America to secure a more adequate diffusion among all who are scientifically interested and all who apply its principles is the justification for the initiation of this new periodical."

The reason why *Sound* was abruptly discontinued was financial. Lindsay, in a news article in the January 1964 issue of the *Journal*, states that the Executive Council voted to on 9 November 1963 to discontinue it. "Rising costs of publication, coupled with inability to increase the circulation produced a financial loss that the Council could not reconcile with the best interests of the Society." It was a reasonably slick and substantial magazine and must have been a financial burden on the Society.

By most accounts that have been related to the present writer, the magazine was well received and liked by the Society membership. While slanted toward a broad readership, several of its articles are frequently citedwithin current research articles in acoustics. Examples that come to mind are the two articles on "Strange sounds in the atmosphere," that were authored by Richard K. Cook and Jesse Young. (Lindsay, for example, included these in his benchmarks in acoustics volume on physical acoustics.)

ECHOES

Echoes, the current newsletter of the Society, is a far more modest publication than was *NOISE Control* and *Sound* and has had a substantially longer life. It began as part of a public relations effort by the Society. A new administrative committee, the Public Relations Committee, was created in 1988 and Alice Suter was its first chair, serving through 1994. In the premiere issue, dated Spring 1991, there is a brief letter from Charles Schmid and Alice Suter, the Ad-Hoc Editors for *Echoes* that states that "the debut of this newsletter is the result of the ASA Executive Council's approval of a funding request by the Public Relations Committee to publish two trial issues." The trial was evidently successful, and *Echoes* continued on indefinitely with ASA funding as a quarterly. Alice Suter is listed as the official editor beginning with the Winter 1991 issue (Volume 1, Number 4), and continued to serve through the early part of 1997, when she was succeeded by Thomas D. Rossing.

Back issues of *Echoes* from Summer 2001 (Volume 11, Number 3) are posted on the web at the site http://asa.aip.org/echoes.html. It is sent free to all the members of the Society and to selected persons outside the Society who might find the news items of interest. A typical issue is 8 pages long, although some have been 12 pages, with two columns. The cover begins with a brief article of some general interest, and there is a "we hear that" column on the inside front cover, followed by a potpourri of items. As Rossing said, in a brief article when he first assumed the editorship, "*Echoes* has no staff of reporters, [but, in a sense] it has thousands of reporters: the members and friends of ASA."

Acoustics Research Letters Online (ARLO)

Acoustics Research Letters Online is an electronic letters journal of the Society and is devoted to research in all fields of acoustics. At the beginning, before it became a stand-alone electronic-only journal, it wasproduced as a section of the *Journal of the Acoustical Society of America* from March 1999 until September 2000. The first article was posted online on 9 March 1999 and was also published in the May 1999 issue (Volume 105, Number 5) of the *Journal* within a special section at the end of the issue. Twenty-two papers were published in this manner.

ARLO was launched as a stand-alone journal with the first issue having the date July 2000, and the first article in this issue having the posting date of 25 August 2000. Although articles are posted as soon as they are approved for posting, the journal is a quarterly. Volume 1 had two issues, because it started in July, all of the successive issues have four issues and correspond to a calendar year.

The uniqueness of *ARLO* is due to the vision of Robert E. Apfel, the founding editor, who served until his death in the summer of 2002. (Ronald Roy took on the job after Apfel's death.) Robert Apfel proposed such a journal to the Executive Council sometime in the late 1990's and, after extended discussion, convinced the Council that it was worthy of support. Apfel's vision included the following basic tenets: (1) the journal should be a letter journal and the lengths of all articles should be so restricted, (2) access to the journal should be totally free, anyone in the world with internet access could view any article in *ARLO*, and (3) the authors of *ARLO* articles should be free to include multimedia content (audio and video), such that persons viewing *ARLO* articles online would be able to hear and/or view such included files by a simple click of the mouse button.

As might be expected, there was some concern that such an enterprise would be a financial drain on the Society, since there would be no revenue from nonmember subscriptions, in contrast to JASA. Reservations in this respect were offset somewhat with the stated upfront policy that all *ARLO* authors (or their institutions) must pay a fixed, albeit modest, fee to publish an article.

ARLO is still in a relative infancy, and its rate of publication of published articles is not markedly different from that of other newly created journals. The largest recent issue, that of July 2003, contains nine articles, and there were 23 articles in the volume for 2003.

Books Plus

The Society established a Books Committee in 1983, with Tony F. W. Embleton serving as it first chair. As stated in the Rules of the Society, the Books Committee is "charged with exploring and proposing to the Executive Council the reprinting of out-of-print books on acoustical topics, and the printing of other books and other types of publications in response to the needs of the Society." The impetus for creating such a Committee was presumably because many of the classic texts and monographs on acoustics either had gone out-of-print or would soon go out-of-print. It is the present writer's understanding that commercial publishers in the United States must pay taxes in advance of revenues whenever they make a printing run of a book. Thus if a publisher prints 1000 copies of a book with an announced price per copy, then the the publisher must pay some fraction of this price times 1000 in taxes. Presumably, if the copies did not all sell at this price, there could be adjustments in the tax returns at a later date, but the existing law caused publishers to balk at reprinting "slowly-selling" books, unless they had some cause to believe the all of the books from this run would be sold within a relatively short time.

In any event, the Committee and its successors took their charge seriously, and succeeded in convincing the Executive Council to authorize a number, which by the time of this writing is 43, of items which have been published by the Society and which are listed as being for sale in every issue of the *Journal.*

The transition from "books" to "books plus" took place when the Society began to publish items other than books—audio tapes, video tapes, and compact disks.

This publication activity of the Society has been quite successful. It is not intended as a means of producing revenue, and the items are priced on the basis that the Society should "break-even." While such has not happened in every individual case, it has tended to be so on the average.

Peer Reviewing

Both the *Journal* and *ARLO* are stated to be peer-review journals, and there is of course a history as to how the peer reviewing has been handled. Most of the articles that are eventually published are submitted without any prior invitation, and then someone has to decide whether the submission should be published or not. The process depends, first and foremost, on persons submitting papers, and the authors generally have a wide choice of journals to which they can submit. Primary reasons for selecting a given journal are (1) the nature and scope of the readers who will either notice to have access to the paper, and (2) the company the published paper will keep. In regard to the latter, readers tend to begin their literature searches and to regularly peruse those journals that are most likely to have substantive articles of quality. The ASA, of course, desires and has always desired that its journals be places where a published paper will find good company. It also desires that quality papers be published as swiftly as possible.

In the early days of the *Journal* the peers doing the reviewing were, in essence, the editors and the members of the Editorial Board. Publication was then quite rapid, but then again the level of sophistication in the various subfields were not all that extensive and it was not that difficult to assess whether a given piece of work was truly original. All the manuscripts were sent directly to the editor during the first 21 years of the history of the *Journal.* During the first four years, they were sent to Wallace Waterfall; beginning with July 1933 they were sent to F. R, Watson, University of Illinois, Urbana, Illinois, and then beginning with July 1939 they were sent to F. A. Firestone, 147 East Physics Building, University of Michigan, Ann Arbor, Michigan. Beginning in October 1945, Firestone's address was changed to 3318 Fessenden Street, NW, Washington, DC.

One can note that the number of manuscripts as such in the *Journal* in these early years was not too large. If one takes, for example, the July 1942 issue (which was published on August 20, 1942), there were only 13 articles. The dateline below the authors' names gives the first article as having been received on June 5, 1942, the second as being received on June 6, the third as being received on March 20, the fourth as being received on January 28, the fifth (of which Firestone was a coauthor) as being received on April 30, the fifth as having been received on June 5, and the sixth as having been received on May 28. There is no indication that any of the articles had to undergo a revision.

Skipping forward to the last issue of 1949, at which time the *Journal* was a bimonthly, one finds 11 articles. The stated publication date on the back cover is November 25, 1949, and the stated reception dates are August 6, 1949, May 20, 1949, May 28,1949, June 16,1949, and June 15, 1949, for the second, third, fourth, fifth, and sixth articles. (No reception date was given for the first article.)

The practice of having all manuscripts be submitted to a central place ceased in 1950, with a wholesale delegation of responsibilities from the Editor to the members of the Editorial Board, who thereafter were listed as Associate Editors. This new listing appeared for the first time on the inside front cover of the January 1950 issue (Vol. 22, No. 1). The technical areas that were used in classifying articles for the *Journal's* index then had 11 major categories and each of the five associate editors was responsible for one or more (typically two) of these categories. For example, Robert Bruce Lindsay, who was eventually to succeed Firestone as Editor, was responsible for the categories of Ultrasonics and Underwater Sound. The March 1950 issue carried a historic announcement, the text of which is partially repeated here:

> *In order to decrease the burden of mail on the Editor's office, papers for publication should hence forth not be sent to the Editor but should be sent to that particular Associate Editor having cognizance of the field of subject matter into which the paper falls . . . The Associate Editor will transmit your paper to the Editor after it has been refereed and placed in final form for publication.*

The long succession of Associate Editors who took on these duties of receiving manuscripts and who took on the responsibility of deciding on the merits of the manuscripts for publication is a distinguished list, which includes many of the prominent members of this Society. The full list can be found in the recent *Membership Directory and Handbook*, and it is anticipated that it will soon be posted on the ASA web site.

Firestone's decision undoubtedly resulted in a far more careful consideration of the submitted manuscripts, and over the course of time, the time between reception and appearance in print crept up to an average of 18 months. There were several factors that contributed to this time-stretching. One was the inherent nature of the job of being an Associate Editor; it was and continues to be a purely voluntary job, and not every Associate Editor has the time and the inclination to diligently do the sometimes mundane tasks that help to speed a manuscript through to publication. Another was the increasing tendency of reviewers to request that authors revise their paper, in conjunction with a tendency for authors to put doing such revisions at a low priority. Then, there was the gradual reduction of secretarial support that was available to professionals in research. In a few cases, the Associate Editors were privileged to have ample secretarial support supplied by their employers, in a few other cases, they were able to employ part-time secretarial help at a modest rate, and the Society was able to pick up the costs. But most of the Associate Editors struggled to handle manuscripts without any help. Another problem was that the proliferation of authors was not necessarily accompanied by a comparable proliferation of reviewers capable of writing a dependable review, so the number of reviews a good researcher was asked to write tended to increase substantially. There were also administrative problems in that there were no central records as to what manuscripts had been received and at what stage of processing were they in.

Part of the problem was the advent of the personal computer and the assumption that people could use computers to do tasks that previously would have been done by support staff. The standard method for correspondence became electronic mail, but the traditional system for handling submitted papers relied almost entirely on postal services with hard copy correspondence.

The creation and launching of *ARLO* in 1999 and 2000 presented an example for an alternative way of handling manuscripts which promised to significantly reduce the average amount of time between reception and publication. Robert Apfel, with the aid of staff from the American Institute of Physics, devised a computerized system, termed the Manuscript Management System, which made it possible to handle manuscripts entirely electronically. Authors would submit manuscripts on line, reviewers would be solicited by e-mail, decisions would be sent out by e-mail. It was a grand vision and on the leading edge of a transition that is currently transforming the archival peer-review journal "industry."

In 2001, the present writer, then the newly appointed Editor-in-Chief for the Society, began to discuss with various colleagues whether something comparable might be done with the Journal. Although many problems were anticipated, it was decided to return to a centralized system whereby all manuscripts would be received at the ASA headquarters in Melville, NY. Elaine Moran, the office manager in Melville, agreed to take on the task of shepherding the manuscripts through the process and of interfacing with the Associate Editors, with the expectation that additional staff would eventually be employed to help in this endeavor. The thought was that the Associate Editors would continue to handle manuscripts as they had previously, but that all correspondence would channel (preferably, electronically) through the office in Melville.

The July 2001 issue (Volume 110, Number 1) carried the announcement that all authors should send their manuscripts to the JASA Editorial Office in Melville, New York, along with a brief discussion for why this change was instituted. One can note the statement "some fine-tuning may be necessary, and there may be some rough going during the transitional period." A further change was announced in the January 2002 issue (Volume 111, Number 1, part 1). Authors were requested to send in only one hard copy of their manuscripts (rather than the four that were required previously), and it was stated that the ASA planned to scan each submitted manuscript and convert it to PDF form, this being what would be transmitted electronically to editors and reviewers.

This interim centralized system was difficult to administer because of the large number of manuscripts that were received. Most of the tasks done in Melville were relatively routine, but they often had to be handled one at a time. Some system analogous to that being then used by *ARLO* was desirable so that such routine tasks could be aided by computers. The AIP had been intrigued by the *ARLO* Manuscript Management System, but decided to use instead a system based on software developed by eJournalPress. (Information about this company and its products can be found at the site http://www.ejournalpress. Clients besides the AIP include *Nature*, the American Geophysical Union, SIAM, and the *Journal of the National Cancer Institute.*) The AIP implementation was dubbed PEER X-PRESS (PXP), and the intention was that all AIP produced journals would use this system. The first such AIP journal to implement it was *Chaos*. The ASA Editor-in-Chief visited the AIP on February 19, 2002 and heard a short presentation on PXP from Reid Terwilliger, the AIP manager for Web-based editorial services. Terwilliger subsequently made a presentation to the ASA Officers and Managers Meeting in Melville on April 3, 2002. This was followed by a presentation at the Editorial Board meeting in Pittsburgh on June 4, 2002. It was subsequently decided by the Executive Council that the ASA would proceed to implement PXP for both the *Journal* and *ARLO*. An extensive development period followed, with efforts to learn how to use the system and to configure it so that it would be appropriate for each of these journals. Then, on August 15, the PXP system for the two journals was officially launched.

At the time of this writing, the PXP system seems to be working quite well for both journals. There are the invitable rough spots and bugs, but it appears that these will be overcome in time.

The Future

The ASA and its publications have survived the first 75 years rather well. The *Journal*, by all measurable standards, continues to be by far the leading acoustics journal for the entire world. The Society is sensitive to the changes that have have come about in regard to electronic publication and communication and seems to be coping with such changes as well as is to be expected. Speculation on the future is fun to do, but the present writer believes that what will happen and come to be depends primarily on the actions of individuals. If the Society continues to have good leadership, creative individuals, and dedicated volunteers, it and its publications will continue to do quite well, and the Society will continue to fulfill its purpose—*to increase and diffuse the knowledge of acoustics and promote its practical applications.*

Chapter 3

Development of the Technical Council

Anthony A. Atchley, Vice President & Technical Council Chair 2004-2005

ASA Silver Medal

Wallace Clement Sabine Medal

Trent Crede Medal

Pioneers in Underwater Acoustics Medal

von Békésy Medal

Development of the Technical Council

Anthony A. Atchley, Vice President & Technical Council Chair, 2004-2005

The Acoustical Society of America (ASA) is, first and foremost, a Society dedicated to the increase and diffusion of technical knowledge of acoustics. In an era of continually increasing specialization, it is this common interest that keeps the ASA of 2004 a coherent society, comprised of scientists, engineers, and other professionals having widely disparate technical interests. Because the scope of the Society is so broad, Technical Committees and Groups were established to "be responsible for representing and fostering one of the fields of interest within the membership of the Society." [Bylaws, Article VII]. The Technical Council coordinates the activities and policies of these committees and groups.

Technical Committees (TCs) had their origins in the early 1940's. According to the minutes of the May 6, 1941 meeting of the Executive Council:

"President Watson read to the Council a letter from Professor G. W. Stewart suggesting the establishment of a committee 'to represent the Society in the encouragement of improvements in musical instruments and in any other musical matters where those interested in the science of acoustics and in music may have common interests."

This committee reported sporadically for the next eight years. By that time, the Society recognized the benefit of such committees and appreciated the need to expand their number and scope. The minutes of the meeting of November 16, 1949 reads as follows:

"The President pointed out that there is need for special committees to make sure that the Society is adequately serving the special fields of interest covered by the Society's scope. One committee could have as its assignment "Effect and Control of Noise" and another "Architectural Acoustics." Such committees might start as ad hoc committees to make surveys and might later become permanent committees charged with keeping in touch with members working in the specific field and preparing program material at appropriate intervals. There was some discussion and it was the consensus that the plan was good and that the President should proceed with the appointment of committees."

In addition to Music, Architectural Acoustics, and Noise, four other TCs were established between 1949 and 1955: Psychological and Physiological Acoustics, Speech Communication, Ultrasonics, and Underwater Acoustics.

The future of the Society, its direction of growth and the balance between basic research and application, were topics of considerable debate during the early and mid 1950s. The Committee on the Development and Promotion of the Society was appointed to address these and related issues. Part of the debate was centered on the purpose, governance, and activities of the TCs, as well as possible alternatives to them. In an open letter to the membership dated October 28, 1955, the Development and Promotion Committee laid out a vision of a structure in which all fields of acoustics of interest to the Society would be covered by TCs and that they, among other things, should promote within the Society knowledge of activities that arise and develop outside the Society, promote knowledge of activities of the Society among nonmembers, and represent the Society in joint sponsorship of meetings with other organizations. Under the then-existing TC structure, the subjects covered by TCs and the TC chairs were controlled by the Executive Council. Under the new proposal, the composition and leadership of the TCs would be determined by the membership and the TCs would assume a more important role in the activities of the Society.

In a move to broaden the representation of the TCs, the Promotion and Development Committee recommended to the Executive Council in December 1955 that the name of the Committee on Ultrasonics be changed to the Committee on Physical Acoustics, and that three new committees be established: Audio Engineering and Electroacoustics, Shock and Vibration, and Sonic and Ultrasonic Engineering. These recommendations were adopted, bringing the total number of TCs in 1957 to ten.

The current structure of the TCs and the Technical Council began to solidify in 1958. According to the minutes of the November 1958 meeting of the Executive Council: "Mr. [Kenneth W.] Johnson recommended ... that a new Technical Council be established ... composed of all Technical Committee chairmen and presided over by the President-Elect, that this new Council be responsible for receiving reports from Technical Committees and making recommendations to the Executive Council, and that it hold regular meetings at each Society meeting."

The Society set about implementing this recommendation and the Technical Council, with the ten existing TCs, was formally established at the Providence Meeting of the Society in June 1960.

The intervening four decades have seen the number and scope of the TCs adapt to the changing interests of the membership. By July 1961, the name "Audio Engineering and Electroacoustics" had been shortened to "Electroacoustics." The September 1961 issue of JASA [Vol. 33 (9), 1250-1254] contains annual reports of all the TCs, including lists of their members.

In June, 1964 the committees on Electroacoustics and Sonic and Ultrasonic Engineering, merged to form the present day Engineering Acoustics Technical Committee.

The 1980's was a particularly important decade in shaping today's Technical Council. In 1987, the Committee on Shock and Vibration changed its name to Structural Acoustics and Vibration. Also, the Society made provisions to foster new or evolving areas of acoustics not within the scope of existing TCs, and for creating new TCs. Provisional Technical Committees and Technical Specialty Groups were established to organize technical sessions at meetings in acoustical areas not within the scopes of existing TCs for fields of technical interest which may be smaller than those of the usual TCs. One Provisional Technical Committee and two new Technical Specialty Groups were created that went on to become Technical Committees: Biological Response to Vibration in 1984, Animal Bioacoustics in 1988, and Acoustical Oceanography in 1989. Later, a provision for the creation of Interdisciplinary Technical Groups was established to provide for increased cooperation among TCs. The newest Technical Committee, the Committee on Signal Processing in Acoustics, followed this route in becoming a full TC in 1994.

During an oral history interview recorded by the American Institute of Physics Center for the History of Physics, Wallace Waterfall, ASA founding member and Secretary from 1929 to 1969, reflected upon the formation of the Technical Committee and Technical Council structures. He recounted the growing sentiment within the Society that members wanted an expanded role in conducting the activities of the ASA. He went on to say that he felt that the TCs together with the Technical Council gave the ASA a "House of Representatives" with a large committee representation which could broadly influence the direction of Society. Waterfall said "I feel that this kind of a grassroots representation has been very healthy."

In this 75th Anniversary year, there are thirteen Technical Committees:

Acoustical Oceanography
Animal Bioacoustics
Architectural Acoustics
Biomedical Ultrasound/Bioresponse to Vibration
Engineering Acoustics
Musical Acoustics
Noise
Physical Acoustics
Psychological and Physiological Acoustics
Signal Processing in Acoustics
Speech Communication
Structural Acoustics and Vibration
Underwater Acoustics

These committees and the Technical Council have evolved to assume an increasingly important role within the Society. Today, they serve as the main channel of communication among members of the Society as well as between members and the Society's leadership. The adaptability of the Technical Committees and Technical Council structure is vital to the future health of the ASA. It will be interesting, indeed, to see what changes lie ahead.

Author's Note: *The author is indebted to Elaine Moran for enthusiastically researching much of the material upon which this brief history is based and for thoughtful comments and suggestions throughout its writing.*

"We also try to seek out groups who are working in some area of acoustics and try to show them the Society will be of value to them. Over the years there has been a lot of discussion about what should be the scope of the Acoustical Society. I choose to take the position that acoustics and the scope of our Society should include whatever those who call themselves acoustical scientists are doing, which they regard as acoustics."

Wallace Waterfall
Address to the ASA Narragansett Regional Chapter, 1966

ASA at 75

Chapter 4

Acoustical Oceanography

Peter F. Worcester, Chapter Editor
History Lecture, Robert C. Spindel

Acoustical Oceanography

Introduction

The ocean is largely transparent to sound, but opaque to light and radio waves. Light travels only a few hundred meters in the ocean before it is absorbed. Sound can travel long distances and with great speed underwater. All who work in the sea therefore rely on sound to sense their surroundings, to communicate, and to navigate. Oceanographers use sound in the sea for a wide variety of purposes, including assessing populations of fish and plankton, measuring ocean bathymetry, profiling ocean currents, measuring large-scale ocean temperature variability, communicating underwater, transmitting data from subsea instruments to the surface, and navigating underwater. The Technical Committee on Acoustical Oceanography provides a home in the Society for those developing and using acoustical techniques to study the oceans.

The genesis of the Technical Committee on Acoustical Oceanography occurred when Michael Buckingham, David Farmer, and Van Holliday cornered Herman ("Hank") Medwin at the foot of the escalators in the hotel at the Fall 1988 meeting of the Acoustical Society in Honolulu. They felt that a technical committee focusing on the development and use of acoustical methods to study the ocean was needed to attract new people into the Society. Buckingham, Farmer, and Holliday urged Medwin to take advantage of a new Society rule that allowed for starting a technical committee by petition. Medwin subsequently conducted the drive to collect the required signatures to present to the Executive Council. The Technical Specialty Group on Acoustical Oceanography was formed, making it the second Technical Specialty Group, after Animal Bioacoustics, which had started two years previously. Acoustical Oceanography became a Technical Committee two years later, in 1991. Medwin was elected Chair of the Technical Specialty Group and subsequently became the first chair of the Technical Committee on Acoustical Oceanography.

The Acoustical Oceanography Technical Committee is responsible for representing and fostering Acoustical Oceanography within the Acoustical Society of America. It is concerned with the development and use of acoustical techniques to measure and understand physical, biological, geological and chemical parameters and processes of the sea.

In physical oceanography acoustical methods are used to study air-sea interactions, turbulence and mixing, ocean surface waves, internal waves, solitary waves, fronts, circulation, and salinity and temperature structures. Detection, classification, and quantification of marine organisms and habitat characterization can be done acoustically in biological oceanography. Frequency dependent absorption measurements allow variations in ocean chemistry to be measured. In geological oceanography acoustical techniques are used to measure seafloor properties, both surficial and internal, sediment suspension and transport, and undersea earthquakes.

The Lecture on the History of Acoustical Oceanography was given by Robert C. Spindel at the Fall 2001 meeting of the Society. He is Professor of Electrical Engineering and Adjunct Professor of Oceanography at the University of Washington, Seattle, Washington. He received his B.E. from The Cooper Union, New York, in 1965 and the M.S. and Ph.D. degrees from Yale University, New Haven, Connecticut in 1966 and 1971, respectively, all in Electrical Engineering. In 1971 he joined the Woods Hole Oceanographic Institution as a Postdoctoral Research Fellow, and the following year he became a member of the scientific staff in the Department of Ocean Engineering. In 1982 he was promoted to Chairman of the department. He left Woods Hole in 1987 to become Director of the Applied Physics Laboratory at the University of Washington, serving in that position until 2003. Dr. Spindel's research expertise is acoustical oceanography and underwater acoustics. He played a leading role in the development of ocean acoustic tomography, including the development and deployment of the required instrumentation. He was awarded the A.B. Wood Medal by the Institute of Acoustics (U.K.) in 1981, the Gano Dunn Award from The Cooper Union in 1988, the Technical Achievement Award from the Institute of Electrical and Electronic Engineers (IEEE) Oceanic Engineering Society in 1990, and the Walter Munk Award in recognition of Distinguished Research in Oceanography Related to Sound and the Sea, granted jointly by The Oceanography Society, the Office of Naval Research, and the Office of the Oceanographer of the Navy, in 2001. He is a Fellow of the IEEE, the Acoustical Society of America, and the Marine Technology Society.

Peter F. Worcester, Chair
Technical Committee on Acoustical Oceanography

Acoustical Oceanography

Robert C. Spindel, University of Washington

As far as I can determine acoustical oceanography has no written history. And the field is so new that we are living through its formative years. It has often been said that the worst time to write history is while it is being made, and it has also been said that a writer can only expound on what he knows. With this in mind, I hope I have been able to do the subject justice, and that my good Acoustical Society of America colleagues will not find too much missing.

What is Acoustical Oceanography? Clay and Medwin define it in the preface to the first edition of their book on the subject as the application of acoustics "to the location and identification of blobs in the sea, to features on the seafloor, and to the physical characteristics of the layers beneath the bottom." [1] It arose out of the mariner's need to determine water depth and to avoid icebergs, which produced the echo-sounder and echo-ranging, the geophysicist's desire to probe the Earth's crust beneath the seafloor, which resulted in the seismic profiler, and the military's need to hunt for submarines, out of which came sonar. Acoustical oceanography includes methods that range from the simple use of the speed of sound and measured travel time to calculate distance, to techniques that require detailed understanding of how the dynamic ocean distorts propagating sound so that acoustic fluctuations can be unraveled to reveal characteristics of the causative ocean processes. At high frequencies these are the motion of the sea surface, and small scale phenomena such as bubbles, turbulence, particulate matter, and marine life. At low frequencies the processes are spatially larger and temporally longer—tides, currents, mesoscale eddies and ocean basin temperatures.

Because acoustical oceanography and underwater acoustics are inextricably intertwined, writing mutually exclusive histories is impossible. Understanding the so-called forward problem, how sound propagates in the sea, is a necessary condition for solving the inverse problems that are the goal of acoustical oceanography. The roots of acoustical oceanography are in underwater acoustics, and the reader is forewarned there will be overlap between this chapter and the one devoted to underwater acoustics.

Early developments set modern acoustical oceanography into historical perspective. One of the first acoustical oceanographers was Lt. Matthew Fontaine Maury, the first Hydrographer of the Navy who, in 1859, tried and failed(!) to use acoustics to measure the depth of the ocean. He wrote, "attempts to fathom the ocean both by sound and pressure, had been made, but out in blue water every trial was only a failure repeated. The most ingenious and beautiful contrivances for deep-sea soundings were resorted to. By exploding petards, or ringing bells in the deep sea, when the winds were hushed and all was still, the echo or reverberation from the bottom might, it was held, be heard, and the depth determined from the rate at which sound travels through the water. But, though the concussion took place many feet beneath the surface, echo was silent, and no answer was received from the bottom." [2] Maury did not say how he listened for the echo, but it was likely done by men on deck. Brackett Hersey, commenting on Maury's failure wrote, "Had they used Leonardo's long tube or some other sensible coupling device, the first practical application of underwater sound might have developed a half century sooner." [3]

In the years after Maury's experiment there were few other attempts to use sound underwater. In the 1880's Lucian Blake did some experimenting in the Taunton River in Massachusetts, and Thomas Edison invented an underwater method to communicate between ships. But interest mostly waned for the next 25 years until, in 1907, Andrew Fells was granted a U.S. patent for a sounding device. His invention does not seem to actually have been put into practice, and therefore credit for the first successful echo-sounding is given to Alexander Behm, a German, who in 1912 was able to gauge water level using sound waves created by the impact of bullets fired into the water. (There were no marine mammal or endangered species acts in those days.) In 1920 he founded the Behm-Echo Sounder-Association in Kiel and built a factory to produce echo sounders.

The loss of the *Titanic* in 1912 when it struck an iceberg spurred the development of echo-ranging. Richardson, in England, and Reginald Fessenden, (See Fig. 1) a Canadian working for the Submarine Signal Company in Boston, both filed patents for acoustic iceberg detectors. Fessenden's was a 540 Hz, air-backed, electrodynamically driven, clamped-edge circular plate. In January, 1914, in Boston harbor, he demonstrated underwater Morse code communication by modulating the driving oscillator. In March of the same year the system was tested on the U.S. Coast Guard cutter *Miami* on Newfoundland's Grand Banks where it echo-ranged on a two mile distant iceberg. It also was able to echo-range on the bottom. Fessenden's oscillators (at 500, 1000, and 3000 Hz) were so successful that they were installed on all World War I U.S. submarines and were still in use in World War II (WW II).

Between the wars the focus of underwater acoustics was on developing better equipment, more efficient and powerful transducers, more sensitive hydrophones, and improved recording systems and displays. Acoustical oceanography, although not yet called that, was just getting going. It was recognized that low frequencies penetrated deeply into the bottom, and that reflections occurred from layers in the sediments, thereby providing clues to the geophysical make-up of the Earth, and a means for prospecting for oil beneath the seafloor. Pioneering work was done by Maurice Ewing at Lehigh University, later at Columbia, and Allyn Vine, Brackett Hersey and Sidney ("Bud") Knott at Woods Hole, where Hersey and Knott patented the continuous seismic profiler. Vine was a Lehigh graduate, and while there he had worked with Ewing and undergradute Joe Worzel. (Ewing was Worzel's physics professor.) In 1934 the three of them (See figs. 2 and 3) produced one of the earliest seismic recorders which was based on Hamilton watch movements, and on galvanometers connected to geophones. Tremors were converted to movements of a beam of light reflected from a mirror on the galvanometer which were recorded on film. There were also seismic research groups at Scripps Institution of Oceanography that included Russell Raitt (See fig. 4) and Art Maxwell (then a student), and in England, at Cambridge University, where John Swallow and colleagues were using seismic profiling methods to study the seafloor of the Pacific and eastern Atlantic.

Fisheries acoustics had its roots during this period. The possibility of detecting echoes from sardine and herring schools was suggested in 1924 by Portier, [4] in France, and a few years later the French navigator Rallier du Baty attributed abnormal signals on his sounder to a shoal of cod on the Grand Banks [5]. The first successful experiment demonstrating the acoustic detection of fish was published in 1929 by Kimura, in Japan [6, 7].

In most of these applications of acoustics, the ocean itself was an impediment. Sound was used to go through it, not to measure it. The effects of temperature variations, currents, and surface, bottom and volume scattering were an annoyance. WWII changed that. German U-boats, mostly in the Atlantic, and our own U.S. submarine force deployed in the Pacific against the Japanese, made clear the importance of submarines to modern Naval warfare. The Cold War further emphasized their tactical and strategic roles, and led to a race for better sonar performance against ever more quiet submarines. The exploitation of the ocean for military use heralded the beginning of modern acoustical oceanography, where sound is used to measure ocean processes themselves, rather than simply as a form of energy that goes through the ocean to measure something else.

By the end of the war most of the physics of sound propagation in the sea, and most of the characteristics of echoes from the bottom, the sub-bottom, and from Clay and Medwin's "blobs" in the water had been discovered. In 1944, as part of the war research effort, Ewing and Worzel at Columbia demonstrated low-frequency, long-range, deep-sea SOFAR (Sound Fixing and Ranging) propagation, and Chaim Pekeris at the Weizmann Institute in Rehovoth, Israel, developed normal mode theory. [8] The Russians too were working on improved sonars, and academician Leonid Brekhovskikh not long ago confided to Walter Munk that they had discovered the SOFAR channel independently in 1946, but had been prevented from publicizing their results due to war security rules. (See fig. 5)

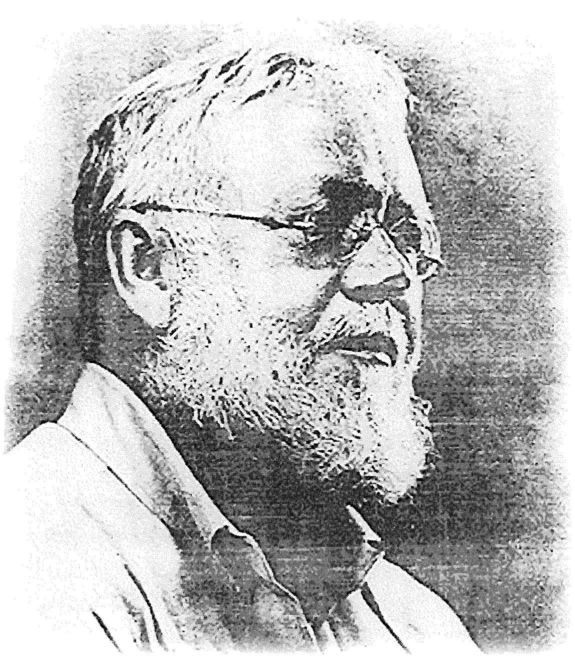


Figure 1. Reginald A. Fessenden.

Figure 2. Allyn Vine and Maurice Ewing on board the RV Atlantis, 1938. (Courtesy Woods Hole Oceanographic Institution).

At the higher frequencies of ship and torpedo sonars, reporting on a set of 24 kHz experiments conducted in

1942 and published in the Society's journal in 1948, Carl Eyring, Ralph Christensen and Russell Raitt described the almost ubiquitous diffuse echoes of the Deep Scattering Layer (DSL), with it's diurnal cycle—at a depth of about 1000 feet in the daytime, rising to near the surface at night, and migrating downward again at dawn. [9] It's composition was somewhat of a mystery, and remained so until the mid 1960's. Evidence suggested that gas-filled fish swimbladders were responsible, but biologists could not catch enough such fish to explain the scattering. On the other hand, the krill they did catch did not have included gas, and Vic Anderson, while a post-doc in Ted Hunt's Lab at Harvard, showed that scattering from krill and krill-like organisms, in the numbers caught, couldn't explain most of the DSL scattering. Dick Backus and Brackett Hersey at Woods Hole noticed that the layers scattered sound more strongly at some frequencies and depths than at others, as if there were depth dependent resonances. [10] Their observations were consistent with the behavior of a gas bubble, and made a strong case for fish with swimbladders. (The reason for the discrepancy between the number of swim bladder organisms caught and the intensity of the observed echoes— unkown at the time but later confirmed by experiment— was that the small euphausids comprising the DSL easily maneuvered away from the biologists' towed nets.) The details of the DSL and fish scattering were worked out by, among others, R.P. Chapman, J.R. Marshall, [11] E.G. Barham [12] in the U.S., and I.B. Andreeva and Y.G. Chindinova in the Soviet Union. The DSL figures prominently in the development of acoustical oceanography because it led to the work on fish swimbladder resonance that is the basis for fish finding and stock assessment sonars.

The key to sonar improvements seemed to be tied to understanding the basis for signal fluctuations which degraded performance in two ways. Deep amplitude fades resulted in lost contacts, and distorted wavefronts compromised beamformers. As a result, targets could not be heard, and they could not be localized. Both ship and torpedo active sonars that operated at short ranges and high frequencies, from several to several tens of kilohertz, and low frequency passive sonars such as SOSUS (Sound Underwater Surveillance System), that listened for signals generated by the machinery in distant submarines, were affected. Most of the research aimed at these problems was directed by the Office of Naval Research (ONR) and was sponsored by the Director of Antisubmarine Warfare in the office of the Chief of Naval Operations.

High frequency active sonars were tackled first. It quickly became clear that signal fluctuations were caused by random temperature inhomogeneities, and much of the early work in the U.S. and Soviet Union focused on reconciling experimental data with various theories of wave propagation in random media. In 1951, in a typical experiment, Leonard Lieberman at Scripps' Marine

Figure 3. Joe Worzel, bomb in hand, circa 1938. (Courtesy Woods Hole Oceanographic Institution).

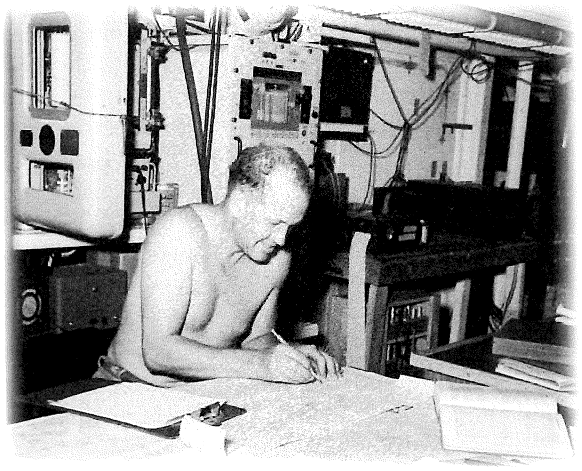


Figure 4. Russell Raitt examining seismic records. Capricorn expedition, South Pacific, 1952-53. (Courtesy Scripps Insitution of Oceanography Archives, UCSD).

Figure 5. Leonid Brekhovskikh, center, and Walter Munk, right. Bill Nierenberg, the Director of Scripps is on the left.

Physical Laboratory used a thermometer mounted on a submarine to measure and characterize the nature of small-scale temperature fluctuations. [13] David Mintzer at Brown University worked on the theory of Born approximations [14], and V.I. Tatarski [15] and L.A. Chernov [16] in the Soviet Union developed theories of wave propagation in random and turbulent media, and imported many ideas from the more mature fields of optical and electromagnetic scattering. The Soviets also made measurements, typified by a 1961 Atlantic expedition of Moscow's Acoustic Institute ships *Vavilov* and *Lebedev*. Instead of a thermometer they used a clever acoustic sound velocity meter operating at 2 MHz thereby measuring sound speed fluctuations directly, rather then inferring them from temperature measurements. [17]

Also in the fifties and early sixties efforts were made to quantify the effects of sea surface conditions such as wave height, directional spectrum, and wind velocity on acoustic scattering. The foundation was Lord Rayleigh—naturally—with his theory of scattering from periodic surfaces. Carl Eckart, at Scripps, published a theory of scattering from a random sea surface in 1953. [18] Many others contributed to understanding surface scattering including Wysor Marsh, at the Navy's New London, CT, laboratory, Morris Schulkin, Clarence Clay, Claude Horton, Bill Meecham, and E.P. Gulin, K.I. Malyshev, and V.V. Ol'shevskii among others in the Soviet Union. [19]

The emphasis on low frequencies came with the development of SOSUS in the 1950's, and later, submarine towed arrays. At these frequencies, roughly below 1 kHz, attenuation is low, and useful propagation distances span entire oceans. But as construction methods improved, submarines became quieter, machinery noises were harder to detect at long range, fades began to be troublesome and beamformer performance declined. Further, ever increasing missile ranges called for quicker detections at greater ranges. Because of the importance of nuclear ballistic missile submarines to strategic deterrence, this erosion of surveillance system performance generated sizable research programs.

Most were carried out by the Bell Telephone Laboratories, because Bell Labs' Western Electric division had the Navy contract for the SOSUS system. Almost all of the work was classified at the time, and much remains so today. One of the first publications with long range, low frequency data was a 1967 paper by Nichols and Young who described the fluctuations of a signal received at Bermuda from a source located 700 nm distant at Eleuthera Island in the Bahamas. They observed long period variations of cycles/hr which they attributed to internal waves, and small, periodic variations which they attributed to the sea surface.[20] A year later, John Beckerle, of Woods Hole who was originally from Bell Labs, published data that showed fluctuations in the arrival angle of acoustic wavefronts that had traveled some 20 miles. He noted that the period of wavefront wander, about an hour, was what might be expected if groups of internal waves crossed the transmission path.[21] Unfortunately, no internal wave measurements were made at the time. Even more to the point of acoustical oceanography was a paper he and E.O. LaCasce published several years later, in 1974, which described an experiment designed to determine the feasibility of monitoring Rossby waves through their effect on acoustic propagation. His idea was to see if spatial variations in the acoustic signal along different paths were consistent with Rossby wave scales.[22]

In 1987, John wrote to me about this work just after Bruce Howe, Peter Worcester and I had published a paper in the *Journal of Geophysical Research* on measuring ocean mesoscale currents using ocean acoustic tomography [23]. In it we had mentioned the possibility of monitoring Rossby waves. In his letter John said, "although we didn't introduce the term oceanic tomography (back in 1974), we did propose then that the data and correlations indicated would permit the kind of experiments or monitoring you described of Rossby waves." Beckerle's 1974 attempt to use acoustics to measure Rossby waves might have been the first acoustical oceanography experiment whose objective was what is called "the inverse problem;" measure the sound, and invert the data to obtain ocean properties. A few years later Robert Porter and the author, both at Woods Hole, suggested using a single sound source with several acoustic receivers to measure oceanic eddies. [24]

Interestingly, Gordon Hamilton's earlier 1961-64 experiment suggested the possibility of measuring mesoscale eddies acoustically, but his work was not published until 1977.[25] Hamilton, who ran ONR's acoustics and oceanography programs during the 1970's and into the '80's, repeatedly detonated underwater explosions at the same spot near Antigua, and measured the time the signal took to arrive at hydrophones at Eleuthera and Bermuda, roughly 1500 km distant. The aim of the experiment was to determine the stability of the sound speed at the sound channel axis to support the development of missile test ranges. The point of missile impact was to be determined by the impulsive sound of the impact received on distant hydrophones. Hamilton's data revealed periodic variations of sound speed with durations of months, consistent with a mesoscale eddy field moving through the transmission path. At the time, however, the ocean mesoscale had not been "discovered" and he simply concluded that the observed variations were due to something happening in the water between source and receiver.

The first systematic research to understand long-range low frequency acoustic fluctuations began in Miami in 1960 at the Institute for Acoustical Research. Under the sponsorship of Alan Sykes at ONR, it was led by John Steinberg, Morton Kronengold and John Clark, and including Harry DeFerrari from the Rosenstiel School of the University of Miami, and Ted Birdsall from the University of Michigan. Over an approximately twenty-year period they undertook a remarkable set of observations using two fixed acoustic ranges, one 80 km long across the Straits of Florida, and the other 1250 km long from Eleuthera to Bermuda, both using a stable, well-controlled, 420 Hz source. Their measurements showed extraordinary phase stability and very strong correlations between acoustic phase and ocean tides and transport.[26]

These developments, aimed at better sonars, pointed to a strong connection between ocean processes and acoustic variability. It was apparent that if the details of the connections were understood, then acoustic signals themselves could be used to measure the ocean. It was somewhere around this time, the mid-1970's, that the term for measuring ocean processes using acoustics—acoustical oceanography—was coined.

During this same period oceanography itself was undergoing a revolution. British oceanographer John Swallow first launched his acoustically tracked neutrally buoyant floats and observed deep subsurface flows in 1955. In 1959 he dropped them into the Gulf Stream where they revealed completely unexpected highly variable currents. In the 1971-1974 U.S. and U.K. Mid-Ocean Dynamics Experiment, and then in the 1977-1978 mostly U.S. and Russian POLYMODE, it was shown that these currents were parts of organized mesoscale eddies. To track their trajectories, Doug Webb, at Woods Hole, and M.J. Tucker on sabbatical at MIT from England (and shortly joined by Tom Rossby, from Yale, but who is now at the University of Rhode Island) took Swallow's floats a step further acoustically speaking. Swallow's contained pingers and were acoustically tracked by a following ship. The new devices, called SOFAR floats, emitted low frequency tones which permitted them also to be tracked acoustically, but remotely from afar, using receptions on the Navy's SOSUS receiving system. [27]

Thus in the seventies and into the eighties we find acousticians working on the relationship between acoustic fluctuations and the ocean processes that caused them –mostly for Navy purposes—and oceanographers wondering how to observe and characterize the newly discovered ocean mescoscale in a systematic way.

Early in the 1970's, the Defense Department's Advanced Research Project Agency, ARPA—today's DARPA—commissioned its think-tank, the JASON group, to focus on understanding acoustic fluctuations in order improve antisubmarine warfare (ASW) systems. The group included physicists Fred Zachariasen, Stan Flatte, Roger Dashen, and others, and oceanographer Walter Munk. Using data from the Institute for Acoustical Research, Terry Ewart's (University of Washington) Cobb Seamount measurements, and Navy data collected by the New London Laboratory in experiments off the Azores, they were able to derive direct and quantifiable relationships between ocean physical processes and acoustic fluctuations.[28]

Meanwhile, MIT's Carl Wunsch was working on the application of inverse theory to oceanography. He and Munk collaborated in bringing oceanography and acoustics together in a seminal way through their development of Ocean Acoustic Tomography, which they proposed in 1979 as a method for monitoring the ocean mesoscale.[29] In 1981 the first acoustic tomography experiment was conducted in the Atlantic using a variant of Webb's SOFAR floats as acoustic sources, and special acoustic navigation systems and receivers developed by the author.[30] Peter Worcester, Munk's graduate student, was doing his thesis research at the time on another new development in acoustical oceanography, using reciprocal acoustic transmissions to measure currents.[31]

These were the origins of the acoustical oceanography practiced routinely today. From the quest for better high frequency sonar performance one can trace the use of acoustics to study bubbles and flows, pioneered by Herman Medwin at the Naval Postgraduate School in Monterey, and practiced by David Farmer at the Institute of Ocean Sciences, and Steven Thorpe at the Southhampton Oceanography Centre in the UK[32]. Here was the basis for Scripps' Rob Pinkel's innovative, multi-beam, coded-pulse Doppler sonars used to measure internal waves. Understanding the nature of the background noise at these frequencies led to Jeff Nystuen's (University of Washington) elegant instruments for monitoring rainfall at sea acoustically[33]. Understanding fish swimbladder resonances, which are the root of the ocean's Deep Scattering Layer, also provided methods to use acoustics to assess fish stocks—quantity as well as species. From the pursuit of improved surveillance sonars, and the daunting task of adequately sampling vast ocean eddy and current systems, came ocean acoustic tomography and thermometry.

The brief history of Acoustical Oceanography is hardly over. The first text on the subject was Clarence Clay and Herman Medwin's "Acoustical Oceanography: Principals and Applications", which appeared in 1977 (Ref. 1). Acoustical Oceanography did not become a Technical Specialty Group in the Acoustical Society of America until 1989[34], and only achieved Technical Committee status in 1991. Acoustical techniques, with their unique ability to remotely probe the ocean, to monitor biology, and to measure ocean properties over basin-wide scales, are certain to continue to be developed and exploited. They are well suited to the operational global ocean observing systems under development in many countries today. The practice of acoustical oceanography is certain to remain alive and flourishing for a long time to come, and it is certain there will be new chapters in its history.

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Acoustical Oceanography Timeline

1827 •••• Colladon and Sturm measure the speed of sound in water.

1859 •••• Maury, Hydrographer of the Navy, attempts to measure ocean depth by echo-sounding.

1907 •••• Fells is granted a U.S. patent for an echo-sounding device.

1912 •••• Behm, Germany, makes first echo-sounding (using bullets as sound sources). Titanic sinks, spurring development of echo-ranging, forerunner to sonar. Richardson granted first patent for "detecting the presence of large objects under water by means of the echo of compressional waves..."

1914 •••• Fessenden demonstrates echo-ranging (on an iceberg).

1924 •••• Portier, France, suggests using sound to detect herring and sardine schools.

1929 •••• Kimura, Japan, demonstrates detecting fish with sound.

1942 •••• Eyring, Christensen and Raitt conduct first comprehensive experiments on the deep scattering layer.

1944 •••• Ewing and Worzel demonstrate low-frequency, long-range ocean sound propagation using the SOFAR channel.

1946 •••• Brekhovskikh, Soviet Union, independently discovers SOFAR channel.

1953 •••• Eckart publishes theory of acoustic scattering from the sea surface.

1955 •••• Swallow observes deep ocean motions by acoustically tracking neutrally-buoyant subsurface floats.

1960 •••• Institute for Acoustical Research established in Miami by Office of Naval Research and two fixed acoustic ranges installed, one across the Straits of Florida, the other from Eleuthera to Bermuda. Relationship between tides and acoustic phase demonstrated.

1962 •••• Hersey, Backus and Helwig associate Deep Scattering Layer constituents with small swimbladder-bearing fish.

1964 •••• Andreeva develops theory for scattering of sound by air bladders of fish.

1966 •••• Weston shows effects of fish on long-range propagation and scattering at low frequencies in the Bristol Channel. Work declassified and published in 1989.

Acoustical Oceanography Timeline

1970 •••• Webb and Rossby develop SOFAR floats to observe large-scale ocean motions by acoustically tracking low-frequency, subsurface sound sources. Medwin measures bubble populations acoustically.

1974 •••• Ehrenberg describes the dual-beam principle for making in situ target strength measurements of individual fish.

1976 •••• Pinkel describes acoustic Doppler current meter. Developers include Pinkel, Spiess, Davis, Deines and Rowe. Worcester makes first current measurements by reciprocal acoustic transmissions.

1977 •••• Clay and Medwin publish first textbook on acoustical oceanography, *Acoustical Oceanography: Principles and Applications.*

1979 •••• Flatté, et al. publish "Sound Transmission Through a Fluctuating Ocean", using path integral methods to predict acoustic fluctuations caused by ocean internal waves. Munk and Wunsch suggest possibility of Ocean Acoustic Tomography for monitoring the ocean mesoscale.

1980 •••• Hamilton's "Geoacoustic modeling of the sea floor" published.

1981 •••• First Ocean Acoustic Tomography demonstration. Nystuen conducts experiment to measure rainfall using acoustics.

1983 •••• Foote describes the linearity principle for fisheries, placing fisheries acoustics on a firm theoretical basis.

Clifford and Farmer employ acoustical scintillation technique to measure ocean flow.

1989 •••• Acoustical Oceanography becomes a Technical Specialty Group in the Acoustical Society of America.

1991 •••• Acoustical Oceanography becomes an ASA Technical Committee. Heard Island Feasibility Test (HIFT) conducted.

1993 •••• Clarence Clay becomes first recipient of the ASA Silver Medal in Acoustical Oceanography.

1996 •••• Acoustic Thermometry of Ocean Climate (ATOC) system installed in North Pacific to make acoustic ocean-basin-scale temperature measurements.

2000 •••• First ASA Medwin Prize in Acoustical Oceanography awarded (to Leighton).

Past and Present Chairs of Technical Committee on Acoustical Oceanography

1989-92 Herman Medwin
1992-95 Michael J. Buckingham
1995-98 Darrell R. Jackson
1998-01 James F. Lynch
2001-04 Peter F. Worcester

Recipients of the Silver Medal in Acoustical Oceanography

1993 - Clarence S. Clay - For contributions to understanding acoustic propagation in layered waveguides, scattering from the ocean's boundaries and marine life, and ocean parameters and processes.

1997 - Herman Medwin - For contributions to the understanding of acoustical scattering, absorption and ambient noise, particularly in relation to the acoustics of bubbles in the sea.

Recipients of Interdisciplinary Silver Medals

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Acoustical Oceanography and Underwater Acoustics

1998 - David E. Weston - For seminal work on the physics of explosive sources, scattering, and the horizontal refraction of sound.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Underwater Acoustics, Acoustical Oceanography and Signal Processing in Acoustics

2003 - Arthur B. Baggeroer - For applications of model-based signal processing to underwater acoustics and for contributions to Arctic acoustics.

Medwin Prize in Acoustical Oceanography

The Medwin Prize in Acoustical Oceanography was established with a generous gift from Hank and Eileen Medwin, who established the prize to honor continuing research accomplishments of young and mid-career scientists in Acoustical Oceanography. The award is given to individuals whose work demonstrates the effective use of sound in the discovery and understanding of physical and biological parameters and processes in the sea. For the purposes of this Prize, research based solely on computer models is not accepted as a substitute for ocean experiments or effective, small-scale laboratory models and experiments. The recipient of the prize must be under 46 years of age on January 1 of the year the award is made and must have demonstrated his or her primary interest in Acoustical Oceanography through publications and oral presentations. The award consists of certificate and a $2,000 stipend.

2001 Timothy G. Leighton
2002 Bruce D. Cornuelle
2003 Jeffrey A. Nystuen
2004 Stan E. Dosso

ASA *at* 75

Chapter 5

Animal Bioacoustics

Mardi C. Hastings, Chapter Editor
History Lecture, Arthur N. Popper & Robert J. Dooling

Animal Bioacoustics

Introduction

The Animal Bioacoustics Technical Committee of ASA represents and fosters an understanding of animal bioacoustics. Membership is open to any interested member of the Society. Animal bioacoustics is the study of sound in non-human animals from insects through mammals. It includes acoustic communication, sound production mechanisms, auditory anatomy and function, sonar, acoustic tracking, and the effects of noise on animals.

Although Animal Bioacoustics as a discipline had its beginnings in the mid-19th century (see the following article), the technical committee was not formed until 1988 when William C. Cummings formally organized the Animal Bioacoustics Technical Specialty Group (TSG). The TSG primarily consisted of marine mammal scientists, underwater acousticians, and acoustical oceanographers who were interested in dolphin sonar and the effects of noise on marine mammals. Bill led the TSG for six years and expanded its breadth to include members interested in terrestrial mammals, fishes, amphibians, and insects, before stepping down as Chair in November 1994. From 1994 to 1997, Whitlow W. L. Au and Ann E. Bowles cochaired the TSG and continued to expand its horizons. They helped it achieve full Technical Committee status by encouraging members to specify "Animal Bioacoustics" as their primary area of interest in the 1995 Membership Directory survey. The TSG became the Animal Bioacoustics Technical Committee (ABTC) in 1996, thereby achieving voting representation on the ASA Technical Council. Whitlow Au became the first elected Chair of the ABTC and the Associate Editor of JASA for Animal Bioacoustics in 1997. Mardi Hastings became Chair in 2000-2003, and Andrea Simmons is the elected Chair for 2003-2006. Although the Animal Bioacoustics Technical Committee is very young, it has already succeeded in awarding a Silver Medal to Whitlow Au in 1998 and the R. Bruce Lindsay Award to James Finneran in 2002.

Dr. Arthur N. Popper and Dr. Robert J. Dooling have done an outstanding job in discussing the "History of Animal Bioacoustics" and presenting the lecture at the Fall 2002 Meeting in Cancun. In their paper and presentation, Drs. Popper and Dooling show that interest in animal bioacoustics is quite ancient and that in the mid-1900s it started to grow and become the focus of the research interests of more and more investigators. Popper and Dooling were active in the field of animal bioacoustics long before the Animal Bioacoustics Technical Committee existed in ASA and continue their active contributions even today. Both are renowned researchers in the field and lead the Comparative and Evolutionary Biology of Hearing program at the University of Maryland, College Park. Dr. Dooling is currently a member of the Technical Committee and Dr. Popper served on the Committee through 1997.

Mardi C. Hastings, 2000-2003 Chair,
Technical Committee on Animal Bioacoustics

Animal Bioacoustics

Arthur N. Popper & Robert J. Dooling,
University of Maryland

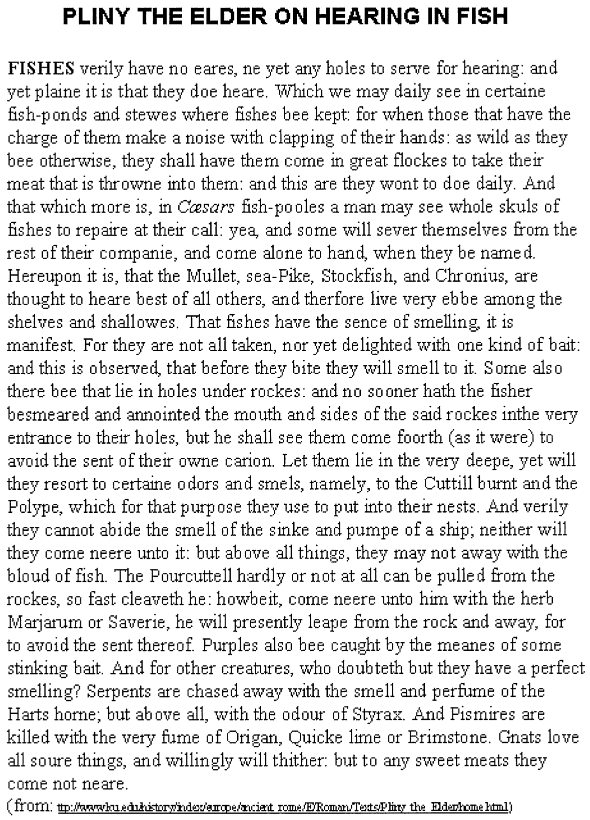
Animal Bioacoustics is an exceptionally broad field of study that requires input and expertise from a variety of disciplines and technologies in order to fully explore the nature of communication using sound. For purposes of this review, we decided that the best current definition is the one proposed by the Animal Bioacoustics Technical Committee of the Acoustical Society of America which says that animal bioacoustics is the "...study of sound in non-human animals. It includes acoustic communication, sound production mechanisms, auditory anatomy and function, sonar, acoustic tracking, and the effects of human-made and environmental noise on animals."

Animal Bioacoustics Before the 20th Century

One can easily imagine that humans have always been aware of animal sounds and took advantage of these sounds in finding animals for food and avoiding predators. So too, humans have probably always been aware that animals used sound to communicate and that variations in these sounds could provide useful information about the state of the animal, both wild and domesticated. Many early references to sound production and communication by animals attest to the interest humans had in such sounds.

In fact, ancient Romans and Greeks had a sophisticated sense of the role of sound and hearing even in organisms that were not easy to observe. As early as 350 BC, Aristotle in *On Sense and Sensible* recognized the special position of hearing among the other senses for both animals and humans.

"The senses which operate through external media, viz. smelling, hearing, seeing, are found in all animals which possess the faculty of locomotion…seeing, regarded as a supply for the primary wants of life, and in its direct effects, is the superior sense; but for developing intelligence, and in its indirect consequences, hearing takes the precedence…hearing announces only the distinctive qualities of sound, and, to some few animals, those also of voice. Indirectly, however, it is hearing that contributes most to the growth of intelligence. For rational discourse is a cause of instruction in virtue of its being audible, which it is, not directly, but indirectly; since it is composed of words, and each word is a thought-symbol. Accordingly, of persons destitute from birth of either sense, the blind are more intelligent than the deaf and dumb…those which are incapable of hearing sounds are intelligent though they cannot be taught, e.g. the bee, and any other race of animals that may be like it; and those which besides memory have this sense of hearing can be taught."



PLINY THE ELDER ON HEARING IN FISH

FISHES verily have no eares, ne yet any holes to serve for hearing: and yet plaine it is that they doe heare. Which we may daily see in certaine fish-ponds and stewes where fishes bee kept: for when those that have the charge of them make a noise with clapping of their hands: as wild as they bee otherwise, they shall have them come in great flockes to take their meat that is throwne into them: and this are they wont to doe daily. And that which more is, in *Cæsars* fish-pooles a man may see whole skuls of fishes to repaire at their call: yea, and some will sever themselves from the rest of their companie, and come alone to hand, when they be named. Hereupon it is, that the Mullet, sea-Pike, Stockfish, and Chronius, are thought to heare best of all others, and therfore live very ebbe among the shelves and shallowes. That fishes have the sence of smelling, it is manifest. For they are not all taken, nor yet delighted with one kind of bait: and this is observed, that before they bite they will smell to it. Some also there bee that lie in holes under rockes: and no sooner hath the fisher besmeared and annointed the mouth and sides of the said rockes inthe very entrance to their holes, but he shall see them come foorth (as it were) to avoid the sent of their owne carion. Let them lie in the very deepe, yet will they resort to certaine odors and smels, namely, to the Cuttill burnt and the Polype, which for that purpose they use to put into their nests. And verily they cannot abide the smell of the sinke and pumpe of a ship; neither will they come neere unto it: but above all things, they may not away with the bloud of fish. The Pourcuttell hardly or not at all can be pulled from the rockes, so fast cleaveth he: howbeit, come neere unto him with the herb Marjarum or Saverie, he will presently leape from the rock and away, for to avoid the sent thereof. Purples also bee caught by the meanes of some stinking bait. And for other creatures, who doubteth but they have a perfect smelling? Serpents are chased away with the smell and perfume of the Harts horne; but above all, with the odour of Styrax. And Pismires are killed with the very fume of Origan, Quicke lime or Brimstone. Gnats love all soure things, and willingly will thither: but to any sweet meats they come not neare.

(from: ttp://www.ku.edu/history/index/europe/ancient_rome/E/Roman/Texts/Pliny_the_Elder/home.html)

Figure 1. Pliney the Elder on Fish Hearing. (Note, spelling follows the translation on the web site given. Translation was done in the early 17th century.)

There are excellent descriptions of song learning and speech learning in birds by the Roman Pliny the Elder in his treatise on natural science over 2000 years ago. He describes what may also have been the first comparative study of hearing in fish as translated in English in 1601 (Fig. 1).

The mid-19th century saw the first formal beginning of what would become animal bioacoustics. The first systematic documentation of the role of acoustics in the biology of animals is clearly evident in the expansive field observations of Charles Darwin. These range from his observations of the hoarse roar produced by Galapagos tortoises during breeding season to his observation on dog vocalizations described in *The Expression of the Emotions in Man and Animals*:

"The cause of widely different sounds being uttered under different emotions and sensations is a very obscure subject. Nor does the rule always hold good that there is any marked difference. For instances with the dog, the bark of anger and that of joy do not differ much, though they can be distinguished. It is not probable that any precise explanation of the cause or source of each particular sound, under different states of mind, will ever be given."

In its earliest stirrings as a science and lacking modern-day technical advantages, animal bioacoustics progressed by relying on techniques from studies of human speech and music. As an example, in the mid-1800s, the explorer Richard Burton, a gifted linguist, listed 60 different sounds made by chimpanzees, probably by relying heavily on his linguistic abilities to classify these sounds,(cited in Busnel 1960). So too, F. Scuyler Matthews' *Field Book of Wild Birds and Their Music*, published in 1904, provided what is probably the first quantitative description of bird song by describing common North American songbird vocalizations using musical notation.

At the dawn of the 20th century, shortly after the time of Darwin, there began to be a distinct association between technological developments in acoustics, scientific developments in behavioral biology and psychology, and advances in animal bioacoustics (see timeline in Fig. 2). A student of animal bioacoustics at the beginning of the 20th century would probably be aware that the first "recording" of animal sounds was made in 1892 when R. L. Garner, working at the newly established National Zoological Park in Washington, D.C., used wax cylinders to record and consider "the speech of monkeys" (cited in Morton and Page 1992).

Around this time, experimental psychologists were weighing in with various creative procedures for measuring an animal's hearing and auditory perception. It is probably fair to say that the modern study of animal bioacoustics began here and was marked by the simulta-

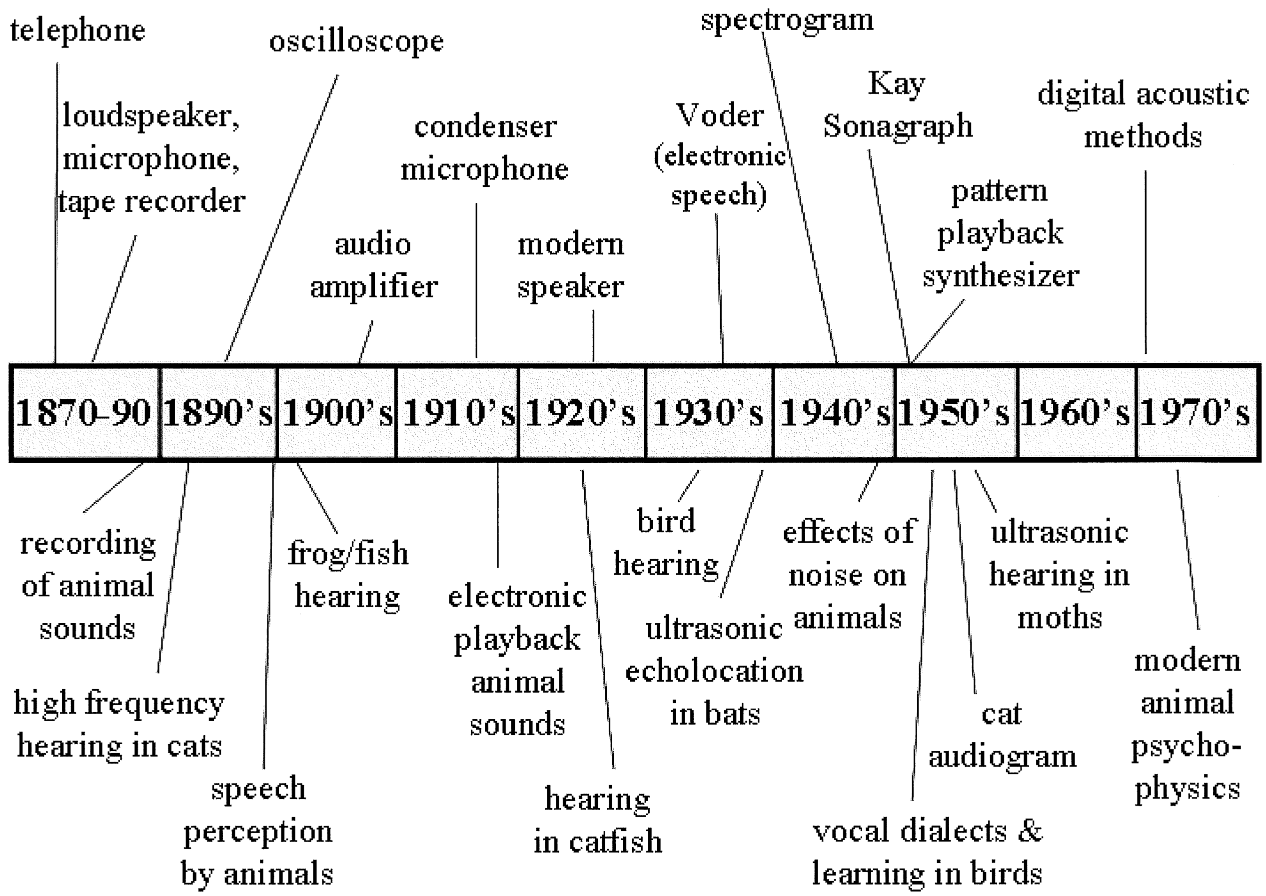


Figure 2. Time line of major technological advances that led to the modern era in studies of animal bioacoustics (above dates) along with an indication of the time when some of the major scientific advances were also made (below).

neous invention of devices to record and analyze animal sounds and the development of creative techniques that enabled investigators to "ask" animals what sounds they could hear and how sounds were used in communication.

For instance, while the basic outline of how frogs produce sounds had been described by Boulenger in 1898, nothing was known about their hearing. In 1903, the psychologist Yerkes, convinced from field observations that frogs could hear, provided the first experimental demonstration. He suspended a blindfolded green frog on a stand with its hind legs hanging free and then hit the frog on the head with a small rubber hammer. A bell was rung either before, during, or after the blow. The frog jerked its leg more strongly if the sound occurred before or at the same time as the blow but not if the sound occurred after the blow—demonstrating, for the first time, that frogs could hear.

Working with more complex sounds, Thorndike and Shepherd about this time conducted the first experimental studies on the discrimination of human speech sounds by animals (Thorndike 1911). Even then, the perceptual constancy problem in speech had been identified, and these investigators showed that animals learn to ignore irrelevant acoustic variation and attend only to relevant acoustic variation. Shepherd (1911, 1912) described training cats to approach the experimenter to obtain food when the word "pet" was spoken and to not approach when the phrase "no feed" was spoken. He then described control tests that were quite prescient in terms of the modern understanding of the challenges of speech perception where

"...words were called in varying tones of voice, in quite low tones, and in very low tones…and by different people…and the percentage of proper reactions remained as in the experiments proper."

In a more anatomical domain, when the ear of the fish was first described by Casserius in 1610, it was assumed they could hear, but proof did not come until the turn of the 20th century when G. H. Parker (1903) provided the first clear experimental evidence that fish are able to detect sound. Parker performed behavioral studies on normal fish, fish that had the lateral line nerves cut, and fish that had the eighth cranial nerve cut. He was able to demonstrate responses to sound in the normal animals and in fish that had the lateral line eliminated, but not in fish that had the eighth nerve cut. This led other work by the great German biologist Karl von Frisch, who used a whistle to determine the sounds that catfish could hear (von Frisch 1923).

Playback experiments have contributed, and continue to contribute, tremendously to what we know about how animals use and perceive sound. As near as we can tell, the first "all electronic" playback experiment was probably conducted by the German biologist Regen (1913). He transmitted the calls of a male cricket (*Gryllus campestris*) over the telephone to another room where a female approached the earphone—a playback experiment demonstrating sound alone was responsible for a response.

Animal Bioacoustics in the Last Half of the 20th Century

The 1958 publication of *Animal Sounds and Communication* by Lanyon and Tavolga did much to pull together the early contributions in field of animal bioacoustics by bringing a number of studies together into a single, focused volume. This book, and the 1958 symposium that led to it, arose out of desire to bring together people working on wide range of animal acoustic behavior with others interested in the biology of communication (preface, Lanyon and Tavolga 1960).

In this paper, we used several strategies to describe the study of animal bioacoustics from around the middle of the 20th century to the present time. First, the growth of the field over the past 50 years was measured by counting the number of publications over this time period that fit the definition of the field by the ASA Technical Committee, using a select group of journals including the *Journal of the Acoustical Society of America* (Fig. 3). Second, even the most cursory examination of the field reveals an intimate and fertile connection between technological advances and scientific advances and a brief description of some of these throughout the history of bioacoustics are provided (Fig. 2). Finally, through informal queries of our colleagues, we have identified six individuals who together represent the spirit, breadth, and diversity of the field of animal bioacoustics in the 20th century.

Journal Coverage

The modern growth in animal bioacoustics can be assessed by counting the number of publications in the *Journal of the Acoustical Society of America* (JASA) (Fig. 3a) and also in selected journals that routinely publish work that fit the ASA definition of animal bioacoustics (Fig. 3b). These journals provide a broad representation

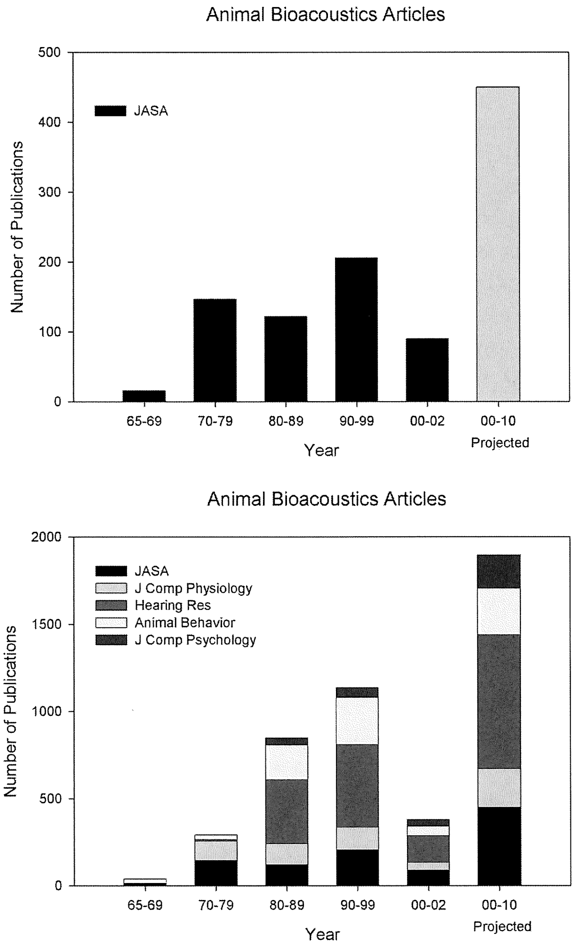


Figure 3. Analysis of the number of papers in "animal bioacoustics" published at 10-year intervals in (a) Journal of the Acoustical Society of America (top) and (b) five representative journals (bottom). Note that the projected publication rate for 2000-2010 is based upon the actual number of papers published in 2000-2002.

of interests in scientific questions and thus generally cover the field of animal bioacoustics.

It is of some interest that Stevens and Davis in 1936 published the first paper in JASA that dealt with the biological basis of hearing and therefore was "bioacoustic." The paper, *Psychophysiological Acoustics: Pitch and Loudness* (vol. 8, pp. 1-13), was focused solely on humans. It was not until 1940 that Lurie published a paper on guinea pigs and cats *Studies of Acquired and Inherited Deafness in Animals* (vol. 11, pp. 20-42), which appears to be the first animal bioacoustics study in JASA. By 1948, we can routinely find papers that comfortably fit the current definition of animal bioacoustics, including several that presented the first studies in JASA on non-mammals and on invertebrates. One was a study by Allen, Frings, and Rudnick entitled *Some Biological Effects of Intense*

High Frequency Airborne Sound (vol. 20, pp. 62-65) in which the authors examined the effects of high intensity sounds on mice and six species of insect. The other was by Everest, Young, and Johnson who reported on *Acoustical Characteristics of Noise Produced by Snapping Shrimp* (vol. 20, pp. 137-142).

Figure 3a shows a distribution of animal bioacoustics papers in JASA since 1970. Since the early 1970s the number of papers on the subject have increased substantially in both JASA and other journals as well (Fig. 3b). The most recent data for JASA, the data for 2000, represents only a two-year period but shows a considerable increase in numbers of publications, perhaps signaling an increased interest in animal bioacoustics. Of the 53 papers published in JASA since 2000, 25 deal with marine mammals, while six each are on bats, fish, and birds. The remaining papers are on a variety of other organisms from insects to dogs to elephants. This suggests that JASA is becoming a primary home to marine mammal work and work on echolocation.

The trend to increasing rates of publication in animal bioacoustics is also evident in Figure 3b which provides a ten-year cumulative count of papers in five representative journals, including JASA. The increase is sharp since the year 2000 also suggests a continued strong increase in animal bioacoustics. Most of these papers are in the journal *Animal Behaviour* and tend to be on acoustic communication and behavior. The next most popular journal for animal bioacoustics is *Hearing Research* which typically focuses on mechanisms of sound detection and discrimination.

Individuals Who Have Influenced the Field [A]

Even a cursory look at the history of the field of animal bioacoustics reveals a number of people who have strikingly influenced its ontogeny and evolution and who have made fundamentally important contributions that have influenced the way the field has developed. With the help of colleagues from around the world, we have identified six people whose work fits closely well within the ASA definition of the field and whose influence continues even today through their outstanding students and protégés. By definition, these individuals come not from the present scientific generation but from one to two scientific generations before [B]. Below are short biographical sketches of these six individuals presented in alphabetical order.

Robert Capranica

Bob Capranica did his first work on frogs at the Massachusetts Institute of Technology Research Laboratory of Electronics as part of his doctoral dissertation. This dissertation made several important contributions to the field of bioacoustics and neuroethology (e.g., Capranica 1966; Capranica et al. 1973). Capranica was among the first to create and use synthetic animal calls in experiments and to use these calls to assess the specific signal properties that elicit behavioral responses from other individuals.

Animal bioacoustics clearly benefited from Capranica's ability to blend engineering and ecology. The early technology used to synthesize and analyze calls was a complex array of capacitors, resistors, and coils. It was clearly the work of an engineer. But his work was also influenced by more ecological ideas about species-isolating mechanisms and frog calling behavior, ideas that were discussed by anuran field biologists such as Littlejohn and Blair.

In 1969, Capranica joined Cornell University where his work focused on signal processing in the anuran auditory system and elevated frogs to the status of neuroethological model system. Capranica put forward the concept of the "matched filter" for processing species-specific signals, an idea that still forms the basis of much neuroethology.

Donald R. Griffin

Don Griffin actually began his research on echolocation in bats as an undergraduate at Harvard. He coined the term "echolocation" in the early 1940's, marking the beginning of his enormous contributions to our understanding of biological sonar systems in bats. Griffin and his mentor G. W. Pierce brought bats into the lab and began to study their calling behavior (Pierce and Griffin 1938). It was Griffin and Galambos (1941) who discovered that bats emitted high frequency sounds whose echoes bounced off of objects.

Over the years, Griffin made many major discoveries about echolocation. He also conducted comparative studies of bat echolocation signals in the field and was the first to describe species-specific signal designs. In his later years, Griffin's work took another turn with considerations about whether animals were able to think about and perceive the events that occurred around them. This led to a new field of "cognitive ethology" around 1975 and several books on animal awareness and cognition by Don Griffin that re-energized the field of animal awareness and blurred some of the distinctions between humans and animals.

Peter Marler

Peter Marler received a Ph.D. in Botany at University College in London under the mentorship of William Thorpe and Robert Hinde and completed a second Ph.D. in Animal Behavior with his work on the chaffinch in Madingley Wood (Marler 1956). Some of his observations during this time included the fact that passerine birds of the same species but living in different locales had different dialects (strong evidence for vocal learning in birds) and the fact that different songbird species seem to have structurally similar, high-pitched, ventriloquial alarm calls (evidence for common selective pressures in the evolution and design of acoustic signals).

Marler's work on bird song and later on meaning in primate vocalizations teased apart the innate and learned aspects of bird song by deafening young birds or hand-rearing them under various conditions (Marler et al. 1962). He first made the compelling case for parallels between bird song learning and human speech development including vocal dialects, selective vocal learning, perceptual predispositions for learning species-specific vocalizations, a sensitive phase for song development, and a babbling phase in vocal production.

Kenneth Roeder

Ken Roeder's experimental background did not start in bioacoustics but rather in the neurophysiology of insects. Some of his earliest experiments involved examining mantid and cockroach behavior and then electrophysiological recordings of insects.

As often happens in science, Roeder stumbled into the world of bioacoustics serendipitously. By observing moths evading attacking bats in his backyard, Roeder predicted that by using paired tympanic organs in the thorax, the moths could hear the ultrasonic cries of bats and then perform antipredator maneuvers to avoid capture. He dissected a moth's "ear" and attached recording electrodes connected to an oscilloscope (e.g., Roeder and Treat 1957). At the same time, he rigged a flash camera capable of photographing moth-bat encounters. The moth's ear responded to the sound of bat calls (as seen on the oscilloscope) and Roeder discovered that the bat's cry as perceived by the dissected moth's ear changed when the bat received echoes from a moth.

While Griffin studied the mysteries of bat echolocation, Roeder unraveled the same story from the prey's perspective (e.g., Roeder 1966). He introduced microphone array techniques to estimate the emitted sound pressure of freely flying bats in the field. Using this technique he was not only the first to estimate realistic source levels for freely flying bats, but he could also determine the detection distance for the moth via the activity of its ear. Such experimental results were the foundation of his many seminal ideas and discussions of predator-prey interaction.

William N. Tavolga

Bill Tavolga started out to study embryonic development of lizards, but due to a paucity of material, he was guided to fishes, and fish became the basis for his doctoral research at New York University. Tavolga started a series of studies on gobies shortly after getting his doctorate and continued his work with studies of their reproductive behavior and particularly their reproductive endocrinology. After a friend suggested that he put a hydrophone into the water during goby courtship behavior, Tavolga (1956) discovered that part of the behavioral sequence involved in courtship included sound. This study continues to be a classic example of the complex interactions between sensory cues and behavior. Tavolga then developed an interest in fish sound production and acoustic behavior in a number of fish species. He teamed up with Jerry Wodinsky and did the first study to quantify hearing capabilities of fish (Tavolga and Wodinsky 1963). This study broke open the field of marine bioacoustics and spawned all future studies of fish hearing.

Perhaps the most important aspect of the 1963 study, and later work by Tavolga and his colleagues, was the application of quantitative methods of what was then "experimental psychology" to studies on hearing in fishes. Tavolga's work emphasized the quantitative aspects of behavior control, stimulus specification, and psychophysical methods, all in the context of comparative and evolutionary biology. Tavolga also was one of the early investigators to understand the jargon and issues of psychoacoustics and he fearlessly applied them to animals.

Ernest Glenn Wever

Glenn Wever made three broad categories of contributions to the field of animal bioacoustics. First, with Charles Bray, he effectively began the study of inner ear electrophysiology with the discovery of the cochlear microphonic potentials (also known as the Wever-Bray effect) before 1930. In the first observations of electric potentials that virtually mimic stimulus waveforms, it was suggested that their origin was neural, but these signals were soon found to originate from the organ of Corti itself and for many years were described as receptor potentials that either were the precursor to neural excitation or were an epiphenomenon with regard to transduction.

The volley theory (Wever 1949) was Wever's duplex synthesis of place and temporal theories of pitch, and it constitutes his second main contribution to the field by showing how several distinct aspects of auditory coding could cooperate to represent pitch across different frequencies of sound.

Wever's third contribution derives from his own interest in using the cochlear microphonic as a tool to understand physiological acoustics—that is, mechanical coupling of sound to the inner ear in all its ramifications. Wever and several colleagues used cochlear microphonic potentials as a tool for tracing the flow of signals into the ear and for investigating outer and middle ear function (e.g., Wever 1971). Wever performed an extraordinary set of studies on hearing in a wide range of species using cochlear microphonics and accompanied these studies with meticulous investigations of the anatomy of the ears of the species studied.

The Continuing Influence of These Six Pioneers

Each of the six, through his own work and that of his students and colleagues, did pioneering work that opened new vistas of experimentation and new areas of research questions in multiple fields. Several of these individuals have direct links to the founding of the field of neuroethology (Griffin, Roeder, Capranica) while others made fundamental contributions to our understanding of the mechanisms and principles of animal communication (Marler, Tavolga) and basic hearing processes (Wever). It is quite easy to trace many of the prominent scientists working in animal bioacoustics today back to the direct or indirect influence of these six pioneers. The scientific progeny of these pioneers are working in a number of popular and fertile fields including neuroethology, auditory neuroscience, comparative psychoacoustics, the evolution of hearing, communication, vocal learning, echolocation, and marine bioacoustics.

Technology

Advances in the study of animal bioacoustics can often be related to advances in technology that enabled the investigator to hear, analyze, stimulate, or record from their experimental subjects (Fig. 2). Indeed, it is clear that without such technological advances the field would not have moved forward from its primitive days when Burton discriminated primate sounds by his ear alone to the current state where we can do detailed manipulation of animal sounds in order to determine the components of the sounds necessary for communication.

Figure 2 shows a rough timeline of some of the more obvious technological developments in acoustics related to the study of animal bioacoustics. The development of recording devices first allowed the capture of animal vocalizations for later study. Early loudspeakers and microphones required prohibitively high sound pressure levels and were hardly suitable for transducing the fine details of animal vocalizations. With the advent of the oscilloscope, high quality amplifiers, and the condenser microphone, new approaches to the study of animal bioacoustics became possible.

The technological developments surrounding World War II, however, saw the most dramatic change in the study of animal bioacoustics. The spectrogram, sonograph, and pattern playback speech synthesizer raised the analysis and synthesis of bioacoustic communication signals to a new level of control and sophistication for several decades. Though the pattern playback synthesizer was developed for the study of human speech, it foreshadowed great advances in the synthesis of animal vocalizations. The portable sound level meter brought a new level of inquiry to animal bioacoustics both in the laboratory and in the field.

As important as the technological advances of the 1940s and 1950s there were limitations imposed by the size of these devices. With the development of high-speed microcomputers in the late 1960s and 1970s, that limitation was eliminated. It now became possible to analyze animal vocalization in the laboratory and the field in great detail. Digital storage techniques accommodated huge amounts of acoustic data from animals. The new found portability from digital recording devices and microcomputers allowed for real-time recording, analysis, modification, and playback of animal vocalizations in the field. Digital synthesis of complex speech and animal vocalizations, coupled with the computer control of animal psychophysical testing, raised the level and precision of auditory testing in animals and opened new avenues of investigation. In the hands of comparative psychoacousticians like George Gourevitch, Bruce Masterton, Jim Miller, Dave Moody, and Bill Stebbins, animal psychoacoustics began to rival human psychoacoustics in the questions under study and the precision with which such questions could be asked. This in turn brought the comparison of human and animal hearing and acoustic communication to a new level.

Predating the Origins of the Animal Bioacoustics Technical Committee

While interest in, and the study of, animal bioacoustics has a long history, it did not achieve a formal designation as a discipline until 1988 when the Animal Bioacoustics Technical Specialty Group (TSG) was organized by the Acoustical Society of America. In 1996, the Animal Bioacoustics Technical Specialty Group became the Animal Bioacoustics Technical Committee that is now a vibrant scientific group in the ASA. The founding of the TSG was very much due to a group of investigators with a strong background in marine mammal bioacoustics. Beginning with a focus in marine mammal bioacoustics, the group has expanded considerably since 1988 and now reflects the diversity of interest that is seen in the breadth of the field. In a sense, the Animal Bioacoustics Technical Committee has played a pivotal role in the evolution of a whole field. Several people were instrumental in the evolution of the field of marine mammal bioacoustics, and consequently contributed greatly to the birth of the TSG. These early marine mammal scientists include Kenneth Norris, William Schevill, and William Watkins, all of whom had a profound effect on the field which continues even today.

Ken Norris and his students contributed significantly to our understanding of echolocation, sound production, and sound detection. As a result of serendipitously finding a dolphin jaw during a walk on a beach, Norris developed the idea that dolphins hear through their jaw (see Norris 1964), a finding that has profoundly affected all future studies of dolphin hearing.

Bill Schevill also made important contributions to marine mammal bioacoustics starting in the late 1940s. Along with his wife Barbara Lawrence, he provided a wealth of insight into marine mammal sounds and hearing. As an example, Schevill and Lawrence (1953) were the first to behaviorally condition a dolphin and then to demonstrate that these animals could detect sounds to over 100 kHz. Schevill continued to contribute to our understanding of marine mammal sounds for decades after his early work, often in collaboration with Bill Watkins (e.g., Schevill et al. 1963).

Bill Watkins is a pioneer in the study of the sounds of marine mammals (e.g., Watkins and Schevill 1977). Through imaginative approaches for recording and analyzing sounds of marine mammals, Watkins has not only made major contributions to the study of marine mammals, but he has influenced the science of recording and analyzing the sounds of animals as diverse as insects and birds.

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[A] As described herein, we discuss six people who we think have contributed significantly to the field of animal bioacoustics. These selections, while informed by an informal polling of dozens of colleagues from around the world, are ultimately based on our personal sense of the field.

[B] Though no women made this list, many of the colleagues we polled were women, and it is clear that many women are now highly involved in the field and are making major contributions that will surely warrant their inclusion in the next historical review of the field.

Animal Bioacoustics Timeline

1872	*The Expressions of the Emotions in Man and Animals* by Charles Darwin.
	Recording of animal sounds.
1890's	High frequency hearing in cats.
	Speech perception by animals.
1898	Production of sound by frogs described by Boulenger.
1900's	Hearing in frogs and fishes.
1904	*Field Book of Wild Birds and Their Music* by F. Scuyler Matthews.
1910's	Electronic playback of animal sounds.
	Discrimination of human speech sounds by animals demonstrated by Thorndike and Shepherd.
1920's	Hearing in catfish demonstrated by von Frisch.
	Discovery of cochlear microphonic potentials by Wever and Bray.
1930's	Hearing in birds.
1936	First bioacoustics paper in JASA (Stevens and Davis, Vol. 8, pp. 1-13).
1938	Ultrasonic calls of bats discovered by Pierce and Griffin.
1940's	Effects of noise on animals.
1940	First *animal* bioacoustics paper in JASA (Lurie, Vol. 11, pp. 20-42).
1941	Echolocation in bats discovered by Griffin and Galambos.

Animal Bioacoustics Timeline

1950's	Kay Sonograph. Vocal dialects and learning in birds.
1953	Ultrasonic hearing in dolphins demonstrated by Kellogg, Kohler and Morris, and Schevill and Lawrence.
1957	Detection of bat ultrasonic cries by moths discovered by Roeder and Treat.
1958	*Listening in the Dark* by Donald Griffin.
1959	U. S. Navy Marine Mammal Program established.
1960's	Echolocation in dolphins demonstrated by Norris. *Acoustic Behavior of Animals* by R.-G. Busnel (ed.).
1969	Founding of International Bioacoustics Council.
1970's	Modern animal psychophysics. Matched filter concept for processing species–specific signals by Capranica.
1980's	ASA Animal Bioacoustics Technical Specialty Group formed by Cummings.
1990's	Heard Island demonstration project and U.S. Navy low-frequency active sonar (SURTASS LFA) create worldwide concern of effects of noise on marine mammals.
1996	ASA Animal Bioacoustics Technical Committee established.
1997	JASA's first Associate Editor for Animal Bioacoustics (W. W. L. Au).
2000's	Number animal bioacoustics publications in peer-reviewed journals expected to approach 2000 during this decade.

Past and Present Chairs of the Technical Committee on Animal Bioacoustics

1988-94	William C. Cummings
1994-97	Ann E. Bowles and Whitlow W. L. Au (Co-Chairs)
1997-00	Whitlow W.L. Au
2000-03	Mardi C. Hastings
2003-	Andrea M. Simmons

Recipient of the Silver Medal in Animal Bioacoustics

1998 - Whitlow W. L. Au - For contributions to the fundamental knowledge of the acoustics of dolphin sonar.

ASA at 75

Chapter 6

Architectural Acoustics

K. Anthony Hoover, Chapter Editor
History Lecture, Ewart A. Wetherill

Architectural Acoustics

Introduction

Architectural acoustics, the understanding and practical applications of sound behavior in and around buildings, has always been of interest to many of the Society's members. Technical committees were operating long before the Society formally established the Technical Council in 1960, of which the Technical Committee on Architectural Acoustics (TCAA) was already a seasoned participant.

The scope of TCAA encompasses the following areas of interest as applied to spaces in and around buildings:

- *Room acoustics of all types, including spaces for music and speech performance and listening, as well as work, educational, leisure, and other spaces of all types.*

- *Airborne and impact sound transmission and control.*

- *Noise and vibration control of building systems, including electrical, mechanical, and plumbing.*

- *Electroacoustics applications, including sound amplification and communication systems and their integration with room acoustics design.*

- *Psychophysics and psychoacoustics studies, leading to the development of criteria for good listening conditions in occupied spaces of all types.*

Accordingly, the TCAA is both wide-ranging and interdisciplinary in its activities, overlapping many of the Society's other technical committees. Furthermore, when members of the general public think of acoustics, they immediately identify with auditorium or church acoustics, or of the sounds they experience in common building spaces.

TCAA serves as the focus for interested ASA members and guests at its biannual meetings to present papers at technical sessions, to plan future technical sessions, and to coordinate and support activities in areas of widespread public interest, such as the classroom acoustics task group, research groups in concert halls and theaters, groups that teach architectural acoustics, and a variety of practical and experimental applications. Since the 1980s, TCAA has sponsored the Knudsen Distinguished Lecture series which commemorates one of the founding members of the Society, Dr. Vern O. Knudsen, bringing the results of groundbreaking research from leading practitioners and consultants in architectural acoustics to the Society's meetings. TCAA has pioneered in the publication of a number of works, including a series of books based on special poster sessions on particular building types. These include *Theatres for Drama Performance* (April 1985), *Acoustical Design of Music Education Facilities* (May 1989) and a recent book, *Halls for Music Performance: Another Two Decades of Experience, 1982-2002*, (October 2003) which built upon the successful earlier book, *Halls for Music Performance: Two Decades of Experience, 1962-1982* (April 1982). Other initiatives in architectural acoustics have included the highly successful Wallace Clement Sabine Centennial Symposium, held in conjunction with the 127th Meeting of the Society at MIT in Cambridge, Massachusetts in June 1994. TCAA has co-sponsored two popular and productive Summer Institute Workshops with the National Council of Acoustical Consultants and the Concert Hall Research Group; the first in August 1999 at Tanglewood in Lennox, Massachusetts, and a second in August 2003 at the Saratoga Springs Performing Arts Center in Saratoga, New York.

TCAA has long been a very active technical committee, generally concentrating on applications as well as some fundamental research. Much of the research in architectural acoustics is done in connection with developing criteria for design; members of TCAA continuously look for opportunities for research from each project they undertake, and occasionally direct extended, well-funded research programs. Research studies include speech privacy in buildings, criteria for room noise due to air conditioning systems, and concert hall design criteria. Of course, much acoustical research began with concerns for practical applications, such as for concert hall acoustics, speech communication, noise control in buildings, and sound-reinforcement systems.

Many TCAA members are professional consultants, working on a diverse range of projects at any given time, as well as teaching courses, lecturing in architectural acoustics, and preparing articles, along with the other daily concerns involved in running busy professional practices. The TCAA sessions at ASA meetings are their primary and essential means for sharing discoveries, new ideas, and applications. At the same time, many members are full time professors, representatives of acoustical product manufacturers, or members of other engineering disciplines which relate closely to TCAA's interests. TCAA is a committee which includes an extremely interesting and talented group of individuals involved in practically all the latest research developments, product developments, and methodologies in architectural acoustics.

Our capabilities for progress in architectural acoustics research have increased enormously in recent years with the widespread availability of powerful digital computers for acoustical measurements, analysis, and new design methodologies. The acoustical environments of practically any space can now be rapidly studied and evaluated in advance of construction. One increasingly important aspect of this technology is the ability to accurately "auralize" a space, so that architects, musicians, building owners, and acousticians will be able to "hear" as well as "visualize" spaces before they are built.

The History Lecture on Architectural Acoustics was presented by our distinguished colleague Ewart A. "Red" Wetherill. Red learned the art of consulting as he earned a Master in Architecture degree at MIT, while simultaneously serving on the staff of Bolt Beranek and Newman (BBN), the renowned acoustical consulting firm. Thereafter, Red taught at Clemson University for a number of years, and then rejoined BBN, serving on its consulting staffs at the Cambridge, Los Angeles, and San Francisco offices, and later with other prestigious acoustical consulting firms on the West Coast. He now heads his own independent practice in Oakland, California. Red first became interested in the history of architectural acoustics while working on a 1970's renovation of a lecture hall at the Harvard Graduate School of Design; this was originally the Fogg Museum Lecture Hall, whose "terrible acoustics" when the hall first opened in 1896 launched the career of Wallace Clement Sabine in architectural acoustics. In fact, the Sabine Centennial Symposium in 1994 was largely his idea, and he served as Technical Chair of the Symposium.

The Technical Committee on Architectural Acoustics will undoubtedly remain a focus of activity in architectural acoustics for the Society's next seventy-five years, both in promoting practical applications and in encouraging research. The future of TCAA and the Acoustical Society of America promises to be exciting!

K. Anthony Hoover, Chair
Technical Committee on Architectural Acoustics

The Flowering of Architectural Acoustics in the Twentieth Century

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Alameda, California

From its origin as the creative ability of the master builder who utilized natural resources to create human shelter, the profession of architecture has become a highly sophisticated discipline in which many specialized components are integrated to develop precise solutions to complex user requirements.

The growth of acoustics as an architectural discipline over the past century has been uneven, constantly adapting to changes in building methods and becoming gradually more refined. Much of this development in North America has taken place with the support and guidance of the Acoustical Society of America, which has provided a forum for ideas as well as a source of reference and investigation in acoustics. This paper reviews the major acoustical and scientific advances that have accompanied and contributed to its steady growth over the past 75 years. A summary of important events closely related to the activities of the Acoustical Society is followed by a review of some major elements of architectural acoustics.

Antecedents – Prior to 1929

The scientific understanding of architectural acoustics (i.e. relating to the built environment) in North America is generally acknowledged to have first coalesced in the work undertaken by Wallace Clement Sabine at Harvard University from 1895 to his death in 1919. Figure 1 shows the original lecture room at Harvard's Fogg Art Museum opened in 1985 with impossible acoustics. Sabine's assignment by the President of Harvard University was to determine corrective measures so that the room could be satisfactorily used for lectures. The studies Sabine undertook led to his lifelong career in acoustics.

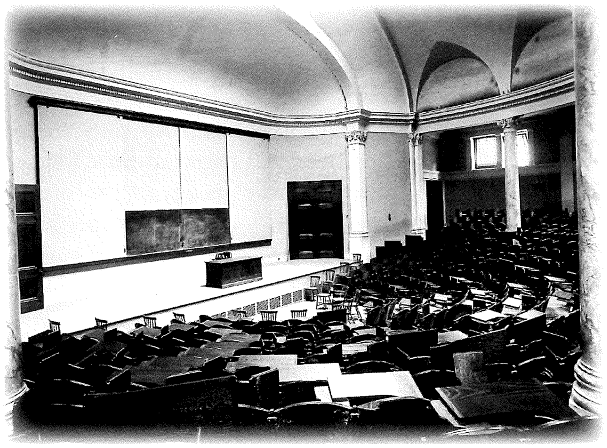

Figure 1. Lecture room of Fogg Art Museum, Harvard University, 1895.

In addition to his derivation of an empirical method for calculating reverberation time, one of Sabine's lasting monuments has been the Riverbank Acoustical Laboratory, which was built to his specifications and completed shortly before he died. His cousin, Paul Sabine became its first director and the initiator of a succession of acoustical explorations that established a testing methodology and developed standards for evaluation of acoustical properties of building materials.

Paul Sabine's work at Riverbank coincided with substantial advances in the understanding of acoustics, such as the concept of speech intelligibility by scientists at Bell Laboratories and the rising demands of new industries such as radio and "talking" motion pictures to which sound control was of particular importance. As interest grew in a greater understanding of acoustics, seven scientific leaders generally referred to as the National Research Council on Acoustics met in 1922 to review acoustical topics of common interest and to consider collaborative efforts to enable continued advances. Several of this group were to take part in the initial meeting in 1929 that marked the formation of the Acoustical Society of America. While the original intent of the founding group was to concentrate on architectural acoustics, in the words of Wallace Waterfall, the first secretary of the society "the desirability of enlarging the scope of the society so as to make it a more stable organization" soon became apparent. The wisdom of this decision has been reaffirmed frequently by continual and mutually beneficial interaction between the many acoustical disciplines that comprise the Society.

Thus, the Acoustical Society of America was launched in December 1928 with a ready-made agenda, as reflected by the wide selection of papers that were presented by the founding group. Its ties to the past are acknowledged in the nomination of Thomas A. Edison as its first honorary member, and its mandate "to increase and diffuse the knowledge of acoustics and promote its practical applications" continues to be fulfilled in the contributions of acoustical science to the world through architecture. As a result of steady scientific advances, several new disciplines have been added to the Society and the balance of activity has occasionally shifted from one discipline to another. However, it is clear that every advance for one has been an advance for the entire Society.

As noted by Wallace C. Sabine in his first presentation to the American Institute of Architects in 1898, it is necessary to consider not only the behavior of sound within the listening space, but also the control of intruding sounds from other sources. While noise analysis and measurement comprise a separate and complete discipline, the means by which unwanted sound intrusion must be controlled in any building is essentially architectural and should be considered in the total integration of acoustics into its architectural design. Any study of room acoustics without reference to background noise is thus incomplete. The first comprehensive work in North America, *Acoustics of Buildings* was written in 1923 by F.R.Watson, one of the leaders in the founding of the Society. This book, which went through three editions, would influence architectural acoustics for many years.

The First Decade – 1929 to 1939

It is difficult today for a newcomer to the Society to conceive the state of knowledge in 1929 regarding acoustics in the building industry. Having the ability to find the detailed sound transmission loss of a material or a wall system in a manufacturer's sales brochure, or to measure reverberation time by the use of a compact and fast electronic device, makes it hard to appreciate the dearth of information and the laborious measurement procedures that were necessary at the outset. For example, in describing the 1919 calibration of the Sound Chamber at Riverbank Laboratories (See figure 2), Paul Sabine noted "the final reverberation time taken for the residual sound from each organ pipe will be the mean of 1100 observations."

A trained observer enclosed in a wooden box, relying upon his ears to determine the duration of audible sound, carried out each single observation. Consequently, the development of some faster and more precise means of sound measurement was crucial to the advancement of research in acoustics. Pioneering work in the 1920's had successfully bridged this gap to the extent that among the first papers presented to the Society in 1930 were several giving the results of noise surveys, while others described progress in the development of better microphones, acoustic filters and subjective evaluation of loudness.

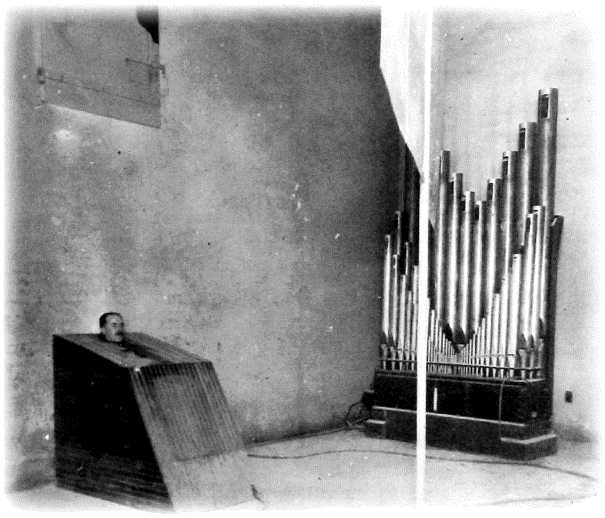

Figure 2. Sound chamber at Riverbank Acoustical Laboratories for conducting sound absorption tests.

The early work of the Society not only continued what had gone before but significantly expanded, and also coordinated and publicized these achievements to the general public. This is clearly emphasized by V.O. Knudsen, another of the founders and author of an important book, *Architectural Acoustics* in 1932, in his 1954 paper on the 25th anniversary of the Society. This paper summarizes the growth of the acoustical materials industry in response to new research information and the resulting demands for acoustical improvements. For probably the very first time, the acoustical character of the building was becoming widely recognized in the building professions and by the general public as something that could be controlled. Why this simple fact is still so difficult to incorporate in the design of most buildings is an anomaly whose hope of eradication requires constant efforts in architectural education.

By the end of the first decade of the Society, which coincided with the beginning of the second World War, the collaborative efforts of research scientists, acoustical product suppliers and academics had laid an effective foundation in the development of criteria for satisfactory use of architectural spaces, of methods for measuring the properties of materials, and of standards against which these properties could be evaluated. The acoustical testing laboratories at Riverbank and the National Bureau of Standards had surmounted early differences and had collaborated with other commercial laboratories in establishing reliable procedures for testing and reporting.

The development of laboratory facilities was very costly because of their size, complex construction and general unwieldiness of use. The reverberation chamber had already been well resolved by the Sabines. Nevertheless, the attainment of a space in which a product could be tested without interference from noise or from internal sound reflections—the anechoic chamber—enabled much more testing to be done under precisely controlled conditions. This knowledge was further expanded in the design of recording and film studios and, to some extent, in auditoria. The primary difference here was that while the studios were left entirely to the acoustical designers, most auditorium design was still largely controlled by the architect with acoustics as but one element to be considered.

In the search for materials that combined sound absorption with durability and a satisfactory appearance a wide range of materials was tested and marketed. A special symposium on sound absorption coefficients took place in 1939, and the major testing facilities collaborated by comparing test methods and the results of measurements. Several of these early materials have survived to become standard construction elements, meeting health and fire safety standards in addition to other architectural requirements, as well as having superior absorptive properties. However, a prescient question raised in at least one paper presented in 1930 asked if acoustical materials could be a health risk. It would take many years of investigation before asbestos, widely used as an excellent acoustical absorber and a fire resistant covering was finally banned from all use in buildings.

Around 1939 the subject index of the *Journal of the Acoustical Society* records two distinct phenomena – the obituaries of several of the founding members of the Society, and the appearance of a new generation who would become the leaders in architectural acoustics. The nature of acoustic research also shifted from basic measurements of materials and spaces to more complex studies, both empirical and theoretical, indicating the advancing sophistication of methods and instruments for analysis. Apart from studio work relatively little attention was given to the use of amplified sound, although the design of microphones and loudspeakers persisted as a vigorous field of study throughout the late 1920's and 1930's.

World War II and Post-War Years – 1940-1948

Following a decade of vigorous growth and research, with limited but continuing international exchanges, the years from 1940 to around 1948 are notable for the lack of emphasis on public spaces such as auditoria and for the substantial level of effort directed to better understanding of building materials. Particular attention was paid to testing methods and facilities, some of which may have had special application in wartime. Detailed studies and measurements of normal modes of vibration in spaces of various shapes and the effects of surface modulation and placement of absorbing materials contributed to the understanding that would be utilized in the design of new spaces for music listening and other acoustically-sensitive spaces in the years ahead.

Studies presented on acoustical materials included detailed testing of many proprietary sound absorbing products, and the performance of spaced absorbers and polycylindrical diffusers. Other uses of sound absorbers were explored for lining of ducts, aircraft engine test cells, anechoic chambers and for noise control in factories. Several references include studies of existing auditoria and broadcast studios and re-examination of criteria for acoustical design.

A pronounced shift in emphasis occurred around 1948 as the resources that had been focused on war-related activities began to address the long-delayed needs of commercial and institutional facilities, ranging from schools and hospitals to entertainment. An international conference on acoustics in 1948 was the harbinger of the succession of events that have created a rich exchange of information worldwide for the past half-century. In this respect the Society has contributed substantially and in return has received much support and recognition from scientists in other countries. A major accomplishment has been the formalization of joint conferences, in which regular meetings of the Society are combined with meetings of other societies, and the creation of closely related scientific organizations dedicated to continuing liaison throughout the world.

Post-War Expansion

The combination of the pent-up demand for new facilities of every type with the release of industrial capacity from wartime constraints created an exceptional opportunity for architectural advances beginning in the late 1940's. In every conceivable aspect of building design new ideas and needs called for a break with the traditional prewar rules for building. This is seen most dramatically in the rebirth of the office building as a metal and glass structure with complete air conditioning and lightweight, demountable partitions. Each element of this new construction promised substantial benefits and, with them, created difficulties that had not been encountered in the older structures.

In the United States, a focal point of both the new architecture and the new internationalism was manifested in the United Nations Headquarters in New York. This was conceived as an open forum for the world's leaders, with comparable facilities to house the secretariat required to control this vast operation. In looking for new ways to address the many acoustical problems posed by this complex, the architect/engineering team entrusted the acoustical design to two professors of physics, both active members of the Acoustical Society. The consulting firm of Bolt and Beranek, later Bolt Beranek and Newman (BBN) was thus created to meet this need (See figure 3).

Here was something new to the acoustical profession, a single company that integrated many diverse disciplines to form a well-balanced team capable of developing design criteria, of inventing new ways of analyzing sound and vibration, and of translating these into a successful design for a working building. The results of this collaboration can still be seen in such everyday design tools as Noise Criteria, in design manuals for quieting air conditioning systems and in perhaps thousands of auditoria. Former members of this group have spread the team approach to acoustical consulting throughout the industrialized world.

The academic ties of the principals—primarily with the Massachusetts Institute of Technology—formed an important element in the growth and endurance of the tradition created by BBN. Many members of the group have taught in architectural and engineering schools in an attempt to spread the understanding of acoustics as a basic element of successful building design. A committee established in the name of founding partner Robert B. Newman, now administered by the Technical Committee on Architectural Acoustics, presents industry-sponsored awards for outstanding work in acoustics by architecture students at over 50 universities in addition to research grants in architectural education.

Figure 4 is an example of a successful creative collaboration between architect, acoustical consultant and artist encouraged by BBN consultants. BBN was commissioned to investigate potential echo and poor sound distribution problems in a new large multi-use auditorium under construction in Caracas, Venezuela. The architect who was a personal friend of the famous sculptor Alexander Calder asked that BBN work with him to produce a striking design for the suspended ceiling and side wall sound reflective panels. These panels were dubbed "Stabiles" as contrasted with Calder's widely known "Mobiles."

A less-well remembered product of the BBN group was a detailed analysis of speech privacy in buildings, published in the *Journal of the Acoustical Society* in 1962, that responded to the many challenges created by new

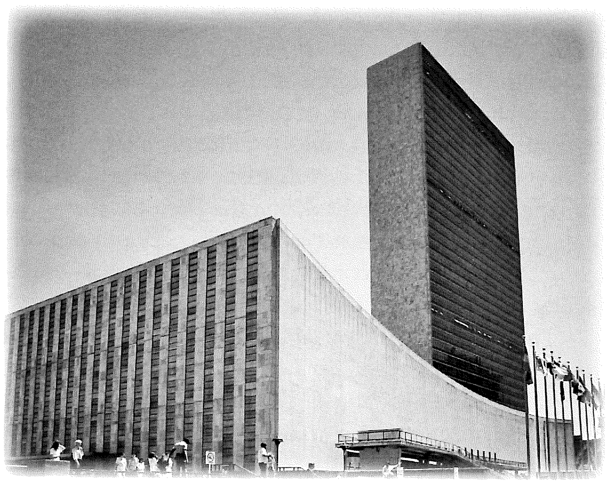

Figure 3. General Assembly, United Nations Headquarters, New York.

Figure 4. Aula Magna, University of Caracas, Venezuela.

building methods. In place of masonry office buildings with plaster or masonry partitions, and relying upon operable windows for natural ventilation, the emphasis had shifted to fully enclosed buildings with complete air conditioning systems, lightweight acoustical ceilings and demountable partitions. This concept was eventually to permeate the entire building industry, creating problems of sound transmission, lack of privacy and noise from ventilation systems that had never been encountered before. As such building systems have evolved over time they have continued to be important topics for research and presentations at Society meetings.

From this beginning emerged the concept of sound masking in which the background noise level is closely controlled to enhance speech privacy. This control technique has become of greater importance as economic/architectural pressures have prompted the trend to open-plan offices and the introduction of variable air volume (VAV) ventilation systems that typically allow a variation in background noise level of 10 to 12 decibels, depending on heating/cooling requirements. Multi-dimensional design issues of this type have formed the basis for much interaction between the Acoustical Society and other concerned engineering and standards organizations.

Late Twentieth-Century Developments

It is important to remember that the design of buildings is a rapidly evolving process requiring constant attention to and rethinking of acoustical concerns. While the commercial office building was probably the most dramatic example of radical design change, practically every other building type in North America has also been influenced by the shift from craftsman-built to at least partially prefabricated construction systems that have been inspired by the example of the aircraft and automobile industries. The parallel however is an imperfect one in many ways because, while cars and aircraft are mostly mass-produced, buildings tend to be one of a kind using traditional materials and thus still entail some level of hand craftsmanship. In addition, the use of high-strength lightweight construction with closely controlled tolerances, which is well suited to these other industries—and incidentally to design for seismic zones—is often entirely inappropriate for control of sound leaks and footfall impacts. Special sessions for discussion of such topics are a staple element of the twice-yearly Society meetings.

The Acoustical Society has been in the forefront of standards development for control of intruding noise in dwellings and special-use facilities such as hospitals and schools. However, in most cases the building requirements are mandated by building codes or other regulations that may tend to dilute the acoustical requirements. One recent noteworthy achievement that was strongly supported by the Acoustical Society has been the successful completion of a new national standard for acoustics of classrooms. It is largely because of a dedicated working group with exceptional leadership by Acoustical Society members that the standard was adopted in the face of strong opposition from some building industries. The new standard is voluntary but it is anticipated that school boards will recognize its benefits and adopt it as a model for future school development.

It should be expected that the evolution of acoustical consulting to adapt to new situations will continue because of the constant economic pressures on building construction that lead to design innovations with profound acoustical implications. Two examples of this change are the open-plan school and the development of rooftop air conditioning units.

The open-plan school concept was undoubtedly derived from the open-plan office concept that became fashionable in the late 1960's and 1970's because of its proponents' claims of increased work efficiency coupled with significant savings in office area. The acoustical implications of this radical change in office design were significant and were the subject of special sessions in which methods for evaluation of speech privacy and establishment of design criteria were debated at length. However, when viewed in terms of the 1962 study on speech privacy in buildings it was apparent from the outset that acoustical conditions in the open-plan office were marginal at best. While special partition and furniture systems have been developed for the ubiquitous office "cubicle," in recent years the lack of privacy is beginning to be viewed as actually detrimental to work efficiency.

The life span of the open-plan school was much shorter than its office counterpart because the inability of teachers to command the attention of pupils in the midst of constant distraction from their surroundings quickly resulted in parental demands to return to the formal classroom. This particular digression was widely criticized by members of the Society who were called on to provide consulting advice. However, the architectural concept had to run its course before its profound limitations were absorbed by school boards and designers. This was a particularly unfortunate development because the cost of returning such facilities to a more traditional configuration is usually very high.

The development of rooftop air conditioning units was also spurred by economic pressures. In a single drastic step, a costly mechanical equipment room accommodating the traditional site-built cooling and air distribution systems was replaced by a factory-assembled air handling and refrigeration unit, in some cases the size of a railroad box-car. Requiring few duct or piping connections, and often with little or no ductwork, these rooftop units continue to compete successfully against traditional systems whenever cost is the only criterion. Unfortunately, they are frequently a significant source of noise and vibration and so are ill suited for facilities where a controlled background noise level is a requirement or where neighbors may be affected. As with the open-plan office, techniques for adapting such systems to noise-sensitive facilities have been a feature of special sessions within the Society and in joint meetings with other societies.

A still more recent building trend has been the successful growth of the "design-build" concept. This has had special appeal for building owners because of potentially lower costs and the simplicity of dealing with a single entity rather than having a design team that is independent of the builder. While successful examples of the design-build approach are widely claimed in the realms of commercial, academic and office buildings, it often places all decisions in the hands of the builder without an independent check on the final results. This is generally not a favourable situation for acoustically-sensitive occupancies where attention to details of construction are important. The role of the Society in such instances has become that of a vitally important forum in which members have the opportunity, formally or informally, to discuss possible ways of ensuring a satisfactory acoustical outcome.

Consulting for the Performing Arts

Probably more than any other building type the concern for acoustical quality in performing arts facilities is well understood by even the general public and, indeed, it is still considered by many architects and builders to be the only building type that requires acoustical consultation. In this context the Acoustical Society has fulfilled several roles: first as a forum for discussion and debate of criteria and of the individual elements that combine to form a performance facility, then as a vehicle for scholarly examination of existing spaces and design parameters, and finally as a catalyst for the dissemination of information to the general public.

Figure 5 is an interior view of McDermott Hall at the Meyerson Symphony Center in Dallas, Texas. This hall is an example of a contemporary concert hall combining the classical "shoe box" acoustical attributes found in halls like Boston Symphony Hall with large reverberation chambers and massive adjustable height ceiling elements to create variable acoustical environments for music performance. Sabine Medalist, Russell Johnson of Artec Consultants has pioneered successful hall designs of this type throughout the world.

Many special sessions have been devoted to performing arts facilities and related building types. The Concert Hall Research Group, an informal committee under the aegis of the Technical Committee on Architectural Acoustics, recently completed its second summer workshop devoted to further examination of room acoustics parameters and standardization of acoustic terminology and measurements. In recognition of past achievements, a special symposium to celebrate the centennial of Wallace Clement Sabine's seminal work on acoustics was held in Cambridge, Massachusetts in 1994. This event, which attracted leaders in room acoustics from all over the world, included a concert at Sabine's Boston Symphony Hall and meetings in some of the spaces that he studied prior to 1898. Such activities contribute to improved understanding of acoustic terminology and criteria by scientists and consultants. They also tend to enhance broader public awareness of the achievements of the Acoustical Society and to strengthen the often-tenuous ties between acoustic research and the performing arts.

One particularly significant undertaking of the Technical Committee on Architectural Acoustics was the 1982 publication of *Halls for Music Performance*, which comprised a series of posters prepared by individual consultants and presented in a poster session at a regular Society meeting. The poster session was complemented by special sessions devoted to music performance spaces and presentations by music critics and architects. This book, which is still in print, paved the way for a series of successful publications on various aspects of acoustics for performance spaces, including an updated study to

Figure 5. McDermott Hall, Meyerson Symphony Center, Dallas.

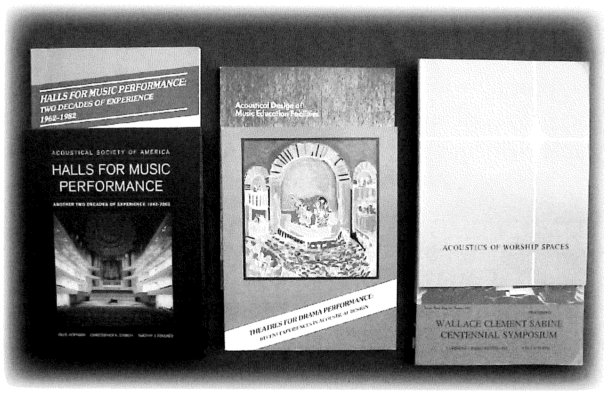

Figure 6. Recent publications on Architectural Acoustics.

reflect the past 20 years of concert hall design.

One book was devoted to places of worship, which, upon close examination, present all of the acoustical challenges of an auditorium, often with the added requirement of stringent liturgical design constraints. Others in this series documented professional experience in the design of theatres and music education facilities. The availability of these books has enabled many architects and their clients to become more closely acquainted with the process of designing a successful facility and has facilitated communication between architect and consultant. They have thus perhaps been a useful influence against the inevitable pressure in the construction industry to measure everything against the initial cost of the building (See figure 6).

The Society has invested a great deal in the re-publication of outstanding books that had been discontinued, including Wallace Clement Sabine's *Collected Papers on Acoustics* describing his initial experiments in room acoustics, which was published posthumously in 1922. Of particular significance for music, the Society has also undertaken the reissue of Leo Beranek's 1962 publication *Music, Acoustics and Architecture* which by any yardstick is the most influential work ever compiled on the subject of music performance spaces. A successor volume has been completely sold out and has been updated. Dr. Beranek has been an active participant in the affairs of the Society and has consistently made technical contributions spanning all aspects of architectural acoustics for more than 60 years. It is entirely fitting that a special session at the 75th Anniversary meeting of the Acoustical Society will honor him.

The Beginning of a New Century

In the years between the first and second poster sessions on Halls for Music Performance a quiet revolution has occurred that has drastically changed the process of acoustical analysis and design. Computer techniques for evaluation of acoustical environments have greatly increased the amount of information that can be elicited from even simple measurements. Consequently, new acoustical dimensions have been defined which have already added new information on existing halls and which may further help to correlate measured data with listener judgments.

More significantly, this new technology allows for simulation of the acoustical characteristics, including aural simulation, of performance spaces yet unbuilt. It also creates the ability to communicate instantaneously with people in other parts of the world, allowing the interchange of information and ideas on a scale never before possible. The Acoustical Society has been fortunate in having attracted members from around the world and in having many of these members attend meetings occasionally. It is hoped that the new-found internet communication link will enable members overseas to play an even greater role in the working of the Society and to possibly collaborate in the establishment of a new international organization, perhaps with the Acoustical Society of America as its nucleus, whose objective is "to increase and diffuse the knowledge of acoustics and promote its practical applications throughout the world."

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Architectural Acoustics Timeline

1900 •••• Opening of Boston Symphony Hall, the world's first hall to be designed using architectural acoustics principles, and still considered to be one of the world's greatest halls. Wallace Clement Sabine was the acoustical consultant, basing his recommendations on his pioneering acoustics research. He is often credited with transforming the understanding of acoustics from a mysterious art to a respected discipline.

1919 •••• Opening of Riverbank Acoustical Laboratory, Geneva, IL, the first commercial laboratory for testing acoustical properties of building materials. Riverbank was designed by Wallace Sabine, and subsequently directed for several decades by Wallace's cousin, Paul Sabine and son, Hale Sabine.

1927 •••• World's first talking movie, "The Jazz Singer," which created the need for proper microphones, sound stages, recording and playback systems, and production and presentation facilities.

1929 •••• Founding of the Acoustical Society of America, which provided a forum for professionals working in acoustics, including a large and growing contingent in Architectural Acoustics. Subsequent professional societies included the Audio Engineering Society (founded 1948), the National Council of Acoustical Consultants (founded 1962), and the Institute of Noise Control Engineering (founded 1970).

1941-45 World War II necessitated solutions for communications, noise control, underwater sound propagation and detection, and many military applications which mobilized a tremendous pool of talent, and eventually led to countless applications of acoustical technology.

1948 •••• Founding of Bolt Beranek and Newman, Inc. (BBN), the first acoustical consulting firm, responding to a variety of acoustical concerns for the new United Nations Headquarters in New York City. The roots of many acoustical consulting firms, research activities of all types, and even computer communication systems can be traced back to BBN.

1957 •••• Establishment of the Wallace C. Sabine Silver Medal, to be awarded by the ASA for outstanding contributions to the science of architectural acoustics.

1960 •••• Formal establishment of the Technical Committee on Architectural Acoustics.

1962 •••• Publication of *Music Acoustics and Architecture* (John Wiley & Sons), by Leo L. Beranek, the culmination of extensive research, studying 55 concert and opera halls throughout the world, and widely influencing the architectural acoustics community. It remains a fundamental resource for study and reference.

1982 •••• Publication of *Halls for Music Performance: Two Decades of Experience 1962-1982* (Acoustical Society of America), which pioneered a series of books based on poster sessions at ASA meetings, featuring particular building types.

Architectural Acoustics Timeline

***1989* ••••** Opening of McDermott Concert Hall, Dallas, TX, ranking among the world's great modern halls, combining classical shoebox design (similar to Boston Symphony Hall) with modern innovations, such as acoustical variability provided by large reverberation chambers and movable stage-ceiling canopy.

***1994* ••••** Wallace Sabine Centennial Symposium, held at MIT in conjunction with the 127th Meeting of ASA.

***2002* ••••** Approval of ANSI Standard-S12.60-2002, the "classroom acoustics standard," which provides criteria for proper listening conditions, developed by the TCAA Classroom Acoustics Working Group, based on decades of research and experience on speech intelligibility, absorption of materials, sound isolation, and HVAC and environmental noise control.

***2004* ••••** Today; Contemporary advances are often results of computer-aided modeling and auralization, firmly founded on the past century's experience, and promising almost unimaginable potential for future development, research, and technology.

Past and Present Chairs of the Technical Committee on Architectural Acoustics

1960-62	Jack B.C. Purcell
1962-64	Thomas D. Northwood
1964-66	Wayne Rudmose
1966-67	Robert W. Leonard
1967-68	William A. Jack
1968-71	Michael J. Kodaras
1971-74	Harold R. Mull
1974-77	William J. Cavanaugh
1977-80	Ludwig W. Sepmeyer
1980-83	David Lubman
1983-86	Alfred C. C. Warnock
1986-89	Ewart A. Wetherill
1989-92	Steven M. Brown
1992-95	Richard H. Talaske
1995-98	Dana S. Hougland
1998-01	Ronald R. Freiheit
2001-04	K. Anthony Hoover
2004-	Lily M. Wang

Recipients of the Wallace Clement Sabine Award

1957 - Vern O. Knudsen

1959 - Floyd Rowe Watson - For his pioneering research in architectural acoustics which established criteria for acceptable reverberation in auditoria and stimulated the development of widely used acoustical materials, and for his services as Editor of the Journal. (Abstracted)

1961 - Leo L. Beranek - For internationally recognized achievements in all phases of architectural acoustics, and his publications on acoustical measurements, anechoic chambers, acoustic materials, building structures, noise control, psychoacoustic criteria, sound systems, broadcast studios, assembly rooms, and the world's great concert halls. (Abstracted)

1964 - Erwin Meyer - For internationally recognized contributions to all aspects of architectural acoustics and his published works on sound propagation and diffusion in concert halls, theatres, and radio studios; investigations on sound transmission and insulation in buildings; and the design of anechoic and reverberation chambers for both acoustic and electromagnetic waves. (Abstracted)

1968 - Hale J. Sabine - For his contributions to the theory and practice of architectural acoustics, for his studies of the theory of sound-absorbing materials, and particularly, for his vigorous leadership in the development of standard procedures for measuring the acoustical properties of materials.

1974 - Lothar W. Cremer - For original and enduring contributions to the theory and practice of musical acoustics and acoustics in buildings, and for teaching these matters to the rest of us with clarity, giving inspiration in person and in print.

1979 - Cyril M. Harris - For his contributions to the theory of room acoustics and for the application of these principles to the acoustical design of concert halls, opera houses, and theatres.

1982 - Thomas D. Northwood - For important contributions to the theory and measurement of sound transmission in buildings and of the sound absorption of acoustical materials, for the development of acoustical standards, and for the general furtherance of architectural acoustics.

1990 - Richard V. Waterhouse - For fundamental contributions to the understanding of sound fields in rooms.

1995 - A. Harold Marshall - For contributions to the field of architectural acoustics, particularly for the understanding and design of concert halls.

1997 - Russell Johnson - For contributions to the understanding of the acoustics of performance spaces and the design of concert halls, theaters and opera houses throughout the world.

2002 – Alfred C.C. Warnock - For broad contributions to architectural acoustics, especially on noise control in buildings and development of technical standards.

Recipient of the Silver Medal in Architectural Acoustics

1976 - Theodore J. Schultz - For significant contributions to the understanding of acoustical design parameters and criteria for concert halls and other music performance spaces.

Recipients of Interdisciplinary Silver Medals

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Psychological and Physiological Acoustics, Architectural Acoustics and Noise

1999 - Jens P. Blauert - For contributions to sound localization, concert hall acoustics, signal processing, and acoustics standards.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Musical Acoustics, Psychological and Physiological Acoustics and Architectural Acoustics

2001 - William M. Hartmann - For research and education in psychological and physiological acoustics, architectural acoustics, musical acoustics, and signal processing.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Noise and Architectural Acoustics

2004 - David Lubman - For work in noise and standards and for contributions to architectural and archeological acoustics.

Vern O. Knudsen Distinguished Lectures

Designing for the performing arts: An historical overview. Michael Forsyth, November 1987, Miami, Florida

The inner universe: A multidisciplinary approach to the acoustics of concert halls. Yoichi Ando, November 1988, Honolulu, Hawaii

Reflections on the acoustical design of halls for music performance. Russell Johnson, November 1990, San Diego, California

Concert hall acoustics–1991. Leo L. Beranek, May 1991, Baltimore, Maryland

Quantifying musical acoustics through audibility. David H. Griesinger, October 1993, Denver, Colorado

Innovation in acoustical design. A. Harold Marshall, November 1995, St. Louis, Missouri

Variance and invariants in room acoustics: A random walk through reverberant fields. David Lubman, May 1996, Indianapolis, Indiana

Concert hall design: A consultant's perspective and retrospective. J. Christopher Jaffe, December 1997, San Diego, California

The compleat concert hall: A century of acoustics development and its lessons for the design of concert halls. R. Lawrence Kirkegaard, November 1999, Columbus, Ohio

Acoustic concerns related to multi-cultural societies. Anders Chr. Gade, December 2001, Fort Lauderdale, Florida

Rorert Bradford Newman Student Award Fund

The Newman Student Award Fund was launched in 1984 shortly after the untimely death of Professor Robert Newman, a gifted teacher of architectural acoustics at both the Harvard Graduate School of Design and the MIT School of Architecture, and partner in the internationally prestigious consulting and research firm, Bolt Beranek and Newman, Inc. The Fund supports teaching and research in architectural acoustics education, and the recognition of both students and teachers who demonstrate excellence in the application of acoustical principles in design, research and teaching. The Fund's activities are administered through a sub-committee of the Technical Committee on Architectural Acoustics (TCAA). Additional information is available on the Fund's website [www.newmanfund.org]. Three principal activities are:

Robert Bradford Newman Student Medals

Newman Medals are awarded annually to graduating students at qualified schools of architecture, engineering and music that teach courses in architectural acoustics and have opportunities for the students to apply that knowledge in senior year design, research or degree thesis projects. Through 2003, 157 Newman Medals have been awarded to students at some 40 universities throughout the world. Many Newman Medalists have gone on to rewarding careers in the building professions as well as in teaching, research and consulting in acoustics. Three past medalists serve on the TCAA Newman Fund Advisory Committee. Besides the Newman Medal, students receive a small stipend and copies of the ASA poster books that have been produced by TCAA from poster sessions on various building types at past ASA meetings.

Theodore John Schultz Grants

Through the generosity of friends and colleagues of the late Dr. Theodore Schultz, noted researcher in architectural acoustics and a founding member of the Fund's Advisory Committee, as well as from continuing contributions from ASA members, the Newman Fund administers and supports the Theodore Schultz Grant program. The Grants provide partial support for the development of improved teaching methods, new curricula, improved teaching aids or targeted research projects in architectural acoustics education.

To date eight Schultz Grants have been awarded as follows:

1990 - Gary W. Siebein, "Demonstration of Basic Acoustical Principles Using Scale Models" (36 min. video tape)

1992 - K. Anthony Hoover, "An Appreciation of Acoustics" (paperback text developed for teaching acoustics to music students)

1994 - M. David Egan, "Architectural Acoustics Workbook" (paperback text developed for students studying architectural acoustics)

1996 - Gary W. Siebein, "Acoustical History of Theaters and Concert Halls" (book, slides and audio tape)

1998 - Neil Thompson Shade, "Sound System Design Guide" (paperback text developed to help students understand the basics of integrating sound reinforcement systems with architectural design)

2000 - Lily Wang, "A Web Based Guide to Concert Hall Acoustics" (CD ROM)

2002 - Jian Kang, "Computer Tools for Architectural Acoustics Education" (in preparation)

2002 - James Cowan, "Model On-Line Basic Course in Architectural Acoustics" (in preparation)

Wenger Prizes for Student Design Competitions

Student design competitions have been periodically scheduled at TCAA sessions during ASA meetings since the early 1990's. Through the continuing generosity of the Wenger Corporation, monetary prizes are awarded for student projects which demonstrate excellence in the application of acoustical design principles. The competitions are judged by juries of professionals including architects, consulting engineers, acoustical consultants, educators and researchers, and the winning projects are displayed at the ASA meetings. Archived results for all previously held competitions may be viewed on the Newman Fund website [www.newmanfund.org].

The most recent Student Design Competition was held at the 145th Meeting of the Society in April 2003, in Nashville, Tennessee. As with earlier competitions, this was sponsored and administered by the TCAA Sub-committee on Student Design Competitions chaired by Prof. Robert Coffeen and supported by the National Council of Acoustical Consultants and the Newman Student Award Fund. There were sixteen submissions from students or student teams from nine universities and the design program involved acoustical applications for a music education building at a small liberal arts college. The jury awarded the following honors:

FIRST HONORS [$1000. Wenger Prize]

Brendon Campbell, University of Arizona
Faculty Advisor, Prof. William Bickell.

FOUR COMMENDATIONS [$500. Wenger Prizes]

David Fanning, Nicholl Campbell and Weifgang Wang, Rensselaer Polytechnic Institute.
Faculty Advisors, Profs. Yasushi Shimizu and Rendell Torres

Bill Elliott, Massachusetts Institute of Technology
Faculty Advisor, Prof. Bill Hubbard

Robert E. Lee, University of Kansas
Faculty Advisor, Prof. Robert Coffeen

Geoffrey Sparks, Matthew Hall and Joshua Bonati, Johns Hopkins University.
Faculty Advisor, Prof. Neil Thompson Shade

The 2004 Student Design Competition is scheduled for the 147th ASA "75th Anniversary" Meeting in New York City, May 2004, and the winning projects and student teams may be viewed on the Newman Fund's website shortly thereafter.

Special Symposia And Workshops Sponsored By TCAA

WALLACE CLEMENT SABINE CENTENNIAL SYMPOSIUM, in conjunction with the 127th Meeting of the Acoustical Society of America, Massachusetts Institute of Technology, Cambridge, 5-7 June 1994. A report on this highly successful symposium organized and administered by TCAA appears in the Acoustical News USA section of JASA [J. Acoust. Soc. Am., Vol. 97, No. 3, March 1995]. In addition, the Symposium Proceedings are available on CD ROM from the ASA Bookstore.

1999 CONCERT HALL RESEARCH GROUP SUMMER INSTITUTE, August 29-September 1, 1999, Tanglewood, Lennox, Massachusetts, co-sponsored with TCAA, the National Council of Acoustical Consultants and the Newman Student Award Fund. This first-of-a-kind workshop for students and practicing acoustical consultants, architects and acoustical researchers is reported in the Acoustical News Section of JASA. [J. Acoust. Soc. Am., Nov. 1999].

2003 CONCERT HALL RESEARCH GROUP SUMMER INSTTUTE, August 11-14, 2003, Saratoga Performing Arts Center, Saratoga Springs, New York, co-sponsored by TCAA, the National Council of Acoustical Consultants and the Newman Student Award Fund. This second institute doubled the attendance of partial and full scholarship students, and focused on the application of state-of-the-art knowledge to create successful concert hall and musical theatre designs. The full report on the 2003 institute will appear in a future issue of JASA.

ASA at 75

Chapter 7

Biomedical Ultrasound/Bioresponse to Vibration

Robin O. Cleveland, Chapter Editor

History Lectures, Donald W. Baker & Janet M. Weisenberger

Biomedical Ultrasound/Bioresponse to Vibration

Introduction

The Biomedical Ultrasound/Bioresponse to Vibration Technical Committee was formed in 1984 as the Biological Response to Vibration Technical Committee. The early scope of the Technical Committee addressed the effects of vibration on the body and touch as communication sense and the effects of infrasound and ultrasound. The name change, adopted in 1996, reflected the enormous growth in the use of ultrasound in biomedical applications both for therapeutic uses (temporary or permanent alteration of tissue) and for diagnostic imaging inside the body. Currently the primary focus of the technical committee is biomedical ultrasound, however, as Jan Weisenberger notes in her chapter it is possible that the field of Bioresponse to Vibration will "again call the ASA its scientific home."

The BU/BV TC has seen strong growth in the last decade. Attendance at the TC meeting (normally held on Thursday evenings) is between 30 and 40. Over the past few years BU/BV has typically sponsored or cosponsored four special sessions at each meeting. The BU/BV is multi-disciplinary committee and has co-sponsored special sessions numerous other TCs including: Physical Acoustics, Signal Processing in Acoustics, Engineering Acoustics, Musical Acoustics as well as the Committee on Standards. An event that the BU/BV TC has implemented, initiated by the immediate past Chair E. Carr Everbach, is the Topical Meeting that is held annually at the Fall ASA Meeting. Topical Meetings are one-day events that focus on a particular topic by bringing numerous experts together (many from outside the Society) to present the state-of-the-art through a series of lectures and panel discussions. These Topical Meetings have provided a wonderful forum for frank debate on the important issues and problems in biomedical ultrasound.

Looking forward, the growth potential of ultrasound in the biomedical field appears to be enormous. There are opportunities and challenges in both imaging and therapy, which are touched on below. Perhaps the most exciting avenue is the combination of ultrasound imaging and ultrasound therapy as an integrated tool for diagnosis and treatment. But as scientific and technological barriers are overcome, as yet undiscovered applications will avail themselves.

In the imaging field, there has been a steady improvement in the quality of diagnostic ultrasound imaging and in the last two years there have been two groundbreaking commercial developments: 1) the advent of real-time 3D imaging capability and 2) hand-held ultrasound scanners. Both of these developments will spawn exciting new opportunitites such as ultrasound-guided surgery (surgeons can carry out procedures without requiring optical access), and remote-telemedicine (portable ultrasound scanners can go anywhere even into space). One challenge facing the ultrasound imaging community is that diagnostic ultrasound is not yet able to fully characterize the state of the tissue that it images. For example, ultrasound can detect cysts in many organs but it cannot discriminate between a benign tumor and a malignant tumor. A second example is intravascular ultrasound, which can be used to determine plaque burden in arteries but cannot yet differentiate stable from vulnerable plaque. Although measurements on isolated tissue samples show that acoustic properties (e.g., attenutation and backscatter) do correlate with pathology, implementing algorithms to obtain this information on a clinical scanner is challenging. A second challenge is removing artifacts associated with aberration due to inhomogeneities in the tissue. Despite much research, in many cases clinical images are still fraught with aberration problems and associated artifacts.

The therapeutic use of ultrasound has blossomed in the last 20 years. The earliest work in biomedical ultrasound was the development of early therapeutic devices in 1930s, however, daunting technical challenges sidelined this effort. Technology is now catching up and the promise of using ultrasound as a noninvasive surgical tool has finally come to fruition; this is perhaps the most exciting area in biomedical ultrasound today. Already, shock wave lithotripsy is the predominant surgical option for the treatment of kidney stones. Shock waves also appear to be effective at helping heal broken bones and even reducing pain in joints. Currently, the most exciting developments involve the use of high intensity focused ultrasound (HIFU) to effect focused ultrasound surgery (FUS)—a process where focused ultrasound is used to selectively heat or ablate tissue so that cells can be destroyed in a localized region while the nearby cells remain viable. A number of clinical devices, either FDA (Food and Drug Administration) approved or in the final stages of development, exist for: treating glaucoma, fighting cancer (in many organs), and controlling internal bleeding. New applications are constantly being presented at ASA meetings. Advanced therapies such as puncturing holes in the heart, promoting localized drug delivery, and even carrying out brain surgery through an intact skull appear to be feasible and safe with ultrasound.

Within the next decade it is inevitable that ultrasound will be packaged as a complete solution to a host of medical conditions. Diagnostic ultrasound will be used to image the body and diagnose problems, therapeutic ultrasound will then be used to treat the problems, with the treatment monitored and controlled using ultrasound imaging, and then diagnostic ultrasound will be used to ensure that the treatment was successful. This will all have been done non-invasively and with little or no pain to the patient.

The Acoustical Society of America maintains a strong presence in the field of biomedical ultrasound despite formidable competition from other societies. The *Journal* has recently appointed a new Associate Editor in the field of ultrasound imaging in response to the increase in submissions in that area. The BU/BV Technical Committee is active and ensures the ASA has a high profile in this field. The TC has enormous potential for further growth as the field of biomedical ultrasound continues its expansion. The TC consists of an energized and enthusiastic group of people with a variety of backgrounds who can facilitate this growth. The Biomedical Ultrasound/Bioresponse to Vibration Technical Committee will serve the Society well in this evolving area that directly impacts greater society.

Robin O. Cleveland, Chair
Technical Committee on Biomedical
Ultrasound/Bioresponse to Vibration

Origins and Evolution of the Developments Which Led to Echo-Doppler Duplex Color Flow Diagnostic Methodology

Donald W. Baker, University of Washington

Research efforts to develop instrumentation for animal physiologic research to better characterize the cardiovascular system in engineering ultimately evolved for application on man and led to the Pacific Northwest becoming the current foci of the medical ultrasound industry. This presentation will trace the events from my being a student in Electrical Engineering to heading the Cardiovascular Instrument Development Program originally begun by Dr. Robert Rushmer in 1957. This narrative will range from early instruments for measurements on research animals to their development for noninvasive use on man. The instruments covered will be the transit time flow-meter, CW Doppler, pulsed Doppler, duplex scanner, and color flow mapping. The role of collaboration in both engineering many specialties of medicine will be demonstrated. Many of the original instruments have been in the Smithsonian Museum of American History and will in the near future be on permanent exhibit there.

For more information on the history of ultrasound use for medical imaging visit
http://www.ob-ultrasound.net/history.html

History of Bioresponse to Vibration in the Acoustical Society of America

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The Broad Definition of "Acoustics"

A dictionary definition of the portion of the energy spectrum defined as "acoustic" stimulation includes a range of frequencies audible to the human ear, commonly stipulated to be from 20-20,000 Hz. However, the breadth of technical areas addressed within the Acoustical Society has included work in frequency regions at the lower bounds of this audible range, in regions called "vibration." Similarly, work with stimulation in frequency regions well above the audible range (in fact, in the MHz range), commonly referred to as "ultrasound," has also become a focus of interest within the ASA. The human response to stimulation in these upper and lower regions became the purview of the Technical Committee on Bioresponse to Vibration/Biomedical Ultrasound, which was initially formed in 1984. The goal of this chapter is to provide historical context for scientific contributions made by researchers studying the human response to the lower region, vibration. It is not possible in limited space to provide a truly comprehensive history; rather, this chapter attempts to highlight major developments and focuses on areas in which considerable activity occurred in the Acoustical Society. The first part of this story takes place largely outside the Acoustical Society of America, but is provided as part of the historical context.

Because of the wide range of stimuli to which receptors in the skin respond, including pressure, warmth, cold, and noxious stimulation, there has been considerable debate over the centuries on whether the sense of touch was a single sense, as first espoused by Aristotle, or instead comprised multiple senses. Weber (1826) noted that stimulation of the human skin surface could lead to sensations of location, pressure (or weight), and temperature, suggesting that receptors in the epidermis or dermis conveyed the neural impulses for such sensations (Boring, 1942). Although initial investigations searching for specific receptors to subserve these sensations were not successful, nonetheless von Frey in 1896, extending Müller's doctrine of specific nerve energies, argued for the notion of receptor specificity in tactile sensation. Twentieth-century researchers have provided support for this notion; indeed, it is now believed that there are multiple specialized receptors just for sensations of pressure and vibration, as described below.

The skin is the largest receptor surface in the body, occupying some 1.8 m2 (Sherrick and Cholewiak, 1986). There have been thorough studies of the response to skin indentation, documenting both detection threshold and spatial difference threshold across locations on the body surface (e.g., Weinstein, 1968; Stevens and Choo, 1996), indicating greater sensitivity on the hands and face than on the torso. However, a study by Nafe and Wagoner (1941) illustrates why vibration is an exemplary stimulus for the tactile sense. In their study of adaptation to pressure stimulation, Nafe and Wagoner found that a sensation of pressure is reported upon initial indentation of the skin surface, but that as the skin is further compressed, a point is reached where the skin is fully compressed and the pressure sensation disappears. Nafe and Wagoner referred to this loss of sensation as "stimulus failure," and argued that pressure sensations persist only for the time that the stimulus is actually moving into the skin surface, such that the response is based on the detection of movement velocity. When the velocity drops below some threshold value, the sensation of pressure disappears.

To obtain a more constant sensation of pressure at a particular skin location, what is needed is a stimulus that indents and withdraws repeatedly, such that there is always movement of the skin surface—in other words, vibration. Thus, vibration is a highly appropriate stimulus for the tactile system, and some skin receptors seem to be specialized for its detection. These are reviewed briefly below to provide a foundation for the studies described later in the chapter.

Brief Overview of Mechanoreceptor Physiology

Several different pressure-sensitive receptors in the epidermis and dermis, referred to as mechanoreceptors, have been identified. These include the Pacinian corpuscle, a large encapsulated receptor located in the dermis, which responds to vibration across a range of frequencies up to about 1000 Hz; the Meissner corpuscle, a more loosely encapsulated structure at the junction of dermis and epidermis, which is not differentially sensitive to vibration, but which has greater sensitivity than the Pacinian corpuscle to frequencies below 40 Hz; and the Merkel disk, also near the division between epidermis and dermis, which appears to have great spatial sensitivity but which also responds to vibratory inputs (for a review of receptor physiology, see Sherrick and Cholewiak, 1986).

Early Work in the Psychophysics of Vibratory Sensitivity

One early behavioral study of vibratory sensitivity was that of Knudsen (1928), who mapped detection thresholds as a function of vibratory frequency, reporting a U-shaped function with best thresholds in the region of about 250 Hz. This function was replicated by other researchers, as reported by Geldard (1941), and was later shown to mirror the sensitivity curve of the Pacinian corpuscle, as measured by a number of researchers in the early 1960s (see, e.g., Sato, 1961). The first comparison of vibrotactile thresholds with the response curve of the Pacinian corpuscle was published by Verrillo (1966). Other important early work was reported by Wilska (1954), who showed that vibration sensitivity was different across body sites, with the finger and facial regions showing greatest sensitivity.

Vibrotactile Psychophysics in the ASA

Perhaps because of the overlap in the range of frequencies for vibratory response with that for auditory response, a number of auditory researchers became interested in measuring sensitivity to vibration. Among these was von Békésy, who published work in vibrotactile psychophysics as early as 1939. In the late 1950s, he used pressure sensitivity on the forearm to model the phenomenon of traveling waves in the cochlea [J. Acoust. Soc. Am., 1955], and became interested in vibrotactile sensitivity of itself as an additional sensory modality that appeared to display his notion of "neural funneling." [J. Acoust. Soc. Am. 1958, 1959]. These papers were among the first in JASA to focus on vibratory sensitivity per se.

Other work soon followed, including that of Verrillo and his colleagues at the Institute for Sensory Research at Syracuse University. Verrillo's contributions to the psychophysics of vibrotaction cannot be overemphasized. His first JASA paper on the subject appeared in 1962. In the early 1960s, Verrillo and colleagues investigated a number of the variables that influenced measurement of the threshold for detection of vibration on the skin, including the size of the contactor, presence or absence of a surround, contact force, etc. These studies established that the tactile system shows spatial and temporal summation of stimulation in defined frequency regions. Threshold was found to be a U-shaped function, as noted above, but the threshold function shifted downward as the size of the contactor increased. This finding held true only for stimulation frequencies above about 40 Hz, however. At lower frequencies, increasing contactor size had no effect on threshold sensitivity. Anomalies such as this led Verrillo in 1968 to propose the "duplex mechanoreceptor hypothesis," in which he posited that there were two distinct classes of mechanoreceptors that governed detection of vibration. One class, which did not show spatial summation and was not differentially sensitive to stimulus frequency, governed detection for frequencies below 40 Hz; the other, which did demonstrate spatial summation, was responsible for detection for frequencies above 40 Hz. At that time, Verrillo asserted that the high-frequency, spatially summating mechanoreceptor was almost certainly the Pacinian corpuscle, but was less definite about the identity of the low-frequency system.

Work on the hypothesis continued, with a paper suggesting that there were actually three systems published in the 1970s, and culminated in the publication in JASA by Bolanowski et al. in 1988 of a now-classic paper that provided evidence for four different classes of mechanoreceptors. Bolanowski et al. brought together findings from mechanoreceptor physiology (response profile), temperature sensitivity, and behavioral studies to conclude that the U-shaped portion of the threshold curve was indeed attributable to the Pacinian corpuscle; he referred to the other three systems as NP (Non-Pacinian) I, II, and III. These mechanoreceptors are most likely the Meissner corpuscle, a small receptive field structure that responds in the range of 10 Hz and above, the Merkel disk, which responds best to lower frequencies (below 10 Hz), and a third, as-yet inconclusively identified receptor, possibly the Ruffini end organ, which responds to high frequencies but does not show the same degree of threshold sensitivity as the Pacinian corpuscle. The general notion of the model is that at threshold, the channel that is most sensitive will govern performance, but at suprathreshold levels, perception is jointly determined by the activity of all of the mechanoreceptors that respond to that frequency. Although considerable work has followed this initial paper in both psychophysics and physiology, the basic findings remain the best theory of mechanoreceptive function.

Many studies of vibrotactile perception have looked at standard sensory measures, such as frequency discrimination. Vibratory frequency is not well differentiated across much of the frequency range, as noted by Goff (1967). Although earlier work, going back to the early 1900s, suggested otherwise, these earlier studies did not control for the perceived intensity of sensation. Rothenberg et al. (1977) reported in JASA that frequency discrimination was also not uniform across body sites.

Regarding the perceived intensity, or loudness, of vibration, studies have indicated that there is considerable variation across frequency. Like the "equal loudness contours" reported for auditory stimuli, similar functions have been generated for vibrotactile stimuli by Verrillo et al. (1969). These follow closely the shape of the threshold function at low intensity levels, but are flatter across frequency at high levels, similar to comparable auditory curves. In the tactile case, it has been postulated that the flattening of the curves at high levels may reflect the contribution of additional mechanoreceptive channels to the overall percept.

Other issues of interest have included the response of the tactile system to masking stimulation, both simultaneous (Sherrick, 1964) and non-simultaneous (a series of papers by Gescheider et al., e.g., JASA, 1983, 1985, 1995). In Gescheider's work, temporal masking functions have been generated that follow the general form of those for audition (for detection, more forward than backward masking at the same temporal separation). Still other questions addressed in papers published in JASA have included the nature and time course of vibratory adaptation (Goble and Hollins, 1993, 1994); vibratory localization (Sherrick et al., 1990); and the response of the system to amplitude-modulated stimulation (Weisenberger, 1986).

Over this same period, several other lines of investigation that employed vibrotactile stimulation also appeared in JASA. Most of this work was of a more applied nature. Three specific areas that generated considerable activity in the Acoustical Society are described below.

Applications of Vibratory Stimulation

1. Assessment of damage from hand-arm vibration

An excellent tutorial paper was published in JASA in 1988 by William Taylor, entitled "Biological effects of the hand-arm vibration syndrome." In this article, Taylor describes the phenomenon originally known as "vibration white finger," or "Raynaud's phenomenon of occupational origin," but now referred to as "hand-arm vibration syndrome." According to Taylor, this syndrome was first described in workers in limestone quarries in Bedford, Indiana in the 1890s. These quarry workers used air hammers for many hours every day for stone cutting. Their symptoms were described as shrunken, whitened fingers, which were nonresponsive to cold, accompanied by numbness and clumsiness in movement. Between attacks, according to the early reports, the fingers were normal in appearance (Hamilton, 1918).

As industrial use of power tools expanded, the number of reported cases of hand-arm vibration syndrome continued to increase. By the 1960s, cases were reported in epidemiological surveys in North America, Japan, Europe, Korea, and Canada. Particularly susceptible occupations included riveters, grinders, and pneumatic drill operators, as well as chainsaw operators in the timber industry.

Clinical symptoms reported by patients in the early stages of hand-arm vibration syndrome include numbness and tingling of one or more fingers. In more advanced cases, periodic blanching of the fingers occurs with exposure to cold, and the damage extends from the fingertips down to the roots of the fingers. Continued vibration exposure leads to involvement of all of the fingers. Following an attack, the fingers often return to a brighter than normal red coloration, accompanied by pain. Eventually, these attacks can occur in both cold and warm temperatures. Other subjectively-reported symptoms include weakness in the affected hand, loss of manual dexterity, and in the most advanced cases, to tissue necrosis and gangrene.

In some respects these symptoms are not different from primary Raynaud's disease, which produces symmetric finger blanching and numbness in cold conditions. This phenomenon occurs primarily in women and is not associated with exposure to excessive levels of vibration. The emergence of symptoms after extended exposure to high vibration levels is an example of secondary Raynaud's phenomenon, as are symptoms arising from a variety of medical causes, including scleroderma, arteriosclerosis, other connective tissue diseases, and peripheral neuropathy from diseases such as diabetes.

The exact physiological causes of the phenomenon are not known, but it is assumed that peripheral vasoconstriction is a primary determinant of some of the symptoms, and likely related to neuropathy in mechanoreceptive pathways. This neuropathy, and attendant loss of acuity in mechanoreceptive sensitivity, has been the focus of some activity in the ASA. Work by Brammer and Piercy and colleagues reported at the ASA investigated the epidemiology of mechanoreceptive loss in HAVS (e.g., Brammer and Verrillo, 1988). Their findings indicated elevations in vibrotactile thresholds that are temporary in the beginning stages of the syndrome, but eventually become permanent. Measurements suggest losses both in the Pacinian channel, as evidenced by elevated high-frequency vibratory thresholds, and in slowly-adapting channels, as evidenced by loss of spatial acuity in the two-point aesthiometry test. Some evidence of reduced neural conduction velocity has also been reported. Further, tests of manual dexterity, such as the Purdue Pegboard Test, and of grip force are also part of the standard test battery and often indicate loss of sensorimotor fine control.

In addition, interactions between basic science and more applied vibrotaction researchers in the ASA led to the development of practical and in some cases portable methods for measuring receptor-specific vibrotactile perception thresholds, the tactile equivalent of audiometry. These methods have recently been codified into an ISO standard (ISO 12091-1).

In the 1980s and 1990s, clinical concerns of an "epidemic" of HAVS among manual workers in the manufacturing and forestry industries in Europe and North America drove the focus of activities in this field into occupational health journals. However, efforts within the Acoustical Society to link this clinical focus with more basic work in vibrotaction led to some significant advances. Perhaps most notable was the development of a model for predicting the onset of vibration-induced white finger in persons occupationally exposed to vibration (Brammer, 1986), initially presented in ASA special sessions. The model has served as the basis for vibration exposure guidelines in national and international standards, and led to enaction of exposure limits in several countries and the European Union.

Recent attempts to monitor HAVS proactively have met with some success. In a manner similar to that used for monitoring noise-exposure hearing loss, workers are now tested periodically to provide early warning of possible HAVS symptoms. In addition, the development of better protective wear and restrictions on duration of use of vibrating tools in the workplace should reduce the incidence of HAVS in the future.

2. Whole body vibration

Another area of focus by researchers in the ASA has been the effects of whole-body vibration. Perhaps the name in the Acoustical Society most often associated with whole-body vibration is that of Henning von Gierke, whose more than 50 years of activity in this area encompassed both original research and standards development. The negative effects of whole-body vibration are dependent on the species and the magnitude and duration of the exposure, and can range from mild discomfort to death. Vibrations in the range of .5-80Hz seem to have the greatest impact, with resonances in the 2.5-5Hz range affecting neck and lumbar regions, 4-6 Hz affecting the trunk, and 20-30Hz the head and shoulders. Internal injuries are typically the immediate cause of death in such intense exposures (Griffin, 1990), and include heart and lung damage and gastrointestinal bleeding. The damage patterns suggest a resonance motion of organs in the range of 3-8 Hz. For less intense exposures, particularly of a chronic nature, back pain from prolapsed or herniated disks is often reported; such complaints can come from crane operators, tractor drivers, and truckers. When a smaller contact area is involved, often the damage is related to the elastic and tensile limits of tissue (von Gierke and Brammer, 2002).

Brammer and Peterson's (2003) chapter nicely summarizes the state of knowledge in this area. They divide the harmful effects of whole-body exposure by the direction of impact. Vertical impacts (e.g., through the seat of a vehicle) produce an upward acceleration, followed by a downward acceleration when the mass of the torso returns to the seat. Horizontal shocks are more often encountered in vehicle crashes, in which rapid deceleration can lead to injuries to head, neck, torso, and abdomen.

Measurements of whole-body vibration can be made using laser vibrometers to gauge tissue vibration in conjunction with accelerometers mounted to the interface that contacts the human (e.g., the seat of the vehicle). These measurements are typically made in the context of a biodynamic coordinate system. The results of tissue measurements have led to the development of models of human tissue as a passive, linear mechanical system, and include measurements of density, viscosity, sound transmission velocity, impedance, and tensile, compressive, and shear strength (see von Gierke and Brammer, 2002). These relatively simple lumped biodynamic models provide a good approximation for the purposes of predicting damage from shock and vibration. More recently, finite element modeling has been employed to provide a more detailed and realistic description of individual body parts. These models are also used in the development of anthropomorphic models for simulations of harmful impacts (e.g., crash test dummies). Such manikins are actually better simulation devices than are cadavers, which lack the appropriate tissue and muscle tension properties.

Work in the area of whole-body vibration has led to the development of estimated health effect and injury criteria that can be used to determine the potential harmful effects of exposure in particular occupations, and thus dictate the use of appropriate countermeasures in the work environment. Such countermeasures include vibration isolation by means of low-pass mechanical filters in suspension systems, tool redesign, and active control vibration reduction systems (Brammer and Peterson, 2003). In addition, these criteria are used in the design and implementation of restraint and protection systems, such as seat belts, airbags, and helmets. A concerted effort within the ASA standards community, led by Henning von Gierke, focused on the codifying the measurement and assessment of human exposure to whole body, hand, and arm vibration. The results of this effort are a family of ANSI standards, now serving as the basis for implementing the European Union Health Directive on exposure to vibration.

3. Tactile aids for speech perception by hearing-impaired persons

A final area that has been addressed by ASA researchers is the use of tactile aids for speech perception. The idea that the tactile system had sufficient information-processing capacity to serve as a substitute sensory system for an impaired auditory system, particularly for the reception of speech input, has a rather long history. Methods for the tactile reception of speech, such as Tadoma, indicate that cues transmitted to the fingers of a receiver are sufficient for the transmission of speech (Alcorn, 1932). Tadoma was developed for use by deaf-blind individuals to take advantage of articulatory cues in the talker's speech. In the Tadoma method, the receiver places the fingers and thumb of one hand on the face of the talker, such that the little finger, on the throat, detects laryngeal vibration, the ring and middle fingers detect jaw and cheek muscle movement and tension, the index finger detects nasal resonance, and the thumb detects lip movement and airflow changes. Trained users of Tadoma are able to receive speech at rates that are only slightly lower than normal speech rates, about 70 words per minute. This finding has been cited as an "existence proof" that the sense of touch has sufficient capacity to process the complex cues in the speech signal. Empirical evaluations of the Tadoma method were conducted by Reed and her coworkers at the Massachusetts Institute of Technology [e.g., Reed et al., 1985].

However, the Tadoma method requires considerable training, measured in years, for proficient use, and also requires direct contact between the talker and receiver, which might be awkward or impossible in many situations. For this reason, researchers became interested in the development and evaluation of vibrotactile and electrotactile devices that convert input acoustic speech waveforms into patterns of tactile stimulation. The first record of such a device was that designed by Gault (1924). Gault's original notion was that the skin could pick up vibrations just as the ear could, but required greater intensity of stimulation. Thus, his first device was based on simply amplifying speech presented via a bone vibrator to the hand of the receiver. When this device did not prove successful, Gault went on to design a device that stimulated the fingers of one hand. He reported some success in training with this latter device. Similarly, Lindner (1937) described the "teletactor," a device that provided electrotactile stimulation to two fingers, one channel delivering stimulation to code speech inputs below 1500 Hz, and the other devoted to speech inputs above 1500 Hz.

The development of the vocoder at Bell Laboratories in the late 1930s stimulated further efforts in designing tactile speech aids (Dudley, 1939). A tactile vocoder was described by Wiener and Weisner in 1951, but widespread interest in tactile aids was not rekindled until the early 1970s, when Jacob Kirman published a review of these devices (Kirman, 1973). A number of researchers in the 1970s attempted to train tactile speech perception with new devices, some based on the vocoder concept (e.g., Engelman and Rosov, 1975). Sparks et al. (1979), reinvestigated the idea of using electrotactile arrays. However, the greatest success with vocoder-style devices was that reported for the Queen's University tactile vocoder by Brooks and colleagues (e.g., 1985). This device, which delivers vibrotactile stimulation to 16 magnetic solenoids in a linear array on the forearm, has been shown to provide effective cues for consonant manner and voicing, and for vowel formants. Users of this device successfully acquired large tactile-only vocabularies of single words. In addition, this device produced considerable benefits when used in conjunction with speechreading in connected speech tasks, such as connected discourse tracking (e.g., Weisenberger et al. 1989).

Encouraging results with such laboratory based devices supported the development of wearable tactile aids. Beginning with relatively simple, single-actuator devices that could be worn with a suspender-like harness on the sternum, wearable tactile aids have also been shown to provide benefit to hearing-impaired wearers. Proctor and Goldstein (1983; see also Geers, 1986) reported results for one profoundly hearing-impaired child, whose vocabulary development showed rapid acceleration after she was fitted with the Tactaid, a device that transmitted amplitude envelope information via a fixed-frequency vibration delivered to a bone-conduction vibrator. More sophisticated wearable devices have employed multiple channels of stimulation, and include the Tactaid VII, and the Tickle Talker, an electrotactile device worn as rings on the fingers of one hand (Blamey and Clark, 1985; Cowan et al. 1990).

These wearable devices have shown considerable promise, particularly for users who might not be appropriate candidates for cochlear implantation, such as patients whose auditory nerve fiber survival in the cochlea is compromised, or patients with retrocochlear losses. Improvements in transducer design and in signal extraction algorithms for speech encoding should lead to further progress in the development of the next generation of tactile aids.

Future Considerations

The Technical Committee on Bioresponse to Vibration in the Acoustical Society, was first formed in 1984. As the first new technical committee added in more than 20 years after the original formation of technical committees in the Society, it paved the way for the addition of technical committees for other new areas of research focus, including Acoustical Oceanography, Animal Bioacoustics, and Signal Processing in Acoustics. Shortly after its inception, the group welcomed researchers in the area of biomedical ultrasound, who also sought a more representative technical committee. The nature of research and the associations and societies that house it is necessarily fluid; the founding of new organizations and journals, as well as reorganizations of existing groups and journals, are part of the process of science. At present, most of the areas of research reported in this chapter are pursued outside the confines of the Acoustical Society, and the primary focus of the technical committee has been in biomedical ultrasonics. However, work in the areas outlined in this chapter proceeds with vigor in other associations and societies, and it is not outside the realm of possibility that such work will once again call the ASA its scientific home.

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Biomedical Ultrasound Timeline

1924	Langevin discovers that ultrasound cause sensation in the hand.
1935	Wood and others use ultrasound for therapeutic applications.
1940	William Fry uses ultrasound for brain surgery.
1942	Karl Dussik reports on the use of ultrasound to image the brain.
1947	George Ludwig carries out first tissue diagnosis using pulse-echo.
1953	Wild and Reid produce real-time 2D images of a breast tumor.
1956	First cardiac ultrasound machine.
1959	Satumura reports that Doppler ultrasound can monitor cardiac functions.
1962	Real time contact B-scanner.
1971	2D grayscale images of tissue in the body.
1980	Treatment of kidney stones by shock waves.
1989	First use of intravascular ultrasound (IVUS).
	Clinical use of ultrasound contrast agents for imaging.
	Holland and Apfel propose the mechanical index (MI) to gauge the likelihood of cavitation. The FDA now requires that all commercial scanners display the MI.
1991	Lizzi et al. develop an ultrasound therapy device for ophthalmology.
1996	Treatment of prostate cancer by focused ultrasound surgery.
	First "Harmonic Imaging" product released.
2002	Release of a real-time 3D ultrasound machine.

Bioresponse to Vibration Timeline

1826	Weber publishes De Tactu, a treatise on tactile sensitivity.
1890's	VonFrey argues for receptor specificity in tactile response.
1890's	First documentation of hand-arm vibration syndrome in quarry workers.
1920's	Gault develops several prototype vibrotactile speech perception aids.
1920-40	Studies of perceptual response to vibration frequency (Knudsen, Geldard).
1930's	Alcorn publishes description of the Tadoma method of tactile speech reception.
1930-60	von Békésy publishes experiments on tactile sensitivity.
1940's	Nafe and Wagoner propose the notion of "stimulus failure" for pressure sensation.
1950's	Development of first vibrotactile speech vocoders.
1950-00	Development of criteria for whole-body vibration exposure by von Gierke and colleagues.
1960's	Verrillo proposes duplex mechanoreceptor hypothesis.
1970's	'Rediscovery' and formal evaluation of Tadoma (MIT, Children's Hospital and Harvard University).
1970-90	Development and evaluation of multichannel tactile speech aids and wearable devices.
1980's	Development of criteria for exposure to hand-arm vibration (hand-arm vibration syndrome (HAVS) (Brammer).
1984	Establishment of ASA Technical Committee on Bioresponse to Vibration.
1988	Bolanowski publishes 4-channel model of vibratory perception.
1992	Srinivasan organizes seminal session on Haptic Interfaces, Virtual Reality and Telemedicine at an ASA meeting.
1990-00	Studies of damage to mechanoreceptors in HAVS (Brammer, Piercy and co-workers).

Past and Present Chairs of the Technical Committee on Biomedical Ultrasound/Bioresponse to Vibration

1984-87	John Erdreich
1987-90	Anthony J. Brammer
1990-93	Ronald T. Verrillo
1993-96	Janet M. Weisenberger
1996-99	Ronald A. Roy
1999-02	E. Carr Everbach
2002-	Robin O. Cleveland

Recipients of the Silver Medal in Bioresponse to Vibration

1989 - Floyd Dunn - For contributions to the understanding of the interactions of ultrasound with biological media.

Recipients of the Silver Medal in Biomedical Ultrasound/Bioresponse to Vibration

1999 - Ronald T. Verrillo - For contributions to the psychophysics and physiology of vibrotactile sensitivity.

Recipients of Interdisciplinary Silver Medals

Silver Medal in Physical Acoustics and Bioresponse to Vibration

1990 - Wesley L. Nyborg - For technical contributions in the application of physical acoustics to biology and medicine.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Physical Acoustics and Biomedical Ultrasound/Bioresponse to Vibration

2000 - Lawrence A. Crum - For advancing the understanding of the physical, chemical and biological effects of acoustic cavitation and of high-intensity ultrasound.

Chapter 8

Engineering Acoustics

Kim C. Benjamin, Chapter Editor
History Lecture, Stanley L. Ehrlich

Engineering Acoustics

Introduction

The Technical Committee on Engineering Acoustics was formed through the combination of two technical committees that came on-line in 1956. These predecessor committees, 1) Audio Engineering and Electroacoustics and 2) Sonic and Ultrasonic Engineering, were formed to allow the *Journal*, and its recent Society publication *NOISE Control*, to 'adequately cover' the practical applications of sound.

In 1964 the scope of the newly formed technical committee was broadened. Presently the committee is concerned with the evolution and improvement of acoustical techniques and apparatus, and with the promotion of new applications of acoustics for useful purposes. The current interests of the committee embrace the following areas: transducers and arrays, underwater acoustic systems, acoustical instrumentation and monitoring, applied sonics, promotion of useful effects, information gathering and transmission, audio engineering, acoustical holography and acoustical imaging, acoustical processing (equipment and techniques), ultrasound and infrasound.

The History Lecture on Engineering Acoustics was presented by Stanley L. Ehrlich at the 139th meeting of the Acoustical Society of America in Atlanta, GA. Stan studied acoustics at Brown University during the years 1941 to 1945, with Bruce Lindsay as his mentor and faculty advisor. He later took a position with Raytheon's Submarine Signal Division in Portsmouth, RI where he helped pioneer the field of modern sonar transducers and arrays for Navy systems until his retirement in 1991. His contributions to the Society have been both significant and numerous over the years. He served as President of the ASA in 1996-97, received the ASA Distinguished Service Citation in 1986, served as chair of the Engineering Technical Committee from 1979 to 1981, and is well known for his role from 1981 to 2002 as Associate Editor of the *Journal* for the areas of Transduction, Acoustical Measurements, Instrumentation, and Applied Acoustics. Stan's lecture reprinted here provides an accurate compilation of the historical developments in the field of Engineering Acoustics.

Kim C. Benjamin, Chair
Technical Committee on Engineering Acoustics

History of Engineering Acoustics

Stanley L. Ehrlich, Stan Ehrlich Associates

In approaching the subject of this talk it is well to recognize that all the specialties in acoustics are interdisciplinary with each other in some way. Acoustics, as a whole is interdisciplinary with most other branches of physics, engineering, the life sciences, the earth sciences and even the liberal arts. Bruce Lindsay provided excellent representation of these interactions in his Wheel of Acoustics, shown in Fig. 1, which he first published in the *Journal* in 1964. He put Fundamental Physical Acoustics at the center of the wheel, because that was his primary interest; however, the wheel may be recast to show any of the specialties in the center to emphasize the interactions with it. The Wheel has also been printed in a brochure entitled *Acoustics and You*, which was first published in the 1960s and has been reprinted at least twice since.

One can trace acoustics through encyclopedias backward from 1800 to works of Benjamin Franklin, Newton, Galileo, and Mersennes among others, and still further to ideas of Archimedes and Aristotle, use of speaking trumpets by Alexander the Great, the Greek theater of

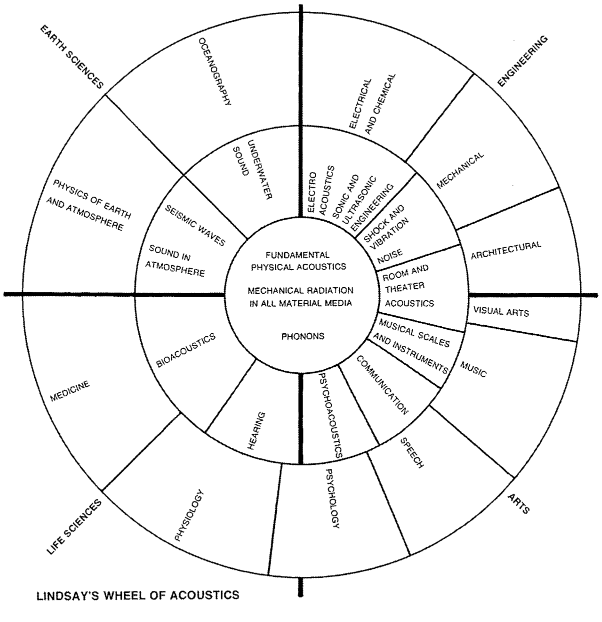

Figure 1. The Wheel of Acoustics (after Lindsay, circa 1964).

Dionysos, and the sound of ram's horns to announce the new moon from hilltops. I took license to extend that to biblical creation in and I have included most of acoustics in the translation that follows.

An Acoustical Engineer's Translation

In the beginning God engineered the creation of the heaven and the earth, starting alphabetically with acoustical engineering a.k.a. ENGINEERING ACOUSTICS. The earth was formed accompanied by intense sound, which was transduced and signal processed through the noisy void in the atmosphere and the darkness over the oceanographic depths underwater, wherein the spirit of God hovered. God using speech communication, said Let there be light; light was produced by acoustooptic transduction. God physically saw the light; it was like music to the ears, and good psychologically. God then structurally separated the light from the darkness; God called the light "Day" and the darkness "Night." The events above were instrumented during the evening and the morning of the first day...God said: Let earth put forth grass, herb yielding seed, and trees bearing fruit to improve the architecture of the landscape...God created sea-monsters, every living creature that walks or creeps, and every kind of winged bird with animal bioacoustic capabilities. Then God said: Let us make man, male and female, physiologically in our image; let them have dominion over all creatures through their bioresponse to vibration...God rested on the seventh day from all the engineering work, outlined above, and measured sonically in multitudes of decibels.

Before 1929

It's time to get more serious and I have divided the rest of my talk into three major sections: the first will be the period before the founding of the Acoustical Society of America in 1929, the second, the period since 1929, and the third a history of the Engineering Acoustics Technical Committee, with examples of its accomplishments.

A timeline of highlights for the period before 1929 would list the most significant scientific and technical accomplishments since acoustics adopted the experimental approach to prove its theories. Benjamin Franklin is credited with the first experimental demonstration of electroacoustics in 1747 using a Leyden jar to create the sparks and the resultant sound. Franklin, who is better known for his other achievements, has been honored on over one hundred U.S postage stamps. He was probably the first American elected to the Royal Society, a British institution founded in 1660. The first magneto-acoustic transducer did not appear until it was invented by Joseph Henry in 1831. Henry was a contemporary of Michael Faraday in the period of major discovery of new magnetic phenomena, and he was the first secretary of the Smithsonian Institution in Washington.

Another contemporary of Faraday and Henry, James Prescott Joule made the discovery of the direct magnetostrictive effect in 1842. He showed that the length of an iron rod was changed by the application of a magnetic field. The inverse effect, in which the magnetization of iron was increased by stretching in small fields, but decreased in large fields, was discovered much later by Villari in 1868. This may be due to the fact that magnetostriction is a second order effect in which the strain is proportional to the square of the applied field, and no inverse effect is observable in the absence of an applied or remanent field. The first order effect, piezomagnetism, was studied much later by Voigt. His experiments to observe the effect in quartz and pyrite were hampered by the fact that the observational errors were larger than the looked-for effect, so that only an upper limit could be set on the size of the coefficients. Walter G. Cady mentions this briefly in his books on piezoelectricity

The years 1876 to 1877 where extremely prolific years. Inventions of the phonograph, shown in Fig. 2, by Thomas Alva Edison; the telephone, shown in Fig. 3, by Alexander Graham Bell; and the microphone by Emil Berliner were contemporary with the encyclopedic publications of Lord Rayleigh and Hermann von Helmholtz.

Edison and Bell were both honored on postage

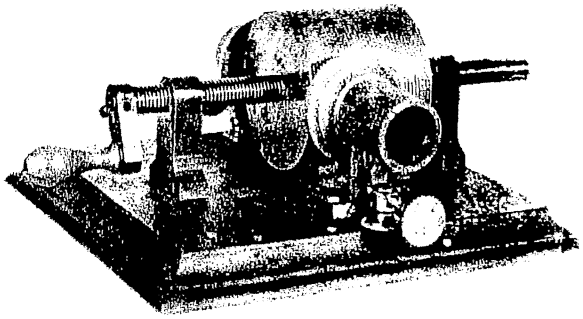

Figure 2. The Edison Phonograph.

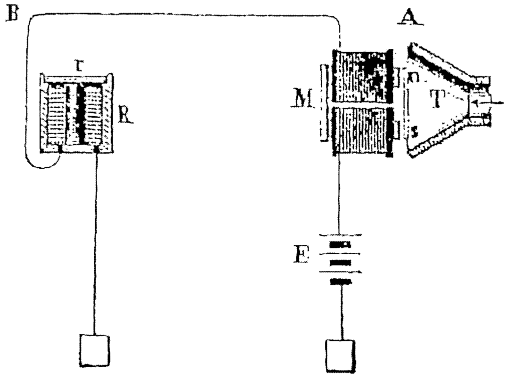

Figure 3. Bell's original telephone.

stamps on the hundredth anniversaries of their births in 1947, Edison in the USA and Bell in Canada. Edison was the only one of the inventors and authors who lived long enough to see the founding of the Acoustical Society of America and to be elected its first Honorary Fellow. The three inventors were all involved in similar ventures, often worked on the same devices, and contributed to their development, as did many others. The result was a considerable amount of litigation over who was entitled to the basic patent for a device, and who was entitled to coverage for a significant improvement in it. I will mention another inventor here, Elisha Gray, who contested Bell on the telephone, because Gray was one of the founders of the Submarine Signal Company in 1899, a company that merged with Raytheon Manufacturing Company in 1946, and for which I worked from 1953 to 1991. Almost everything that was known in acoustics is covered in the works of Rayleigh and Helmholtz, and their work has led others to many newer things that have been uncovered since. I am reminded of a lecture by Karl Darrow that I heard at the meeting of the ASA in Chicago in the fall of 1951 on the occasion of the twentieth anniversary of the American Institute of Physics. In discussing the difference between pure and applied physics, Darrow noted that Leonardo da Vinci was a pure artist when he painted "The Last Supper," but that a few hundred years after his death when the painting was reproduced in quantity he became an applied artist.

For the acoustical engineer, who is a transducer designer, the discovery of piezoelectricity in 1880 by Jacques and Pierre Curie should be of major interest. The earlier discovery of pyroelecticity, along with Lord Kelvin's theory that a state of permanent electrical polarization exists in every pyroelectric crystal, provided background for the work of the Curie brothers. The original discovery was that an applied pressure produced a polar electricity in the same crystals. That same year Gabriel Lippmann proposed that the opposite effect should also exist, and in the following year, 1881, the Curie brothers confirmed this experimentally. While the second-order electrostriction effect was first noted in Rochelle salt crystals, we had to wait more than sixty years before the discovery of electrostriction in ceramic materials, such as first seen in barium titantate

In order to adapt the piezoelectric crystals to transmitting efficiently at lower frequencies than their normal resonances in the ultrasonic range, Chilowski and Paul Langevin in 1915 invented the quartz-sandwich transducer with a piezoelectric crystal cemented between two steel plates. The steel plates served primarily as end masses with a quartz crystal as the spring element. The Tonpilz, or sound mushroom, is a variation in which one mass is very large compared with the other. The larger mass is effectively infinite in the ideal Tonpilz, so that the system becomes a simple spring with one end mass. A transducer I designed in 1954 involved an ammonium dihydrogen phosphate (ADP) crystal block with a square cross-sectional area of 25 by 25 millimeters and two tapered aluminum end masses with circular radiating areas with diameter of about 150 millimeters, and it resonated at 2 kHz. It was intended for experimental use to evaluate performance of sonar systems at the lower frequencies towards which they were intended at that time.

Going back to 1906 on our time line, we find the important invention of the triode by Lee DeForest, which was the forerunner of many subsequent developments in acoustical engineering for sound radiation in air, in liquid, and in solids. Contemporary with that was the first radio broadcast from Nahant, Massachusetts by Reginald A. Fessenden, a Canadian born inventor and pioneer in underwater acoustics. That broadcast was picked up in England. A few years later, soon after the *Titanic* sank on its maiden voyage, Fessenden came up with his Fessenden oscillator, a magneto-acoustic transducer of high power for its time for use in echo-ranging to detect icebergs.

The early microphones of Berliner and others were based on a resistive element, called the carbon button, with the disadvantage of being noisy. Thus, Wente's invention of the condenser microphone, shown in Fig. 4, was a major improvement, particularly with regard to its minimum detectable signal compared with the carbon mike.

Inventions tend to come in quantities greater than one, and 1917 was no exception. That year Alexander McLean Nicolson of the Bell Telephone Laboratories made the basic invention of the crystal filter, using Ro-

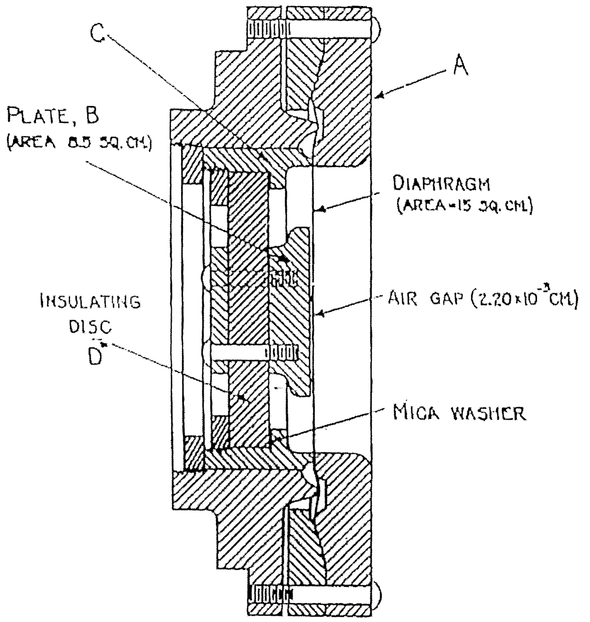

Figure 4. Sectional drawing of Wente's condenser microphone.

chelle salt as the active piezoelectric element. Four years later Walter Cady made the significant improvement of using quartz as the active element, and he applied for a patent, which was denied because of Nicolson's earlier device. Considerable litigation followed, and Cady lost out based on the legalities of patent law.

I first heard Cady speak at a colloquium at Wesleyan University in 1949 shortly before he retired and moved to California. He returned to Providence in 1962 to live in the same house on Power St. where he was born in 1874. When he was asked to speak at an early meeting of the Narragansett Chapter in 1965, shortly before his 91st birthday, Lou Maples suggested that he might like to reminisce about his long experience in acoustics. Cady replied rather promptly: "I don't want to reminisce! I want to talk about what I'm working on now!" And he came to the meeting with a demonstration experiment on a new piezoelectric device he was working on.

The publications by Chester W. Rice and Edward W Kellogg of the General Electric Co. and by Karl S. Van Dyke, a colleague of Cady at Wesleyan University round out the time line preceding 1929. Rice and Kellogg published their classic work on a "new type of hornless loud speaker," shown in Fig. 5, using an electromagnetically actuated voice coil, in the *Transactions of the American Institute of Electrical Engineers*. The AIEE and the Institute of Radio Engineers (IRE) agreed to merge in 1962, and called themselves the Institute of Electrical and Electronics Engineers (IEEE). The IEEE is perhaps the largest engineering society worldwide today. Van Dyke published his work in the equivalent circuit of a crystal in the *Proceedings of the IRE* in 1928. Van Dyke's simple circuit, shown at the bottom of Fig. 6, was expanded on by Warren Mason in a 1935 paper and in his subsequent books, and is shown at the top of Fig. 6.

The basis for the foundation of the Acoustical Society of America was laid by the now well-known triumvirate of Vern Knudsen, Wallace Waterfall, and Floyd Watson in 1928, and the Society officially started in 1929. From the preceding discussion it can be seen that there was much background in acoustics already in place, and the development of the motion picture, first without a sound track and later with one, and the subsequent invention of television provided good engineering needs for the Society.

Before continuing the time line past 1929, I want to present some definitions of basic terms, related to patents. First, I call your attention to differences between a copyright, a trademark, and a patent. Most of you are familiar with the need to transfer a copyright to the Acoustical Society before your paper is published. Since a patent is required to teach others what you have invented, it qualifies as a publication. Often, you will find that someone made an invention similar to yours previously, and usually be required by the Patent Office to reference the work in your patent. There is an alternative for those who choose not to teach others how one of their inventions works, and that is to hold it as a trade secret. The risk in doing this is that someone else may file a patent on the device or publish a paper that teaches how the invention works. The former may require litigation that is not guaranteed

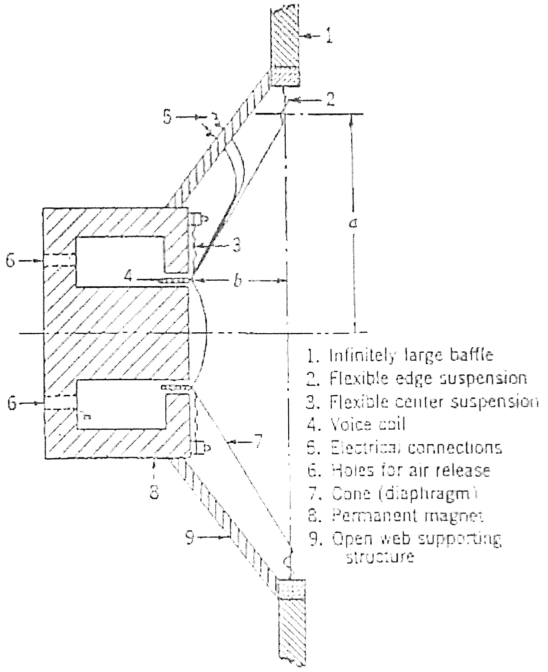

Figure 5. Rice & Kellogg's moving-coil loudspeaker.

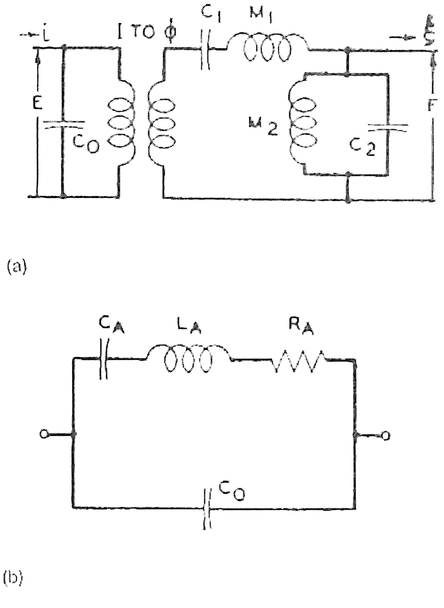

Figure 6. Equivalent electromechanical and electrical circuits for a piezoelectric crystal (Mason, 1950).

to be successful, while the latter sets up a statutory bar against anyone getting a patent. The rules for statutory bars vary from country to country, some giving up to a year to file a patent, and others no right to patent ever.

Since 1929

The timeline for the period since 1929 begins with the founding of the ASA in 1929. ASA started with two meetings per year and established a journal that was issued quarterly as one volume per year. The meetings have become much longer, but have continued at the same frequency, while the journal graduated into a bimonthly and then a monthly. The monthly became too large to contain in a single volume, so two volumes per year are now published, starting in January and in July.

I consider one major invention, the transistor, as one which revolutionized the technology of electroacoustics, although I shall mention a few others. The transistor originally replaced the vacuum tube for receiving applications, and as the technology advanced, power transistors were developed for transmitting applications. The miniaturization of hearing aids was among the earliest applications of germanium transistors. In sonar, the large vacuum tubes designed to deliver around a hundred kilowatts to a transmitting array in the 1950's have long since been replaced with more efficient modular transmitters that are fully transistorized.

There are several basic transducer configurations for sonar. Figure 7 shows a simple spherical transducer, where the interior element is a spherical shell and the radiation pattern is uniformly omnidirectional over the full 4π solid angle. A line array is shown in Fig. 8. The elements are magnetostriction scroll transducers, each of which is effectively a point source at frequencies where the diameter is sufficiently small compared to a wavelength. A simple planar piston array is shown in Fig. 9. The individual elements are commonly mounted on a heavy, nearly rigid backing plate. The active element in the 1940's and 50's was usually a set of piezoelectric crystals, though nowadays one would more likely use piezoelectric ceramics. A cylindrical array is shown in Fig 10. During World War II

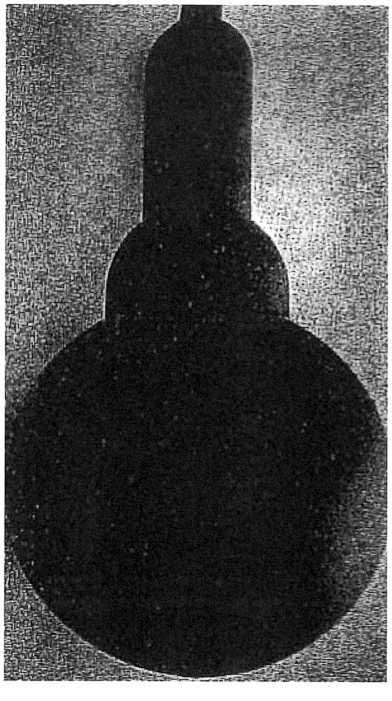

Figure 7. Spherical Transducer (Point Array).

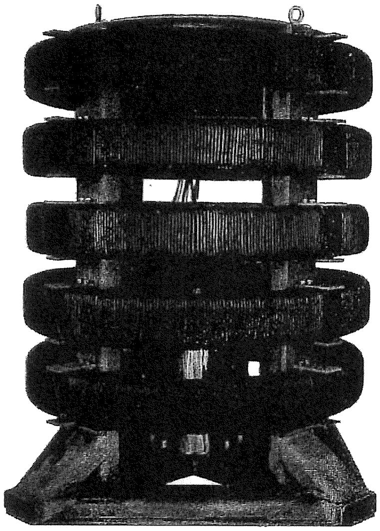

Figure 8. Magnetostrictive Scroll Transducer (Line Array).

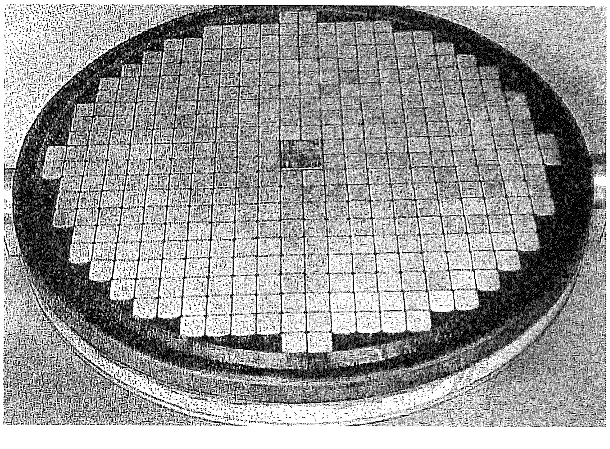

Figure 9. Planar Piston Array.

the active elements were piezoelectric crystals or laminated magnetostrictive structures biased to remanence with permanent magnets, commonly ferrites. The system was called a scanning sonar, in which a single beam was rapidly rotated electronically to provide nearly continuous coverage in azimuth. The height of the array and the operating frequency of about 25 kilohertz determined the vertical beamwidth. The design shown was for a preformed beam sonar with sets of thirty-six azimuthal beams. Their maximum response axes were spaced ten degrees apart in the horizontal plane multiplied by the approximately five elevation angles to which beams were steered vertically. The individual elements were each Tonpilz with ceramic active elements. Fig. 11 shows a spherical array consisting of over a thousand individual transducers arranged in about twenty rows within a spherical zone. The design was planned to fit inside the forward dome of a nuclear attack submarine. As the design evolved, the preamplifiers were sufficiently miniaturized to fit in cabinets that could be mounted inside the sphere on which the transducers were mounted. This freed up space interior to the submarine for increasing considerably the number of preformed beams to cover 360 degrees in azimuth and approximately half the total elevation angle.

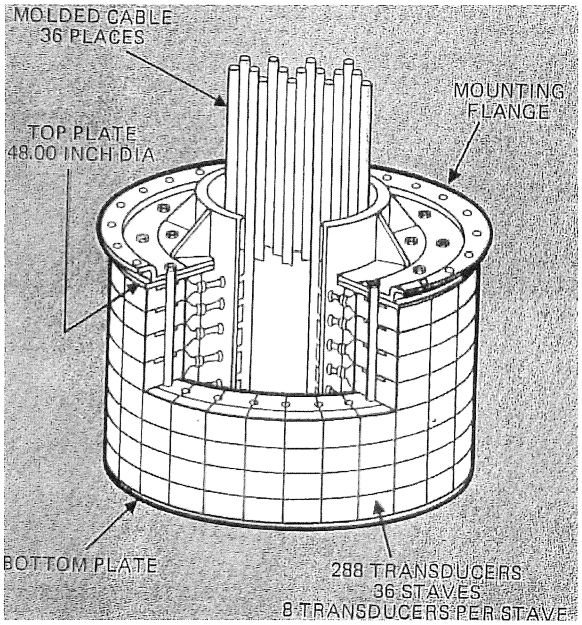

Figure 10. Cylindrical Array.

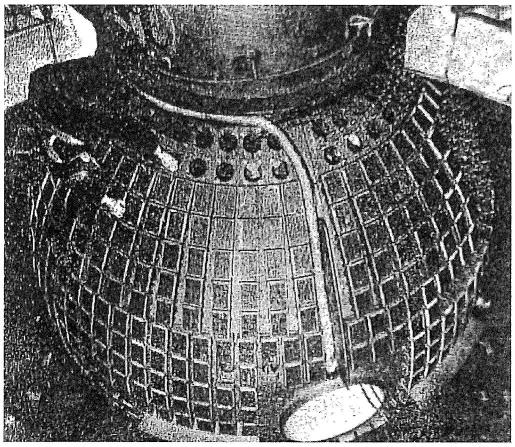

Figure 11. Spherical Array.

More recently there have been developments of flextensional transducer elements shown in Fig 12. The flexing element may be either internal to or external to the extensional drive element. The configurations of flextensional elements into arrays of the types that were shown previously are based on the intended application.

Applications closely related to sonar include oceanography and some seismic systems, such as offshore oil prospecting. A simple seismic transducer is shown in Fig. 13. Medical ultrasonic systems, fluid flow measurement and monitoring, ultrasonic cleaning, and ultrasonic ma-

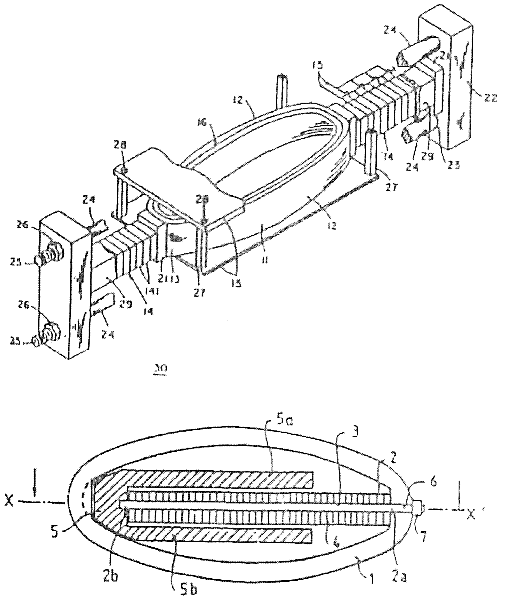

Figure 12. Flextensional Transducer.

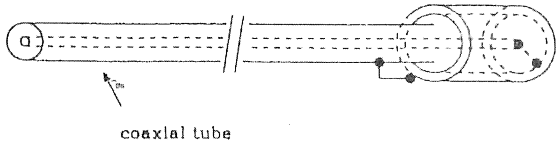

Figure 13. Seismic micromonopole transducer.
PZT is a trade name for a lead zirconate-titanate piezoelectric ceramic material.

chining are among other ventures in engineering acoustics. An example of an ultrasonic machining apparatus is shown in Fig. 14.

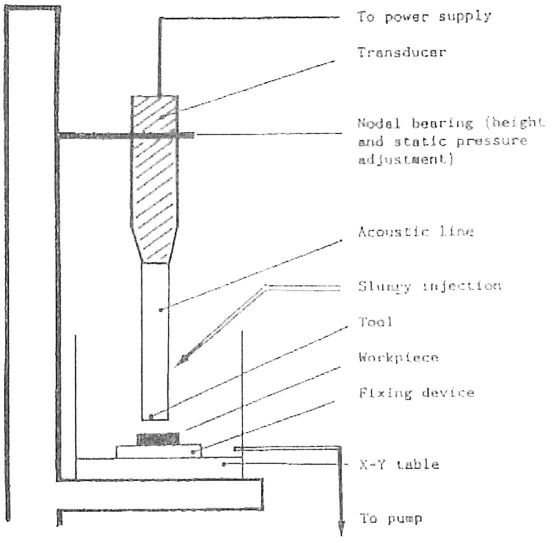

Figure 14. Ultrasonic machining apparatus.

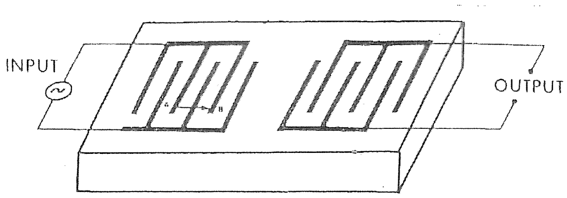

Figure 15. A schematic of a simple surface acoustic wave (SAW) "interdigital" transducer.

I would refer you to the Patents section of the *Journal of the Acoustical Society of America* for reviews of many thousands of patents over the years. That section was initially managed by the late Bob Young, who was a Charter Member of the ASA.

I mentioned earlier the discovery of electrostriction in ceramic materials in 1942. Barium tianate was the first of these materials, and it was soon followed by lead titanate, which showed a fairly large piezoelectric coefficient for volume strain. These materials were commonly polarized to a remanent condition so that they behaved linearly, within fairly large voltage driving functions, as piezoelectric crystals do naturally. A patent by Gray was assigned to the Brush Development Company, which pioneered in much of the piezoelectric crystal and ceramics business, and the company won a patent suit against the U.S. Government for infringement, which is a very unusual occurrence. Lead zirconate-tianate formulations have largely replaced barium titanate today. Increasing their power handling is a competition with all other new materials, both electrostrictive and magnetostrictive.

The development of computers and the Internet have major connections to acoustical engineering and are often involved with the specialty of signal processing. A device which uses surface acoustic waves (SAW) is shown in Fig. 15. Called an interdigital transducer, it consists of sets of electrodes printed on a substrate material such as silicon. One application is as an acoustic filter, usually in an ultrasonic system.

What was not shown on the time line is the proliferation of acoustics in general and engineering acoustics in particular, in North America and internationally. The Audio Engineering Society, the multiple societies within the Institute of Electrical and Electronics Engineers, and the acoustical groups within the American Society of Mechanical Engineers are the principal competitors among the organized groups in the United States, Canada and Latin America. I have been active in the IEEE's Oceanic Engineering Society (OES) and the Ultrasonic, Ferroelectrics, and Frequency Control Society (UFFC). I am also a member of IEEE's Signal Processing Society (SPS) and the Instrumentation and Measurement Society (IMS). You may have chosen other combinations, for in addition to the competition there is also cooperation, sometimes on the national or international level and at other times on a local level. The three joint meetings we have held with the Acoustical Society of Japan in 1978, 1988 and 1996 were all very happy and successful occasions, as was the meeting in Berlin with the European Acoustics Association, a consortium of the national acoustical societies within Europe. Another meeting, the First Pan/Iberoamerican Meeting on Acoustics, held in Cancun, Mexico in 2002, was jointly sponsored with the Mexican Institute of Acoustics and the Iberoamerican Federation of Acoustics. The advantage of some competition is that it spurs us to do better than we had been, and to maintain our well-recognized worldwide leadership in acoustics

One area that needs some attention here, because it is closely related to engineering in acoustics, is the subject of Standards. The development of new devices, new techniques, and new materials requires being able to measure what is relevant to a producer or a customer, and to assure that products are safe. Some of the basic issues are units of measurements, definitions of terms applicable to acoustic technology, and letter symbols needed to make things clear. Fortunately, there are some seven basic units required to cover all of technology, and some connection with acoustics can be found for each of them. The international System of Units, (SI), is the successor to the older designation of MKS, or MKSA. The kilogram is the oldest by date of adoption, that it is the only one that depends on an artifact, which happens to reside at the French standards bureau in Paris, and current work aims to find a way to avoid the need for an artifact. The meter is the one most recently redefined based on the establishment of the speed of light in vacuum as an exact quantity, namely 299 792 458 meters per second.

The base units that are combined to define the newton, which is mentioned in the definition for the ampere, are easily determined from the equation, F = ma, namely that one newton is equal to one kilogram meter per second squared. Using dimensional analysis on other equations, one can derive the base unit representations for energy and for power. Most of engineering acoustics, particularly electroacoustics, can be handled with just four basic units. Three other base units include the kelvin which is important in thermoacoustics and in sound propagation through media that are not isothermal such as air and water. The candela and related units are needed for acoustooptic and optoacoustic devices, including the study of sonoluminescence. I haven't found a place where the mole is needed extensively, though I am confident that someone else knows of or will find one.

The Acoustical Society of America maintains the secretariat for four standards committees under the jurisdiction of the American National Standards Institute (ANSI), and this permits the Society to have an influence on the international standards promulgated by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). The American National Standard on Acoustical Terminology, which is designated ANSI S1.1-1994 and also ASA 111-1994, is an output of the Accredited Standards Committee S1, Acoustics. The American National Standard Letter Symbols and Abbreviations for Quantities Used in Acoustics, which is designated ANSI/IEEE Std. 260.4-1996, was prepared under the auspices of the IEEE Coordinating Committee on Quantities, Units, and Letter Symbols (SCC14) by its Subcommittee on Acoustics (SCC14.5). The majority of the members of the subcommittee are also members of ASA. Both of these standards are commended for your reference, and both may be purchased from the ASA Standards Secretariat.

Included on the Engineering Acoustic timeline are publications I have found most useful in my career, and admit that they tend to cover sonar systems technology more heavily than other areas of engineering acoustics. However, there are several books of benchmark papers in acoustics that Bruce Lindsay oversaw as series editor, in addition to the one listed by Ivor Groves. The paper by Rice and Kellogg, for example, is reprinted in Groves's book, as are several others on airborne sound transducers. A recent book by Bob Beyer, *Sounds of Our Times*, deserves mention, because it is a history of acoustics since 1800 and it includes much of interest on engineering acoustics. We could probably add more than a second hour to my talk by including all the relevant items. When I asked Bob for his advice in preparing my presentation, he said, "First, write a book about it." I haven't done that, but I have relied on some of the things I have written or translated in the past.

There are currently thirteen technical committees in the Acoustical Society. This is the third of the series of talks on the history of those committees. By the 75th anniversary of the Society in 2004, the histories of the technologies that are represented by the technical committees will have been presented and published in this volume.

Predicting the future of engineering acoustics or of any other branch of acoustics, is extremely hazardous. Some general guidelines are obvious and some ideas from the past are relevant. The basis of all engineering is to supply a need that meets the minimum acceptable performance requirements at or near the minimum cost, and that clearly applies to acoustical engineering as well. General principles, such as symmetry, will also be helpful in finding new applications for acoustics. In addition to having a good theory as backing a good sketch of a new idea and, even better, a good three-dimensional mockup is well-advised. Many years ago I had a good supervisor, who promulgated the idea that: If it doesn't look good, it probably won't work! That is still surprisingly true most of the time.

I recently received a request for a copy of a patent that was issued to me in 1966 and was referenced in a presentation by a group at Image Acoustics, Inc. for a new directional underwater communication transducer presented at the Oceans 2000 meeting in Providence.

The technique is based on forming beams superdirectively, using a relatively small aperture to form directive beams. The method in the 1966 patent uses combinations of modes of vibration of cylindrical transducers. Earlier work by Sessler and West with a short line of small microphones provided superdirective beams in air for use in conference rooms and I did similar work on hydrophones in water. I would expect future work that takes advantage of the phenomenon of superdirectivity, knowing that it has been applied in water to the AQS-12 helicopter dipped sonar, the WLR-9 acoustic intercept receiver for use in countermeasures, and the SQQ-62 directional active sonobuoy system (DICASS).

The Engineering Acoustics Technical Committee

As the Engineering Acoustics Technical Committee (EATC) is the main one responsible for engineering acoustics within the Society, it is now time to say something about its history, some of which is noted on the timeline. Three technical committees were added in 1956 to the original seven that had been established in 1954 based on a report of the Committee on the Development and Promotion of the Society. Of the three new committees, two were predecessors of what is now the Engineering Acoustics Technical Committee. One on Audio Engineering and Electroacoustics was chaired by Hugh Knowles and the other on Sonic and Ultrasonic Engineering was chaired by Ted Hueter. The former was successively chaired by Harry Olson, Ben Bauer and Vince Salmon until 1961, when its name was shortened to Electroacoustics and then chaired by Ted Schultz and by Paul Kendig until 1964. The latter was successively chaired by Bill Raney and John Bouyoucos until 1964, when the two committees were merged under the name Engineering Acoustics with John continuing as chair of the merged committee until 1966. The successive chairs to date are listed after the timeline in this chapter.

You can see many familiar names in the Society, some of whom have gone on to election to the Executive Council as members, vice presidents, and/or presidents of the Society. Some received awards of the Society, the Gold Medal, a Silver Medal, or a Distinguished Service Citation, and others will do so in the future. Most are Fellows of the Society, although that is not required for selection as Chair. Besides leading the Committee for a period, now set at three years, the Chair also serves as a member of the Technical Council of the Society and recommends appointments to the Medals and Awards and the Membership Committees.

It is, perhaps, more instructive to look at the current statement of the scope of the Engineering Acoustics Technical Committee which you can find in the ASA Membership Directories. It tends to be very inclusive, and care must be taken to recognize that parts of some items are shared with other technical committees in ways that are not always obvious. One way in which individual members are affected is in the submission of abstracts for a meeting. Authors are expected to designate a technical committee that covers the area of their planned presentation. Representatives of the technical committees receive the abstracts specified for them and arrange them into sessions, each of which normally is somewhat specialized in its coverage. At times, individual papers are reassigned by the representatives or traded off to other technical areas, where there may be a better critical mass of similar papers. The planning of invited paper sessions by the technical committees and announced in the Call for Papers often brings out contributed papers that may be appended to the same session or a follow-on session on the same general subject.

The meetings and the *Journal* are the two most important activities in which the technical committees are involved. The latter is formalized by the appointment of Associate Editors of the *Journal* to one or more technical committees that are relevant to their assigned specialties. Other things that the technical committees are concerned with include questions arising in the Executive and Technical Councils for which a broader opinion is sought, technical discussions sometimes organized as bull sessions either before of after the business meeting of the committee, and cooperative ventures that are devised among two or more technical committees, usually in connection with a meeting.

I have a specific example of how the EATC works, which dates back to my tenure as Chair. One of the other Technical Council members had noted that since 1980 was the hundredth anniversary of the discovery of piezoelectricity, an invited session on the subject should be organized. He felt that the EATC was the committee that ought to sponsor such a session, and I as Chair accepted his challenge and agreed to do so. My first choice to lead the organizing of that session was very clearly Warren Mason, since Walter Cady had passed away in 1974—the day before his one hundredth birthday. However, Warren was already eighty years old, and I doubted that he would want to take on the burden of organizing the session, although he was at that time the Associate Editor of the *Journal.* I called Dr. Mason and volunteered to do the organizing of the session in honor of the discovery of piezoelectricity, if he would present the first paper of the session and work with me to develop the list of prospective authors to be invited. He agreed to do that and also to provide a paper for publication based on his talk. A second arrangement was made with Bruce Lindsay to publish the set of papers evolving from the special session. Without going into a lot of detail, a set of six papers was invited for the special session, and all were published in the December 1981 issue of the *Journal.* I turned over all the manuscripts for review to Warren Mason, except the one by Sessler, because Bruce Lindsay asked me to succeed Warren as Associate Editor in September of 1981, and Gerhard's manuscript arrived early in October. The members of the AIP Editorial staff, primarily Roz Nissim at that time, were extremely helpful in getting all the manuscripts published in the correct order including the late manuscript. Sessler cooperated also by proofreading his paper at the AIP Publication Department headquarters, then in Woodbury, on one of his visits back to the USA from Germany.

Conclusion

I should like to conclude my talk with some general advice for all of you, especially the newer members and attendees, based on my personal experience. In the early years of the Engineering Acoustics Technical Committee and its predecessors, I had made it a habit to attend the meetings, even though I had not been appointed as a member of the committee. On one occasion, in 1966, I chose to hear a paper that made it necessary for me to be late in arriving at the meeting of the committee. When I arrived there was discussion about how to solve a problem, which it was apparent was not the type of problem that could be solved at the committee meeting. I thought it best to delegate the responsibility for its solution to the Chair of the committee, and I raised my hand to speak. I offered my solution, with apology that I was not an appointed member of the committee, whereupon John Bouyoucos said, "If you had got to our meeting on time, you would have found out that you have just been appointed a member!"

My advice is simply to keep in mind that all our technical committee meetings are open, and you should feel free to try out a few of them until you find the one or two you like best to attend. You are likely to become appointed to one of them in time.

Engineering Acoustics Timeline

1747 •••• Benjamin Franklin demonstrates electroacoustics using a Leyden jar to create sparks and resultant sound.

1831 •••• Joseph Henry invents the first magnetoacoustic transducer.

1837 •••• Charles G. Page conducts experiments in electromagetism.

1842 •••• James P. Joule discovers the direct magnetostrive effect.

1876 •••• Thomas A. Edison invents the phonograph Alexander G. Bell invents the telephone Emil Berliner invents the carbon button microphone Edward C. Wente invents the condenser microphone.

1880 •••• Jacques and Pierre Curie discover piezoelectricty.

1906 •••• Lee DeForest invents the Triode (electron tube).

1914 •••• Reginald A. Fessenden demonstrates first use of sound to detect icebergs at sea.

1915 •••• Constantin Chilowski and Paul Langevin invent the Quartz sandwich transducer.

1917 •••• Alexander M. Nicolson invents the crystal filter using Rochell salt.

1929 •••• Chester W. Rice and Edward W. Kellogg invent the hornless speaker.

1928 •••• Karl S. Van Dyke develops the equivalent circuit of a crystal filter.

Engineering Acoustics Timeline

1942 •••• Introduction of piezoelectric ceramics.

1963 •••• Peter Westervelt develops theory for parametric mode sound generation.

1964 •••• Engineering Acoustics Technical Committee formed.

1975 •••• Navy's sound laboratories begin extensive investigation of parametric mode effect.

1976 •••• Robert E. Newnham invents piezoelectric ceramic polymer composites.

1978 •••• Small undersea vehicles begin using acoustic sensors for ocean exploration.

1979 •••• Piezoelectric polymer material (PVDF) becomes a popular sonar receiver material.

1982 •••• Huge magnetostriction effects discovered in rare earth alloys and metallic glasses.

1985 •••• Much of the world's oceans are mapped using acoustic-based techniques.

1990 •••• Relaxor ferroelectric single crystals show ultra high electromechanical coupling coefficients.

2001 •••• Development of audio speakers using parametric effect in air.

Past and Present Chairs of the Technical Committee on Engineering Acoustics

1964-66	John V. Bouyoucos
1966-68	Robert J. Bobber
1968-71	Ralph S. Woollett
1971-74	Harry B. Miller
1974-77	James E. West
1977-79	Mahlon D. Burkhard
1979-81	Stanley L. Ehrlich
1981-85	Mauro Pierucci
1985-88	Robert D. Finch
1988-91	Sung-Hwan Ko
1991-94	George S.K. Wong
1994-97	James M. Powers
1997-00	Thomas R. Howarth
2000-03	Stephen C. Thompson
2003-	Kim C. Benjamin

Recipients of the Silver Medal in Engineering Acoustics

1974 - Harry F. Olson - For his innovative and lasting contributions in microphones, loudspeakers, sound reproduction, and electronic music, his many publications, and his constructive editing.

1976 - Hugh S. Knowles - For leadership, innovation, vision in the application of acoustical science and technology in industry and government and, in particular, for contributions to the advancement of technology for hearing improvement.

1978 - Benjamin B. Bauer - For his contributions to engineering acoustics, particularly in the development of techniques and devices used to pick up, record, and reproduce sound.

1982 - Per Vilhelm Bruel - For significant contributions in sound level instrumentation and precision measurement, and for notable leadership in international standards in acoustics.

1984 - Vincent Salmon - For contributions in the design of horns and the control of noise and vibration.

1986 - Albert G. Bodine - For his ingenuity in developing sonic vibratory devices of great technological importance.

1989 - Joshua E. Greenspon - For his leadership and contributions to the solution of underwater radiation and scattering problems.

1992 - Alan Powell - For leadership in research in the silencing of ship noise and for fundamental contributions to aeroacoustics.

1995 - James E. West - For developing and optimizing polymer electret transducers.

1998 - Richard H. Lyon - For contributions to noise reduction and products through design and to Statistical Energy Analysis.

2001 - Ilene J. Busch-Vishniac - For development of novel electret microphones and of precision micro-electro-mechanical sensors and positioners.

Recipients of Interdisciplinary Silver Medals

Silver Medal in Underwater Acoustics and Engineering Acoustics

1992 - Victor C. Anderson - For pioneering underwater sound research in ambient noise and for the invention and engineering development of the delay time compression (DELTIC) correlator and digital multibeam steering (DIMUS) sonar.

Silver Medal in Physical Acoustics and Engineering Acoustics

1993 - Steven L. Garrett - For leadership in transferring fundamental concepts of fiber optics and thermoacoustics into practical applications.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Engineering Acoustics and Physical Acoustics

1997 - Gerhard M. Sessler - For contributions to electret transducers and the understanding of sound propagation in gases.

ASA at 75

Chapter 9

Musical Acoustics

James P. Cottingham, Chapter Editor
History Lecture, Gabriel Weinreich

Musical Acoustics

Introduction

One of the appeals of acoustics is its interdisciplinary nature. Within the technical areas of the ASA, Musical Acoustics is an especially interdisciplinary field, incorporating ideas and techniques from many other areas of acoustics. This may account for the high "inclusivity index" assigned to Musical Acoustics by Gabriel Weinreich in the following essay, which is an edited version of the history lecture he presented to the ASA in 1999. The many connections of musical acoustics with other technical areas is also reflected in the wide range of technical committees found to be cosponsoring special sessions with Musical Acoustics at a typical ASA meeting.

The Technical Committee on Musical Acoustics is concerned with the application of science and technology to the field of music, with interest in areas including the physics of musical sound production, the psychoacoustics of musical perception, music cognition, and the analysis and synthesis of musical sounds and compositions. The arrival of the digital computer has broadened the field by opening new ways of studying these areas, and also broadened the kinds of music and musical instruments (in the broadest sense) to be studied.

In a relatively short chapter it is impossible to give a comprehensive survey of all that occurred in musical acoustics during the last seventy-five years, and Gabi Weinreich does not attempt to do this. We are fortunate that he has the ability to present a broad picture of this complex history in a simple and original way, by focusing on some simplifying themes and a few salient details. Although he describes himself as a newcomer to musical acoustics, Gabi Weinreich is one of the most distinguished workers in the field, recognized especially for his work on the acoustics of the piano and the bowed string instruments. As illustrated in the following essay, he is also widely recognized for the clarity and wit with which he can present ideas.

James P. Cottingham, Chair
Technical Committee on Musical Acoustics

Musical Acoustics in the Twentieth Century

Gabriel Weinreich, University of Michigan

This essay was originally scheduled to be written by Daniel W. Martin (1918-1999). Dan joined our Society in 1940 and remained active in it for the rest of his career, finally holding the position of Editor-in-Chief from 1985 until 1999. Himself the epitome of a gentleman and scholar, he served the science of acoustics, and more particularly musical acoustics, in a distinguished and noble manner. His death in 1999 was a tragic loss to all of us who were proud to think of him as colleague and friend.

As it then fell to me to take Dan's place as author of this essay, I should begin by introducing myself. I am a relative newcomer at the ASA, since my interest in musical acoustics, inspired by the work of Arthur Benade and Carleen Hutchins, arose only about a quarter of a century ago—which means that I have essentially no personal knowledge of our Society for the first two-thirds of its lifetime. I am neither a triumphalist nor a preacher of doom; nor is this work meant to be a catalog of everything that happened in musical acoustics in the period which it covers. Rather, it is a collection of my own thoughts as they arise when I look into the history of musical acoustics in the twentieth century, a period which, to a great extent, coincides with the history of musical acoustics at the Acoustical Society of America.

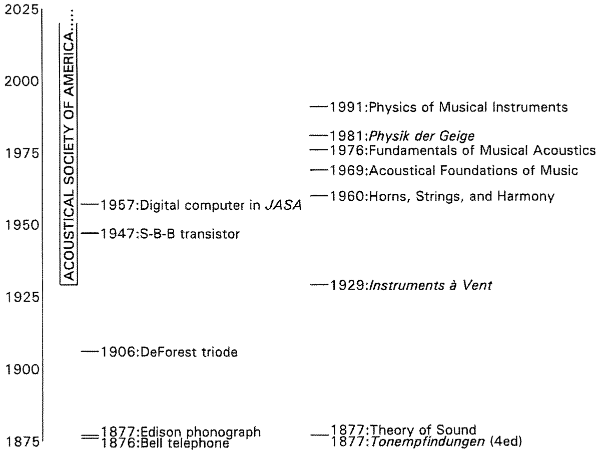

Figure 1. Timeline of Musical Acoustics.

A Century of Musical Acoustics

My original intention in drawing Fig. 1 was to show the development of musical acoustics in the past century; but it soon became clear that the preceding quarter century was sufficiently critical that I must not omit it. Accordingly, the diagram covers one hundred and twenty-five years from 1875 to 2000, with an additional twenty-five blank years to indicate that history is proceeding.

At the leftmost edge of the diagram, and beginning in 1929, is a vertical stripe labeled "ACOUSTICAL SOCIETY OF AMERICA". The remainder of the large field contains the two main columns labeled, respectively, "technology" and "understanding."

Technology

"Technology" is simply a recognition of the fact that the development of twentieth-century musical acoustics —as, indeed, of all acoustics—depended critically on developments of technology, primarily of electronic technology. The first cornerstones of this trend took place in 1876, with Bell's invention of the telephone, and in 1877, with Edison's invention of the phonograph.

Thirty years later—in 1906—came the invention by DeForest of the vacuum triode, and the consequent beginning of what is today called electronics. This field then continued to develop in the form of the amplifiers, oscillators, signal generators and other devices that were all made possible by DeForest's invention. Of course these pieces of apparatus did not arise instantly as soon as the principle of the vacuum tube was known, any more than the more modern era of solid state electronics became instantly available after the issuance, in 1947, of the first transistor patent to Shockley, Bardeen, and Brattain. Yet this second basic invention developed much more quickly: a mere ten years after that basic patent, JASA published its first paper that made use of a digital computer [Pekeris and Lifson, "Motion of the surface of a uniform elastic halfspace produced by a buried pulse," J. Acoust. Soc. Am. 29, 1233-1238 (1957)]. Today there are very, very few papers in JASA in which computers are not used.

Understanding

The right column of Fig. 1 lists the milestones of understanding that have entered musical acoustics, identified in the form of published books. We again begin in 1877 with the fourth edition of Helmholtz's *Tonempfindungen* and the first edition of Rayleigh's *Theory of Sound*, two classics to which the musical acoustician still constantly refers; note that, as indicated in the "Technology" column, Edison's phonograph was invented in the same year, and Bell's telephone in the previous year. Accordingly, we could identify those two years as the true beginning of modern musical acoustics.

Although many important books appeared in the decades after 1877, it seems to me that the next truly original work, which did include much material from Helmholtz and Rayleigh but also some quite original thinking, did not come until half a century later. This was the series of books by Bouasse, and in particular *Instruments à Vent* (published in the year the ASA was founded), which was (so far as I know) the first to treat the nonlinear locking of the multimode air column of a wind instrument to the periodic, but not sinusoidal, driving signal of the air flow through the reed.

Another thirty-one years passed before the publication, in 1960, of Benade's small paperback entitled *Horns, Strings, and Harmony*. Benade was apparently the first writer to have thoroughly digested Bouasse, in addition to filling his book with a wealth of additional original material on various areas of musical acoustics. The same author's *Fundamentals of Musical Acoustics*, first published in 1976, was a reworking of the earlier small book into a full-size textbook; it pretends to be written on an elementary level but is in fact quite advanced.

Acoustical Foundations of Music by John Backus first appeared in 1969, and was the earliest modern textbook of musical acoustics in that it generally took appropriate note of recent developments in the field, rather than simply copying old material. Although it did not, in itself, include the results of new research, it still served as both a textbook and a reference book before reference books were available.

The year 1981 saw the publication of Lothar Cremer's *Physik der Geige* ("Physics of the Violin") consisting largely of important research results original with the author. Finally, Fletcher and Rossing's *The Physics of Musical Instruments*, a fine textbook on an "intermediate" level that is, directed at students who are already well versed in elementary physics and are therefore not afraid of equations, first appeared in 1991.

Funding

Through most of the twentieth century, researchers in musical acoustics had a difficult time obtaining outside funding for their work; even after the Second World War, when (because of wartime developments, and later because of the space race) government support became relatively lavish, musical acoustics was not included. As a result, this field remained limited to amateurs in the old sense of the word — that is, people who did their research as a hobby.

This situation changed in 1978, with the recognition by the National Science Foundation (NSF) that its mission was to support good science research without regard to the question of short-term practical use, judging research proposals by their capacity to enhance the country's reservoir of creative thinking even when practical applications lay far in the future. In that year, the NSF awarded a number of grants for academic research in musical acoustics in the "respectable" amount of approximately 100K$/year per participating professor. Although the absolute number of such grants was not very large (as far as I can remember, there were three during the first year), at the time it seemed like quite a breakthrough.

Musical Acoustics at ASA

How it began: The first meeting

The first meeting of the Acoustical Society of America took place on Friday and Saturday, May 10-11, 1929, in the auditorium of the Bell Telephone Laboratories (463 West Street, New York City). One hundred sixty-five members were registered, but the report in J. Acoust. Soc. Am. 1, 26 (1929) adds that "others were present."

The whole first day was dedicated to 10 papers on Architectural Acoustics, plus an evening demonstration lecture by Dayton C. Miller entitled *The Science of Musical Sounds.* The second day had 6 papers on Speech, 2 on Noise, and 4 on Musical Acoustics. Altogether, then, 22% of the presentations at that meeting, including the featured evening lecture, were concerned with Musical Acoustics.

The situation as of now (1997)

The special place that musical acoustics occupies in the minds of members of the Society today is immediately revealed if we examine the membership statistics in the 1997 Membership Directory and Handbook, according to which, out of a total of >7000 members and fellows, only about 3.5% list musical acoustics as their primary interest; yet about 16% of the special Tutorial Lectures at recent meetings were devoted to musical acoustics-related themes. This indicates that, at least in the minds of the committee that arranged those lectures, interest in musical acoustics is larger by a considerable factor than the number of members who list it as their primary field.

To get at this factor, I devised a quantity characterizing each technical area which I call the inclusivity index, designed to measure the degree to which members of the Society who are interested in that particular technical area are interested in other technical areas as well. I define ξ as $\xi = 5 \ln [(N1+N2+N3)/N1]$, where N1, N2, and N3 are, respectively, the number of members reporting the particular technical area as their first, second, or third interest. It will be seen that if the area in question is chosen as the first interest when it is chosen at all, its inclusivity index will be zero; whereas an area in which many people are interested even if it is not their major specialty will have an inclusivity index that is large. (The coefficient 5 in the defining formula merely sets the scale, of course, and I chose it so as to obtain a convenient range of values; the zero point, on the other hand, has an absolute meaning.)

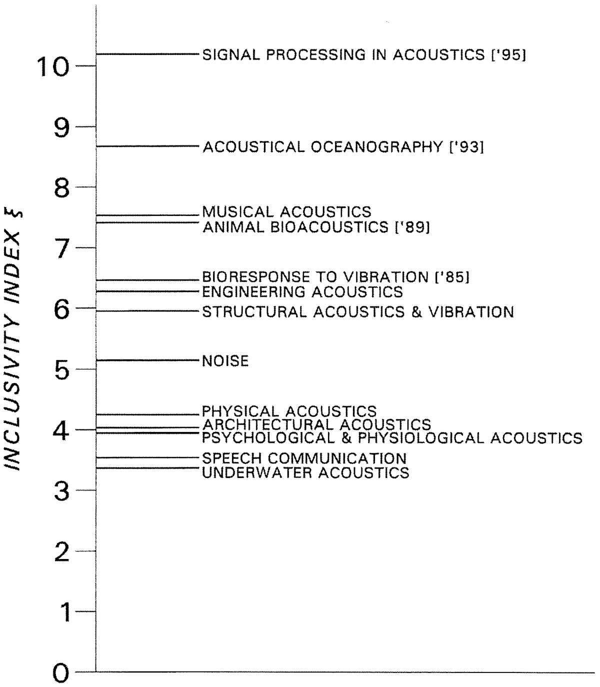

Figure 2. Inclusivity index for the technical areas of the Acoustical Society.

Figure 2 graphically displays the values of the inclusivity index for the thirteen technical areas which are presently recognized in the Society; also shown, where it appears in the statistical table which I used as my source, is the year when data for the corresponding technical committee was first published. As we can see, the largest value of the index ($\xi = 10.2$) corresponds to Signal Processing in Acoustics, where only 13% of members who register some interest in the field indicate it as their primary field. The other extreme of the index is represented by Underwater acoustics, followed closely by Speech Communication; for these two technical areas, the values of ξ are, respectively, $\xi = 3.4$ and $\xi = 3.5$. Musical Acoustics is near the top ($\xi = 7.5$), exceeded only by Signal Processing in Acoustics ($\xi = 10.2$) and Acoustical Oceanography ($\xi = 8.7$).

There is, however, a curious complication in interpreting the inclusivity indices for recently established technical areas. Taking as an example signal processing in acoustics, we note that the motivation for forming it in the first place was that acousticians who identified themselves as working in various other areas all found that much of their work was in signal processing, and they wished to avoid duplication; they continue however (and will for some time) to think of themselves as belonging primarily to their original technical area. This means that, of the people who identify signal processing in acoustics to be one of their interests, relatively few will identify it as being their primary interest, leading to a (possibly transient) high value of the inclusivity index. This kind of reasoning does not, however, apply to musical acoustics, which existed as a strong area of interest even in the first days of the Society.

Prognoses

Opinions concerning the future usefulness of musical acoustics have varied greatly. Thus D. C. Miller, in a paper entitled "The Woodwind Musical Instruments" presented at the Fifth meeting in May 1931, says: "Very little of the scientific method is applicable to the design of musical instruments;" by contrast Vern O. Knudsen, in his paper entitled "An Ear to the Future" (JASA 11, 29-36, based on an oral presentation at the Tenth Anniversary Meeting in May 1939) declares: "...it seems...probable to an acoustician that recent discoveries in the nature of music and hearing, and especially developments in electromusical instruments, will mark the beginning of the world's greatest era in music" (p. 34).

The Greatest Era in Music?

Characteristics of technologized music

Few followers of post-1939 music would give it the blanket description of "the greatest era in music," as Knudsen predicted it might be; some cynics might, in fact, label it simply as "the loudest era in music." Be that as it may, the period can certainly be characterized as "the most accessible era in music." This is epitomized, above all, by the most common indirect object of the verb "to listen" in a musical context: it used to be that one listened to a concert; today, one listens to a CD. "Live" music has become the exception rather than the rule, thanks to the ease with which it can today be translated in space and/or in time. More specifically, thanks to the basic inventions of Bell and of Edison, what we today describe as a performance is no longer identifiable as an event in spacetime: the invention of the telephone allows the same performance to be heard a long distance away (translation in space), and the invention of the phonograph allows it to be heard a long time later (translation in time). So the real kernel of the music is not the event that marked its creation but the CD that marks the source of what we hear.

High fidelity and the loudspeaker problem

The concept of "fidelity" applies, in principle, to the comparison of the original music with what we hear after it has been translated in space and/or in time. With modern electronic components, the fidelity attainable in microphones, recording media, and amplifiers has become so close to perfect that, in effect, the loudspeaker has become the sole bottleneck.

At the same time the emergence of a style of popular music centered on electric musical instruments such as electric guitars, and on a vocal style that depends on the singer's mouth being very close to the microphone (more or less at the distance of an ice cream cone), has changed the situation radically in that in these cases the music can be said to have its primary audible origin in the loudspeaker. The problem of high fidelity then disappears by definition; so, for example, if the sound output of the speaker is not a linear function of the electrical input — which under other circumstances we would refer to as "distortion" — it is here totally irrelevant, since nobody hears the electrical input to the speaker. What matters then is not the linearity but rather whether we (or the people for whom it was meant) are pleased with the music that emerges, since what enters the system is in any case something other than audible music.

The same considerations apply to digital computer music, typically generated by one or more digital-to-analog converters which in turn feed the various electronic channels. In this case, too, the input to the system is not in itself audible music, and therefore the concept of "fidelity" ceases to have a meaning. Thus both popular music and computer music can be said, together or apart, to have signaled the death of high fidelity.

If, on the other hand, one deals with a concert of a more traditional type in which, say, an orchestra playing what are today called "acoustic" instruments is to have its output translated either in space ("live broadcast") or in time ("recorded broadcast"), the concept of high fidelity, although supremely important, at the same time assumes a considerable degree of ambiguity. Are we, for example, trying to mimic the sound which the New York Philharmonic would produce if the musicians were all squeezed into our living room (or bedroom)? Or is the music supposed to reproduce the sounds of Carnegie Hall, resisting any influence of the space that the loudspeaker is actually in? Either one could make a claim to the title of "high fidelity," and either one is devilishly difficult to accomplish. Consequently, here also the idea of high fidelity as a unique aim to strive for loses its meaning.

Anonymization

One of the major limitations of modern loudspeakers—now that human ingenuity has effected such huge improvements over what they used to be—is the problem which Pierre Boulez identified in 1983 when he remarked (in a talk at the International Congress of Acoustics in Paris) that "le haut-parleur anonymize la source réelle," or "the loudspeaker anonymizes the true source." (I give the literal quotation because the verb is as startling in French as it is in English.) The statement refers to the fact that, to a great extent, what one hears when the sounds of various instruments are played through a loudspeaker are not so much sounds characteristic of those instruments as sounds characteristic of the loudspeaker. In view of the excellent frequency and amplitude response that characterize today's speakers, the "anonymization" must result from the fact that no attempt is made to reproduce the spatial characteristics of the sound field of the instrument; whatever the true source, the directionality we hear is that of the loudspeaker. This does relatively little damage to, for example, the sound of a solo trumpet, whose directionality does not radically differ from that of a speaker cone; but it plays havoc with the sound of a solo violin, let alone with that of a symphony orchestra.

The best-known attempt to address this problem is, of course, sterophonic sound. It is interesting that the original motivation for stereo appears to have been to introduce "depth perception" in analogy with the stereoscopic vision that depends on a human being having two eyes rather than one. I am convinced that this analogy is spurious. For one thing, while it is true that a human being has two ears, each of those ears is exposed to the fields of both speakers of a stereo set; in addition, developments such as "SurroundSound," which employ even more than two speakers even though each listener still has only two ears, have recently enjoyed quite a bit of success. As I see it, the main function of stereo is to recover the spatial complexity of the original sound field, a complexity that a single speaker cannot, by itself, produce. It may, in fact, be said that the main purpose of the second (and third, and fourth...) speaker is not so much to localize the sound sources but, on the contrary, to delocalize them, which gives the sound the familiar space-filling property.

We do not, at this moment, know for sure how well the human brain is able to decipher the spatial complexity of a sound field to compare it with another; it may well be (as I personally suspect) that whereas we easily distinguish a field that has some complexity from one which does not, we are not normally able to tell how faithful that complexity is to that of an original recorded field. The question then arises how necessary two separate transmitted signals are for the familiar effects of stereo to be perceived, and how well the same effects could be produced by electronic manipulation of a single signal. In fact, some experiments suggest that similar, and in some cases more convincing, sound reproductions can be produced from just a single recorded channel.

The Concept of Live Performance

In spite of the enormous advances that the last century has brought to the reproduction of music, there remains something very special about a live performance. As I perceive it, in this day and age it is no longer a matter of fidelity of reproduction but of the nature of the activity of making music. We get a hint of its importance from the verb used for that activity, namely to play. This correspondence between the act of making music and the play of children is not just a peculiarity of the English language, of course; among languages with which I have some acquaintance, it exists in French (jouer), German (spielen), Russian and a number of others. And as in many other situations, the concept of playing implies a two-way interaction, in which the performer is aware of his or her audience no less than the audience is aware of the performer. For this reason, I believe that electronic reproduction, no matter how high its quality, will never replace (for those who can avail themselves of it) the sound of a live professional concert, or even the sound of a piano played in one's own living room.

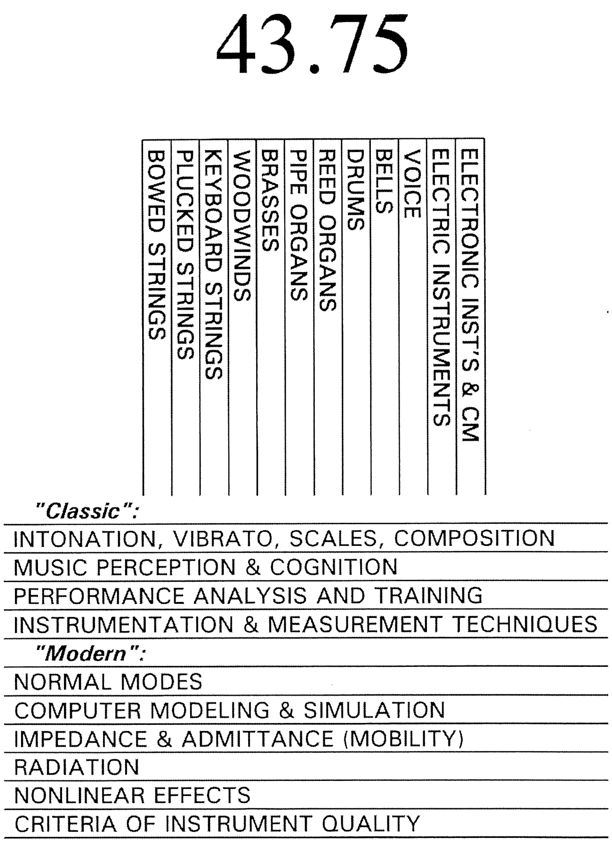

Figure 3. Structure of the PACS category for Musical Acoustics.

The Secret of Stradivarius

Structure of 43.75 today

"43.75" is, of course, the PACS (Physics and Astronomy Classification Scheme) classification number of Musical Acoustics, used not only for subject indexing in JASA but in many other venues as well. As professional librarians are all too well aware, the problem with all such classification schemes is that, in order to be useful, one ordinarily wants it to be one-dimensional (like the arrangement of books on a shelf or cards in a card catalog), even though the actual set of subjects usually has more than one dimension. Thus the case of Musical Acoustics (Fig. 3) includes, first and most obviously, a "vertical" classification by category of musical instrument—such as strings, woodwinds, brasses, keyboards, etc.; and secondly, another "horizontal" classification which can, in principle, be applied to the music of any instrument —such as intonation, vibrato, or performance analysis and training. In recent years, the "horizontal" list has also come to include items (not included in PACS 43.75) such as normal modes, computer modeling, and criteria of instrument quality. This last one is what people have in mind who, when they learn that I study musical acoustics, almost invariably inquire: "Have you discovered the secret of Stradivarius yet?" For various reasons, including its fallacious implication that the old Italian masters knew a single magic secret that allowed them to produce consistently excellent string instruments, such a question should not be taken at face value; as a convenient code word for whatever it is that constitutes an excellent instrument, however, it is both justified and interesting.

Imitative Versus Absolute Criteria

First, we may ask: are criteria of instrument quality imitative or absolute? In the past, of course, they have been chiefly imitative: a most excellent violin is one which is indistinguishable from a Stradivarius, and others are evaluated by the degree to which they approach such a condition. (Of course I use "Stradivarius" schematically for any of the old Italian masters.) Does that mean, I once asked a colleague during a discussion of this point, that "a violin that is better than a Stradivarius" is a contradiction in terms? Yes, he replied, because it would no longer be a violin.

The trouble is that, as long as one limits oneself to imitative measures only, my colleague was right. But suppose we could come up with absolute criteria which formulated what it is, in physical terms, that a violin is supposed to do (for example, "a violin is supposed to play as loudly as possible" —though this particular example is not, of course, correct). Then to imagine a violin better than a Stradivarius would be very easy, and to design one on the basis of physical understanding might well be possible.

Attempts at Absolute Criteria

It seems to me that the essence of a good instrument is its sensitivity, consistency, and range of control, in that order, with regard to each quantity affecting the sound. Thus, other things being equal, a violin is indeed better if it can play louder, but only if its loudness can be controlled by the player with sensitivity and consistency (and not if it simply "blares" and "scratches" out of control). Indeed, it is often as important for an instrument to be able to play very quietly as to do it very loudly, since both affect the range of loudness; but in either case, the sensitivity and consistency of loudness control are more important than mere range.

As an example, consider the vibrato of a violin which, as is well known, consists of a periodic variation not only of frequency and amplitude but also of timbre, since the vibrato puts the frequencies of the various harmonics of the note at varying distances from the violin's resonances. (Because the angular radiativities of the various modes are not the same, the vibrato causes the angular dependence of the sound to vary as well.) For a given amount of primary, or frequency, vibrato, the extent of these secondary vibratos—amplitude, timbre, and angular distribution of the sound—is, of course, determined primarily by the frequency spacing of the modes. Now suppose a way could be found, as Joseph Curtin once suggested to me, of making that spacing (especially at low frequencies) much closer; then the sensitivity of the secondary vibratos would be greatly enhanced, and my expectation is that the consequent finer control of that quantity would cause violinists to regard such an instrument as having a higher quality.

Concept of a Musical Instrument

We should observe, in this connection, that most objects capable of producing sound, such as frying pans, are not musical instruments, because they fall victim to Murphy's Law (whose simplest formulation is "anything that can go wrong will go wrong"); specifically, any attempt to increase the sensitivity, consistency, and range of control with regard to one musically important quality leads to a decrease of those quantities with regard to another. What does characterize a musical instrument is a special singularity which leads to a failure of Murphy's Law. As a simple example, consider a piece of cylindrical pipe used as a primitive trumpet. Straightforward physics tells us that we can get a lot more volume if we flare the diameter of the tube into some kind of horn; also, that such a flaring will, if correctly done, bring the modes of the horn into a harmonic series that adds immensely to the richness of the tone and to its pitch stability. Now according to Murphy's Law, if a certain taper improves one aspect of the sound then it will be the opposite taper that improves another aspect, leading us in the direction of what is called an engineering compromise. But true musical instruments are never engineering compromises but, on the contrary, exceptions to various expected rules.

Finally, we should make some remarks about a computer as a musical instrument. Because a digital computer can, by its nature, be programmed to produce any sound at all, it is, by definition, capable of producing every imaginable sound, and is therefore in neutral equilibrium with regard to Murphy's Law. Whatever one's semantical preference, it therefore remains true that composing for a computer is, by its nature, a radically different activity than composing for physical musical instruments.

Epilogue: What Is It Good For?

The title of the previous section, "The secret of Stradivarius," has the additional implication that studying the musical acoustics of, say, violins ought to enable us to make better violins; in other words, that musical acoustics ought to be good for something. Such an expectation would directly contradict the opinion of D. C. Miller which we previously quoted, namely that "Very little of the scientific method is applicable to the design of musical instruments." In fact, we now know that the truth (as is often the case) lies somewhere in between: science can make considerable contributions in this field, yet it has, so far at least, left various important puzzles unanswered. Accordingly, it may be said that to purist engineers musical acoustics is not worth studying because it is not "good for" enough. Purist physicists, on the other hand, think of their science as unrelated to any kind of practical application—if not, indeed, too refined an activity to have such applications; such people may, accordingly, feel that musical acoustics, precisely because it addresses itself to problems that are externally defined, and because it is occasionally able to come up with results that make for higher-quality instruments, is "good for" much too much.

In fact, however, we professional scientists know that the joy of doing exciting research in a particular field has little to do with it being good for something or, for that matter, with it being good for nothing. Rather, for us the joy of "doing our thing" consists in feeding our overriding addiction to what good research really is: doing what we don't know how to do and, paradoxically, doing it well. Yet there is also a specific excitement in researching musical instruments because so much ingenuity in building them has been acquired by trial and error in the course of centuries if not, on occasion, millenia. We are then given the enormous satisfaction of adding some scaffolding of logical understanding to musical instruments' miraculously singular quality, and to stand in awe of what human beings have, through the ages, been able to develop and harness through the use of intuition, patience, and God's grace alone.

Acknowledgment

This essay is gratefully dedicated to the memory of Daniel W. Martin.

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Musical Acoustics Timeline

1876 •••• Invention of the telephone.

1877 •••• Invention of the phonograph.

Helmholtz, *Tonempfindungen*, 4th Edition.

Rayleigh, *Theory of Sound*, 1st Edition.

1906 •••• Invention of the Vacuum Triode.

1929 •••• First ASA Meeting.

Bouasse, "Instruments a Vent."

1947 •••• S-B-B Transistor.

1957 •••• First Digital computer in JASA.

1960 •••• Benade, *Horns Strings, and Harmony.*

1969 •••• Backus, *Acoustical Foundations of Music.*

1976 •••• Benade, *Fundamentals of Musical Acoustics.*

1981 •••• Cremer, *Physik der Geige.*

1991 •••• Fletcher and Rossing, *The Physics of Musical Instruments.*

Past and Present Chairs of the Technical Committee on Musical Acoustics

1960-61	Daniel W. Martin
1961-64	Earle L. Kent
1964-67	John G. Backus
1967-70	Max V. Mathews
1970-71	Arthur H. Benade
1971-73	William J. Strong
1973-74	Herbert M. Neustadt
1974-77	Paul C. Boomsliter
1977-80	William R. Savage
1980-84	William M. Hartmann
1984-90	Thomas D. Rossing
1990-96	Uwe J. Hansen
1996-99	Douglas H. Keefe
1999-	James P. Cottingham

Recipients of the Silver Medal in Musical Acoustics

1981 - Carleen M. Hutchins - For outstanding contributions and leadership in the development of a new violin family of musical instruments, and for leadership in the acoustical research on bowed string musical instruments.

1984 - Arthur H. Benade - For pioneering research on the acoustics of brass and woodwind instruments and for leadership of a generation of musical acousticians.

1986 - John C. Backus - For pioneering research on the acoustics of woodwind and brass instruments, and for bridging the gap between acousticians and musicians.

1989 - Max V. Matthews - For pioneering work in electronic music and the applications of digital computers to musical acoustics.

1992 - Thomas D. Rossing - For major influence on research and teaching in musical acoustics and contributions to the understanding of percussion instruments.

1998 - Neville H. Fletcher - For contributions to understanding sound production and especially the role of nonlinear processes in string, wind, and percussion musical instruments.

2003 - Johan E. F. Sundberg - For contributions to understanding the acoustics of singing and musical performance and for leadership in musical acoustics research

Recipients of Interdisciplinary Silver Medals

Silver Medal in Psychological and Physiological Acoustics, Musical Acoustics, and Noise

1991 - W. Dixon Ward - For furthering knowledge of auditory perception in psychological and musical acoustics and increasing the understanding of the etiology of noise-induced hearing loss.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Musical Acoustics, Psychological and Physiological Acoustics and Architectural Acoustics

2001 - William M. Hartmann - For research and education in psychological and physiological acoustics, architectural acoustics, musical acoustics, and signal processing.

Chapter 10

Noise

Michael R. Stinson, Chapter Editor
History Lecture, Leo L. Beranek & William W. Lang

Noise

Introduction

Noise is often defined as "unwanted sound." Everyone is affected by noise, whether it occurs in the workplace, at our homes, or in the natural environment. Noise can interfere with speech communication and can mask warning signals. City traffic, aircraft flying overhead, and the neighbor's air conditioner are examples of noise sources that cause annoyance. High levels of noise can contribute to hearing loss.

The purpose of the Technical Committee on Noise is to increase and diffuse knowledge of noise generation and propagation, passive and active noise control, and the effects of noise. Activities of the Committee embrace the practical and theoretical aspects of noise, in its broadest definition, in all areas of acoustics. Specific interests include the following and similar topics: sound sources, source mechanisms, propagation, perception, prediction, measurement, evaluation, analysis, effects, regulation, mitigation, and legal aspects of noise.

The History Lecture in Noise was presented by Leo L. Beranek and William W. Lang. Both are long-standing contributors to the field of noise and its control. Leo Beranek was a co-founder of Bolt, Beranek and Newman (BBN) and a professor at the Massachusetts Institute of Thechology (MIT). He served as President of the ASA in 1954-55 and received the ASA Gold Medal in 1975. William Lang worked at IBM Corporation for much of his career, handling noise control engineering programs and product design. He served as chair of the Technical Committee on Noise from 1967-69 and was awarded the ASA Silver Medal in Noise in 1984. Both authors have also served as President of the Institute of Noise Control Engineering (INCE/USA) and are members of the National Academy of Engineering (NAE).

Michael R. Stinson Chair
Technical Committee on Noise

The Acoustical Society of America's Contributions to the Field of Noise and its Control

Leo L. Beranek, Cambridge, Massachusetts &
William W. Lang, Pougheepsie, New York

The contributions of the Acoustical Society of America (ASA) to the field of noise and its control have been of vital importance world-wide since the Society was founded in 1929. This paper broadly discusses those contributions, as determined from papers published in the *Journal of the Acoustical Society of America (JASA)*, and in the Programs of the biannual meetings of the Society. Of particular importance is the support given by the Society to the standardization of noise measurement techniques and apparatus, and of room noise criteria by the American National Standards Institute (ANSI). The ASA contributions are summarized over several time periods, pertinent references are given, and the Society's future role in the noise field is considered.

Brief History of ASA's Involvement With Noise

The period before World War II

From its founding in 1929, the Society has been active in the noise field. The era prior to World War II witnessed several important developments. The equal-loudness contours were established, and were the basis for the A-weighting network in the sound level meter. With these contours came the standardization of the terms "intensity" and "noise level" (in decibels) as the units of noise measurement. The first important surveys of noise levels in urban areas, inside buildings, and from transportation sources, using audiometer methods, were published in 1930 [1, 2, 34]. Sound level meters were developed by connecting together microphones, amplifiers, filters and meters [5]. Noise analyzers emerged from the laboratory to commercial availability [2]. Then followed the growth of noise problems related to automobiles [7], passenger aviation, broadcasting and air-conditioning that made noise control in studios, commercial buildings and residences the subject of many papers [9-32]. The attenuation of noise in ventilating ducts was an important subject, as was the development of the concept of transmission loss. The National Noise Abatement Council (NNAC)was formed to promote national consciousness of the need for noise abatement and to disseminate information to the public concerning ways and means for controlling objectionable noises. A proposed cooperation between the ASA and the NNAC was put on hold by the advent of WW-II [23].

World War II and the postwar era

During the war and immediately afterwards, major government support of air-borne acoustics research brought forth papers in JASA on anechoic chambers [24], standard microphones [25, 26] noise filter sets, magnetic tape recorders, new measurement techniques [27, 28], the effects of noise on the intelligibility of speech [27, 30] the speech interference level [32], aircraft cabin noise [32, 33] neighborhood noise [34, 35], theories of noise generation in jet engine exhausts [36, 37, 38], and structures for containing jet noise during engine tests on the ground [39, 40, 41, 42].

The 1950s

Noise papers at ASA meetings continued to increase in number. Prominent among the papers of this period were those involving noise in housing [43, 44, 45], the dawn of the jet airplane age [46-54], and associated studies on the effects of the noise on people [55, 52, 57]. At the 43rd meeting in 1951, one-third of the papers presented were directly connected to noise and its control. It seemed apparent that this volume of papers needed to be served by a publication, in addition to JASA, that would carry the applied type of paper dealing with the control of noise. In January 1955 the ASA's publication *NOISE Control* was inaugurated (For references to some of the papers in *NOISE Control*, see "References to contemporary papers in acoustics—Noise" in a number of issues of JASA, starting in June 1955). *NOISE Control* was a successful publication, but ASA discovered that of its readership only about 10% were ASA members. In 1961, the Executive Council voted to discontinue its publication "because it was serving outsiders primarily," and to substitute a more general publication devoted to the practical aspects of acoustics called *SOUND*. This publication lasted only two years, largely for the same reason. During this period, the jet-aircraft age was born, with the first transatlantic passenger service established in 1958. Numerous papers in *NOISE Control* on the external noise generated on takeoffs and landings at airports were published [58-66], and studies were conducted of the noise in communities created by the jets and their effect on people [67, 68, 69, 70].

The 1960s and later years

To fill the gap caused by the demise of *NOISE Control* and *SOUND*, three separate activities came into being. First, the Technical Committee on Noise (TCN) in ASA was formed in 1960. It organized special sessions on noise at meetings of the Society, even though publication of the papers was generally not expected in JASA. Second, the controlled circulation magazine, S)V, Sound and Vibration, appeared in 1967 to provide an outlet for practical noise control and measurement solutions. Third, there being no professional organization in the USA devoted to noise and its control, the Institute of Noise Control Engineering of the USA (INCE/USA) was established in 1971 and, in 1973, the *Noise Control Engineering Journal (NCEJ)* was launched. More will be said later about INCE/USA and its journal *NCEJ*.

The Standards program

The ASA's Standards Program was established in 1932, just three years after the Society's founding. This program was preceded by the appointment of a standards committee at the first meeting of the Society that soon thereafter published a list of recommended acoustical terms. The American Standards Association subsequently chose the Acoustical Society as the sponsor of a new committee, designated Z24, with subcommittees dealing with acoustical terminology, noise measurement, fundamental acoustical measurements, sound absorption, and sound isolation measurement [72].

In 1942, the scope of Committee Z24 was extended to include vibrations. By 1953, the standards work sponsored by Committee Z24 had produced a dozen standards applicable to the measurement of noise, hearing loss and vibration [23].

By 1957, standards activities had grown to such an extent that Committee Z24 was disbanded and replaced by three new Committees: S1 Acoustics, S2 Mechanical Vibration and Shock, and S3 Bioacoustics. No records were found that indicate how many standards applicable to the noise field were published before 1975, but the number was substantial and has helped in the development of better living spaces and quieter transportation and commercial products.

In 1981, the subject of noise was deleted from the scopes of the S1 and S3 Committees and assigned to a newly formed Committee S12, Noise. Each of the S Committees operates in accordance with procedures approved by the American National Standards Institute (ANSI), formerly the American Standards Association, and each is responsible for developing and maintaining its own standards. From 1975, when the ASA Standards Publication Program began, up to the present, 106 American National Standards have been prepared by Committees S1, S2, S3, and S12 and published by ASA. Of these, 36 were produced by the S12 Noise committee. A substantial number of the standards produced by S1 and S2 are also applicable to the field of noise, such as those involving standard terminology, transmission loss, sound level meters, and frequency filter sets.

Papers published and presented

During the ASA meetings held up to the present time, thousands of technical papers on all aspects of noise and its control have been presented. The indexes to many Volumes of the *Journal of the Acoustical Society of America* (JASA) list the titles of the abstracts of these papers. Table 1 lists the number of papers presented in 12 categories for the years 1975-1995 (21 years). An average of 91 papers was presented each year, with the largest categories being Noise Control at the Source, Active Noise Control and Effects of Noise on Man and Society, followed by Rating Methods and Criteria, Buildings and General Machinery Noise, Transportation Noise, Aerodynamic and Jet Noise, and Community Noise (including Zoning and Legislation). Since 1960, the organization of the noise sessions at each ASA meeting has been the responsibility of the Technical Committee on Noise (TCN), which, today, consists of 50 or so members who participate twice yearly in organizing the special sessions held at succeeding meetings.

As shown in Table 2, the average number of papers published in JASA is about one-fourth of the number presented, about 27. Tables 1 and 2 do not include any of the papers presented and published under the Journal's classification of Architectural Acoustics that are directly applicable to noise control, e.g., sound absorption in enclosures and sound-isolating structures.

Significant activities

Next consider some of the more significant activities of the Acoustical Society and its Technical Committee on Noise, starting with an early paper that posed a challenge.

1942: A call-to-action paper by Paul Sabine was published in JASA in January titled "The Acoustical Society and Noise Abatement." The essence of this paper was that the Acoustical Society should actively support a nationwide Noise Abatement Program. He advocated that such a program must produce solutions to practical problems, primarily in schools and housing.

1952-1953: Papers were especially solicited on the control of noise in ventilation systems.

1955-1957: Papers were presented on the calculation of loudness. This subject introduced noise criteria for indoor spaces—the most widely used have been the NC curves.

1954-1960: Technical sessions were held on jet and rocket engine noise, including engine test cells, engine mufflers, and aircraft flight patterns, all designed to reduce neighborhood noise. Many other papers were published, too numerous to reference, that are listed in the "Analytic Subject Indexes" in Volumes 26-32.

1960: The Technical Committee on Noise, mentioned above, was formed.

1961-1970: In this period, the majority of the papers at meetings fell into one of four broad categories: (1) aerodynamic and jet noise, including solid rockets and supersonic aircraft; (2) transportation noise; (3) the effect of noise on man and society; (4) noise in buildings, and (5) household machinery indoors and outdoors. (Volumes 33 to 47).

1965: At the St. Louis meeting, the TCN held its first symposium on the subject of "sonic boom" (Volume 38).

1966: At the Boston meeting, noise and signal processing was the hot subject, and the advent of the fast-Fourier-transform (FFT) was heralded. (Volume 39, p. 1228.)

1968: Featured was a session in Cleveland on "Where do we stand on standards for noise?" Since then, the Standards Office first under Avril Brenig and now under Susan Blaeser has continued the emphasis on standards for noise.

1970: At the Houston meeting, the second sonic boom symposium was held.

1972: The National Science Foundation funded a "Conference on Acoustics and Societal Problems," held at Arden House and attended by 52 participants. The Conference presented a series of topics for further investigation and recommended that the ASA take strong leadership in both initiating and implementing appropriate actions in the following areas: (1) Noise and Man, including damage to hearing, annoyance, community response and criteria

Table 1.

Total Number of Papers Presented At ASA Meetings for 1975-1995 (21 yrs) in Each Category indicated, Taken From the Subject Index in the Sixth Issue of Each Volume (Issues for other years do not show these categories).

		Total for 21 Years	Average Number Per Year
43.50B	Noisiness, rating methods and criteria	157	7.5
43.50C	Noise spectra, determination of sound power	60	2.9
43.50E	Noise generators,gears, bearings, air flow in ducts	53	2.5
43.50G	Noise control at source, mufflers, barriers, attenuators	310	15
4350H	Noise control at the ear	34	1.6
43.50J	Noise in buildings and general machinery noise	153	7.3
43.50K	Active noise control	111	12*
43.50L	Transportion noise sources	263	5.3
43.50N	Aerodynamic and jet noise	149	7.1
43.50P	Impulse noise and noise due to impact, sonic booms	42	2.0
43.50Q	Effects of noise on man and society	420	20
43.50S	Community noise, zoning, legislation	153	7.3
	TOTALS	1905	91

*Active noise control did not begin until 1987 (9 years)

Table 2.

Total number of published papers for 1977-2002 (26 yrs) in each category indicated, taken from the subject index in the sixth issue of each volume. Actual number (see last line) is less, because many papers are listed in several categories.

Class	Title	Total for 26 years	Average per year
43.50B	Noisiness, rating methods and criteria	59	2.3
43.50C	Noise spectra, determination of sound power	49	1.9
43.50E	Noise generators, gears, bearings, air flow in ducts	39	1.5
43.50G	Noise control at source, mufflers, barriers, attenuators	132	5.1
43.50H	Noise control at the ear	28	1.1
43.50J	Noise in buildings and general machinery noise	55	2.1
43.50K	Active noise control	124	7.8*
43.50L	Transportation noise sources	114	4.4
43.50N	Aerodynamic and jet noise	74	2.9
43.50P	Impulse noise and noise due to impact, sonic booms	72	2.8
43.50Q	Effects of noise on man and society	177	6.8
43.50S	Community noise, zoning, legislation	39	1.5
43.50Y	Instrumentation and techniques for noise measurement	53	2.0
	TOTALS	1015	39.0
	Actual Number of Papers Published (Count)	697	26.8

*Active noise control did not begin until 1987 (16 years) for comfort; (2) Environmental noise, including urban noise sources, transportation noise, both air and ground, construction and road equipment, and sound propagation; (3) Education of industry, public, and governing bodies on the effects of noise and means for reducing it; (4) Methods and standards for noise control; and (5) Encouragement of legislation. Many projects for further investigation by engineers and scientists were listed. Most of these recommendations were discussed and acted on at subsequent meetings of the Technical Committee on Noise (TCN). In particular, the TCN at its subsequent 1972 meeting laid the groundwork for ASA's outreach on noise in classrooms and plant and product noise control.

1991: At the Houston TCN meeting, the question was posed by several attendees, "Why isn't the ASA involved to a greater extent?" Dan Johnson, then Chair of TCN, in response formed a Noise Task Group that he instructed to take action.

1992: The Noise Task Group held a panel session at the New Orleans meeting where the current status and possible directions for future action were discussed. Parenthetically, the Noise Task Group has been very active and has given regular reports at ASA and TCN meetings, organized events, and joined with other ASA Technical Committees in solving practical noise problems in the community.

1993: At the Ottawa meeting, an all-day workshop, organized by the Noise Task Group was held to devise a more expeditious action plan that would expand ASA's role in the fields listed above. Six panels held parallel meetings on Environmental, Industrial and Product Noise Control and on Hearing Loss, Education and Government. The issues and action plans developed at that meeting were later published in JASA . In summary, (1) on education, the ASA should develop various CD discs on noise and hearing loss and develop programs on noise for high schools; (2) the ASA should sponsor joint meetings with other professional organizations; (3) position papers should be prepared that would lead to a national noise policy; (4) noise control articles for publication in business/management magazines, regular "Noise" columns in trade publications, and a traveling "noise" exhibit should be produced; and (5) industry representation in consensus standardization should be ensured. One proposed activity that followed was the offering of screening tests for aural acuity at the next five ASA meetings in Cambridge, Austin, Washington, DC, St. Louis and Penn State.

1995: At the Washington, D. C. meeting, TCN reported on the presentation of the fundamentals of acoustics and noise control to students in six high-school classrooms.

1996: At the Indianapolis meeting, a seminar was held on industrial noise control. Attendees included plant engineering, product design and industrial hygiene professionals. ASA members at a regular meeting of the Council for Engineering and Scientific Society Executives (CESSE) conducted a special seminar on noise control for meeting spaces. Those who attended included professionals on plant engineering, product design and industrial hygiene. At the Honolulu meeting, TCN announced that 200 copies of a book on noise control were available.

1997: At the San Diego meeting, TCN members agreed to hold trial seminars to give architects training for which they could receive professional credits from their professional society. TCN also reported that in June 1997, a two-hour seminar on classroom acoustics was given before the design and inspection branch of the Los Angeles School District. In December 1997, a two-day seminar on classroom acoustics was held at the House Ear Institute, Los Angeles, for engineers, architects, school officials, audiologists, and parents.

1998: The US Access Board (a Federal agency) has become interested in the standardization of acoustical conditions in classrooms, and in July 1998, an ASA-wide task force, supported by the Noise Task Group, responded to a "Request for Information" that appeared in the Federal Register at the Access Board's instigation.

1999: At the Columbus meeting, Dave Lubman and Lou Sutherland presented a valuable paper on architectural techniques and immediate cost and long-range cost benefits for providing good classroom acoustics. The TCN declared "Classroom Acoustics" to be a hot subject. They were able to announce that an initiative of the Technical Committee on Architectural Acoustics (TCAA) would produce a booklet titled Classroom Acoustics. Also reported, was a two-day seminar on classroom acoustics held in February 1999 at CUNY, New York, supported by eight organizations. And, in May 1999, an all-day seminar on classroom acoustics was held at the Fairfax School District in Virginia.

2000: At the TCN meeting held in Newport Beach, California, a report was made on progress in the writing of an ANSI standard on classroom acoustics, which includes acoustical criteria and design requirements for control of noise and reverberation in classrooms and other learning spaces. It is argued that there will never be an improvement in classroom acoustics unless architects are convinced that good designs are essential to good education and are cost effective.

The first edition of the booklet "Classroom Acoustics," prepared by Bob Coffeen and his students at Kansas State University, was published in August 2000 by the Acoustical Society of America, and "serves as an introduction to the understanding of the elements of desirable listening conditions in classrooms and demonstrates how good acoustical design can improve the learning environment." Its 4000 copies rapidly sold out, necessitating a second press run.

Subsequent recommendations were made to combine the material of the Lubman/Sutherland paper with this booklet and produce a conventional published text book for use in architectural departments for student education.

2001: During this year, the focus was on community noise and noise policy. At the ASA meetings in Chicago and Fort Lauderdale a total of nine special sessions was arranged by TCN on community noise. At the annual meeting of the Transportation Research Board in Washington, DC, members of the TCN arranged and presented a special session on noise policy in this country and abroad. Progress was reported on the writing of an ANSI standard to develop a model community noise ordinance that is expected to fill an urgent need for those communities that do not currently have such an ordinance. Outreach ASA funding was provided to the Noise Pollution Clearing House to assist that organization in expanding its database.

2002: ANSI published the standard on classroom acoustics. At this writing, the future of this standard is clouded by a petition by the American Refrigeration Institute to ANSI to withdraw the standard.

Consider now a few statistics. From 1990 to 2002, the average number of papers presented per year at ASA meetings under the classification "NS" for noise was 80 (except at the Berlin meeting, held jointly with the European Acoustics Association, where 237 papers were presented and at the Pan-American/Iberian Meeting on Acoustics held in Cancun, Mexico, where 111 papers were presented). In this same 13-year period, the average annual number of papers published in JASA was 16, with the average in the past 5 years rising to 18. Only about half these papers were previously presented at ASA meetings. This number of papers is very small compared to the combined quantity of practical and archival papers published in many other journals and conference proceedings--an average of about 650 per year, as determined from recent ASA "References to Contemporary Papers in Acoustics—Noise and Its Control."

What Is ASA's Situation Today?

With more than 7,000 members, the Acoustical Society of America is the world's largest and leading scientific society concerned with all aspects of acoustics. It has 13 technical committees and groups, each representing a sub-field of acoustics, of which noise is one. In alternate years, the members of the ASA are requested to identify their sub-field of primary interest, as well as their sub-fields of secondary and tertiary interest. In the survey taken in 2002, "Noise" had the third largest number of members with a primary interest (801) behind "Psychological & Physiological Acoustics" (973) and "Speech Communication" (923). When members with primary, secondary and tertiary interests are added together, "Noise" came in a close second behind "Psychological & Physiological" (2231 vs. 2259), with "Speech Communication" a distant fifth (1867). Ranking third and almost first in the most recent survey indicates that the subject of noise and its control is of vital importance to the ASA with approximately one-third of its membership expressing high interest. This interest is shared within the ASA by the Technical Committee on Noise (TCN) and the Technical Committee on Architectural Acoustics (TCAA), the latter representing the primary interest of 671 ASA members.

Other Societies concerned with Noise: A number of American professional societies are also involved to various degrees with the field of noise and its control. They do not have the broad interests of the Acoustical Society, and their members usually specialize in only one or a few of the many aspects of this field. The Institute of Electrical and Electronics Engineers (IEEE) through its Signal Processing Society is interested in the application of signal processing techniques to noise control engineering. The American Society of Mechanical Engineers (ASME) has a Noise Control and Acoustics Division, as well as other divisions, with an interest in the engineering aspects of noise and vibration control. The Society of Automotive Engineers (SAE) sponsors a large, biannual Noise and Vibration Conference focusing on noise and vibration control for the products of the automotive and aerospace industries. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) has a technical committee dealing with the design of quiet heating, ventilating and air-conditioning systems, and the development of testing and rating standards as well as measurement procedures. It publishes the ASHRAE Handbook, which contains a section on "Sound and Vibration Control," that is widely used by air-conditioning engineers. The American Institute of Aeronautics and Astronautics (AIAA) has a Technical Committee on Aeroacoustics with the following scope: "The physics of noise produced by motion of fluids and bodies moving through the atmosphere and by chemical reaction processes and the response of human beings, structures, and the atmosphere to aerodynamic noise." The American Industrial Hygiene Association (AIHA) provides health professionals with a forum dealing with the effects of exposure to noise and vibration, the control thereof, and methods of hearing conservation. The American Speech-Language-Hearing Association (ASHA) certifies audiologists and plays an active role on issues concerning noise regulations and hearing conservation. The combined number of memberships in these organizations is approximately three-quarters of a million. Only a small percentage, perhaps fewer than five thousand, represents those individuals who are professionally concerned with noise and its control. A number of those individuals are members of our Acoustical Society.

The Institute of Noise Control Engineering of the United States of America. (INCE/USA) was formed in 1971 as a professional society sensitive to the needs and responsibilities of noise control engineers, with annual meetings and a peer-reviewed journal and a news publication (*Noise Control Engineering Journal* and *Noise/News International*). INCE/USA is the only independent professional society to have maintained close relations with the ASA over many years. In 1973, an agreement between ASA and INCE/USA was signed that provided for cooperation between the two organizations in regards to meetings and publications. Initially, *Noise Control Engineering Journal* was jointly sponsored by the ASA and the INCE/USA. In 1980, the editors of JASA and NCEJ agreed to coordinate editorial policies of the two journals as follows, "*The Journal of the Acoustical Society of America* is a principal repository of archival information that encompasses the scientific aspects of the field..." and "*Noise Control Engineering Journal* is a principal repository of archival information on the engineering aspects of noise and its control." The agreement of cooperation between ASA and INCE/USA was renewed in 2001 for a five-year period.

In the past, the Acoustical Society and INCE/USA have cooperated in holding three meetings – Washington, DC (1976), State College, PA (1997) and Newport Beach, CA (2000). INCE/USA's NOISE-CON 2000 was held jointly with the 140th meeting of the ASA. Without a requirement for submission of a manuscript for the proceedings, seventy-nine NOISE-CON and five papers in other sessions appear on the CD-ROM that was prepared for that meeting. In the previous five NOISE-CON meetings, where each presenter was required to submit a paper for the conference proceedings, about 120 papers were published on average.

ASA's Future Role in the Noise Field

Over the past three-quarters of a century, the Acoustical Society of America has played a leadership role in developing the sub-field of acoustics focused on noise and its control. The Society initiated in 1955 the first American technical publication (Noise Control magazine) that was devoted exclusively to the technical aspects of the field. The premature demise of that magazine was one of the triggers that lead a number of ASA members to establish INCE/USA in 1971 as a professional organization permitted by the Internal Revenue Service to lobby in Congress and elsewhere in the interests of noise control engineers. As an organization permitted to lobby, INCE/USA played a key role in encouraging Congress to pass the legislation that was known as the Noise Control Act of 1972, now dormant and in need of replacement.

It seems only logical that if the ASA and INCE/USA take concrete steps to work together, American's leadership in noise and its control can be preserved. Otherwise, that role will pass to other organizations.

The major threat to a take-over of world leadership in this field comes from the European societies and the European Union. There is so much activity related to noise in Europe at the present time that many Europeans may be of the opinion they have already achieved that distinction. It is the belief of some of our members that for the ASA to retain its position of leadership in noise, several joint actions between ASA and INCE/USA need to be taken, sooner rather than later.

The major reason why greater cooperation has not taken place between ASA and INCE/USA is that the Executive Council of ASA usually has only one or two of its members who are professionally involved with noise and its control, and sometimes none, even though noise is the sub-field of acoustics that ranks second of the ASA's 12 fields of interest. The discontinuity between the professional interests of ASA members on the one hand and those of the members of the Executive Council on the other hand needs to be addressed. Parenthetically, the Board of Directors of INCE/USA consists exclusively of dedicated noise professionals.

INCE/USA has currently taken a leadership position in creating the basic papers that could lead to the enactment by the U. S. Congress of a new national noise policy for the USA. This effort could be undertaken jointly with the ASA. INCE/USA as a 501(c)(6) organization under the U.S. tax code could serve as the lobbying arm of the policy committee and ASA as a 501(c)(3) organization could represent the scientific arm. The Technical Committee on Noise is in a position to take the leadership role for the ASA in this important endeavor.

Since the initiation of the standards activities by the ASA in 1932, the Acoustical Society has performed an outstanding public service by publishing American National Standards on noise and vibration measurement and their control. Standardization has indeed been one of ASA's major contributions to the noise field. The ASA standards program collaborates in the development of international standards in noise and vibration, and coordinates related international activities. It is important that TCN continue its strong support of the ASA standards program. TCN, working jointly with INCE/USA, could provide advice, counsel and assistance in preparing a long-range plan for the development of American and international standards in noise and vibration.

In conclusion, it is evident from the historical record that the Acoustical Society of America has made vital contributions and has played a leadership role in the field of noise and its control since the Society was founded in 1929. To retain that leadership role in the 21st Century, many members of the Society believe that it must build on the strength of its accomplishments and adopt a proactive role, which we believe should be taken in collaboration with the Institute of Noise Control Engineering. The stated focus of that collaboration would be the achievement of a quieter world.

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Noise Timeline

1930 •••• First key noise surveys.

Development of sound level meters and noise analyzers.

1932 •••• Initiation of standards activities by the ASA.

1933 •••• Fletcher-Munson equal-loudness contours.

1942 •••• Call-to-action paper by Paul Sabine "The Acoustical Society and Noise Abatement."

1955 •••• NOISE Control magazine initiated by ASA.

1960 •••• Formation of Technical Committee on Noise (TCN) in the ASA.

1965 •••• First TCN symposium on "sonic boom."

1971 •••• Establishment of the Institute of Noise Control Engineering of the U.S.A.

1980 •••• Deletion of funding for the Office of Noise Abatement and Control (ONAC) in the Environmental Protection Agency (EPA).

1981 •••• Formation of ANSI Committee S12, Noise.

1991 •••• Noise Task Group formed to find out "why isn't the ASA involved to a greater extent?"

1993 •••• Workshop at Ottawa ASA meeting to define the ASA role in noise and its control.

1999 •••• Classroom acoustics identified as a key issue.

2000 •••• Classroom Acoustics booklet.

2002 •••• Publication of ANSI S12.60-2002 standard on classroom acoustics.

Past and Present Chairs of the Technical Committee on Noise

1960-62	Lewis S. Goodfriend
1962-64	James H. Botsford
1964-67	Tony F.W. Embleton
1967-69	William W. Lang
1969-72	George C. Maling, Jr.
1972-74	Peter K. Baade
1974-77	Glenn E. Warnaka
1977-80	Robert D. Bruce
1980-83	Larry H. Royster
1983-86	Alan H. Marsh
1986-89	Ronald L. Bannister
1989-91	Jiri Tichy
1991-94	Daniel L. Johnson
1994-97	Joseph Pope
1997-00	Richard J. Peppin
2000-03	Bennett M. Brooks
2003-	Michael R. Stinson

Recipients of the Silver Medal in Noise

1978 - Harvey H. Hubbard - For his contributions to the understanding of aircraft noise, its generation, propagation, and control, and its effects on people and structures.

1981 - Henning E. von Gierke - For his contributions to the understanding of the effects of noise and vibration on man, and for national leadership in community noise control.

1984 - William W. Lang - For significant technical contributions to noise control, for sustained national and international leadership in noise and electroacoustics standards, and for advancing the professional status of noise control engineering.

1986 - Tony F. W. Embleton - For fundamental contributions to the theory and practice of noise control, and for international and national leadership in acoustics.

1988 - William J. Galloway - For contributions to aircraft and traffic noise assessment and community noise reduction.

1992 - George C. Maling, Jr. - For outstanding leadership in noise control and in the development of widely used internationally and nationally standardized methods for noise evaluations.

1994 - Kenneth M. Eldred - For contributions to noise control and environmental acoustics, and for leadership in the development of standards.

1999 - Larry H. Royster - For contributions to worldwide hearing conservation.

2002 - Louis C. Sutherland - For contributions to the solution of aerospace and community noise problems, and for studies of molecular absorption and classroom acoustics.

Recipients of Interdisciplinary Silver Medals

Silver Medal in Psychological and Physiological Acoustics, Musical Acoustics, and Noise

1991 - W. Dixon Ward - For furthering knowledge of auditory perception in psychological and musical acoustics and increasing the understanding of the etiology of noise-induced hearing loss.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Psychological and Physiological Acoustics, Architectural Acoustics and Noise

1999 - Jens P. Blauert - For contributions to sound localization, concert hall acoustics, signal processing, and acoustics standards.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Noise and Architectural Acoustics

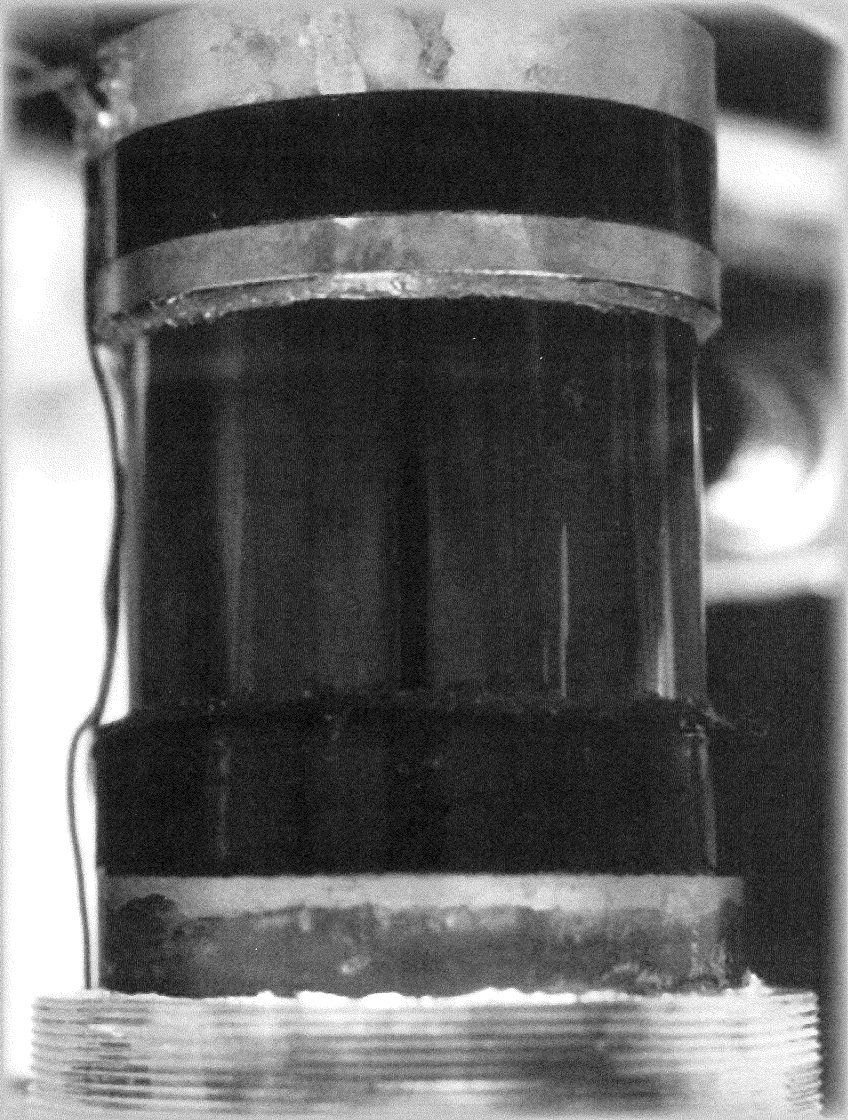
2004 - David Lubman - For work in noise and standards and for contributions to architectural and archeological acoustics.

ASA at 75

Chapter 11

Physical Acoustics

Thomas J. Matula, Chapter Editor
History Lectures, Robert T. Beyer & David T. Blackstock



Physical Acoustics

Introduction

The physical acoustics technical committee is concerned with fundamental acoustic wave propagation phenomena, including transmission, reflection, refraction, interference, diffraction, scattering, absorption, dispersion of sound, and sonoluminescence. The use of acoustics to study physical properties of matter, and to produce changes in these properties, is also of interest. Theoretical, computational, and experimental approaches are used.

Relevant subjects include:

- Ultrasonics and infrasonics;
- Propagation of sound through the atmosphere, fluids, and fluid-filled materials;
- Nonlinear acoustics;
- Biomedical ultrasound;
- Use of acoustics as a tool in studying superconductivity, dislocation in solids, and lattice vibrations;
- Acoustical studies of structural and dynamical properties of matter;
- Interaction of sound with light and other forms of radiation.

Our members come from all over the world, and all contribute greatly to the success of the technical committee. Two of those members, Robert Beyer and David Blackstock, have contributed to write the 75th anniversary chapter for Physical Acoustics. Because physical acoustics covers such a large and diverse range of topics, the chapter is necessarily limited, in this case to sound propagation and absorption in the atmosphere, and to Physical acoustics outside the US. I'm sure you will enjoy the engaging way in which Robert and David bring science, and in particular, physical acoustics to life!

Thomas J. Matula, Chair
Technical Committee on Physical Acoustics

The History of Physical Acoustics: The Worldwide Scene

Robert T. Beyer, Brown University

When I agreed to write this section, I thought that it would be easy. All I had to do was to copy aloud the relevant passages of my recently published history: *Sounds of Our Times.* But that would take too long. And also I am limited to work outside the US. So, let us begin with a quotation from Helmholtz's book *On the Sensations of Tone,* [1] which was published about the middle of the nineteenth century. As far as I have been able to find, Helmholtz (Fig. 1) was the first to use the term physical acoustics. [The usual picture of Helmholtz is that of an old man. This picture is one taken in his younger days, at the time when he enunciated the principle of conservation of energy.] He separated physical and physiological acoustics on the one hand and musical science and esthetics on the other. He then went on to divide the first two terms: under physiological acoustics, he investigated processes that take place within the ear, treating the conduction of sonic motion from the entrance of the external ear to the expansion of the nerves in the labyrinth of the inner ear; under physical acoustics, "the investigations refer exclusively to the motions produced by solid, liquid and gaseous bodies when they occasion the sounding which the ear appreciates. It is essentially nothing but a section of the theory

Figure 1. Hermann von Helmholtz. [2]

of the motions of elastic bodies." From this modest and restrictive definition, the field of physical acoustics has developed into an enormous number of topics, all under the same title. We can only examine a few of them.

To control the length of the article, I shall begin with the early nineteenth century. The great mathematicians of the earlier time, such as Newton, d'Alembert, Euler and Laplace, had studied vibrating strings and the passage of sound through air. A number of their achievements are listed in the chronology of (Fig. 2). With the beginning of the nineteenth century Poisson [3] in France noted that the displacement velocity of air particles in a sound beam had a velocity of propagation that was equal to the sum of the normal, small amplitude sound velocity and the value of the displacement velocity itself, and thus, the field of nonlinear acoustics was born. In the 1840's, Stokes [4] in England investigated the absorption of energy that would occur in a plane wave due to the shear viscosity of the medium, and in the 1860's, Kirchhoff [5] in Germany added a calculation of the absorption that would be due to hearing conduction. Since it would not be possible to measure this sound absorption for another generation or so, the theoretical work of Stokes and Kirchhoff remained unchallenged for half a century.

But Stokes made another contribution. Challis [6] in England had noted a consequence of Poisson's work-the increased velocity of propagation of the crests of the particle velocity would lead to a steepening of the wave front, until a point would be reached at which the waveform would be multivalued (Figs. 3, 4), which would prevent the discontinuity. While Stokes didn't have the complete answer, he was pioneering in the fields of nonlinear acoustics, ultrasonics, and sound absorption and, indeed, weak shock waves, all at the same time.

The early ideas of von Helmholtz also produced remarkable instrumentation—long since obsolete—that ensured the production of sustained vibrations of a tuning fork [9] (Fig. 5). In the upper picture here, he used a tuning fork and a coil of wire. He thus formed an electromagnet. If he had an alternating current of the same frequency, he would be able to sustain the vibrations of the fork. As shown in the lower picture, this alternating current was produced by a circuit in which the current in the circuit was periodically interrupted by the vibrations of an identical tuning fork, and with his famous resonator he made it possible to produce and detect sound of specific frequencies.

1625 Mersenne found the relation between the frequency of a vibrating string and its length.

1687 Newton deduced the isothermal velocity of sound in air

1701 Sauveur used the beats between vibrating strings to determine the actual frequency of vibration. He also gave names to *nodes* and *harmonics.*

1713 Brook Taylor worked out the mathematics of the vibrating string, using F = ma for a continuous medium for the first time.

1747 D'Alembert and Euler set up the partial differential equation for a vibrating string.

1816 Laplace suggested the production of heat during the compressions and rarefactions of a sound wave and arrived at the (correct) expression for the adiabatic sound velocity in air.

Figure 2. Early landmarks in physical acoustics.

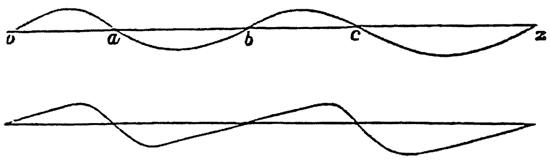


Figure 3. Steepening of wavefront of an intense sound beam (Stokes, 1848) [7].

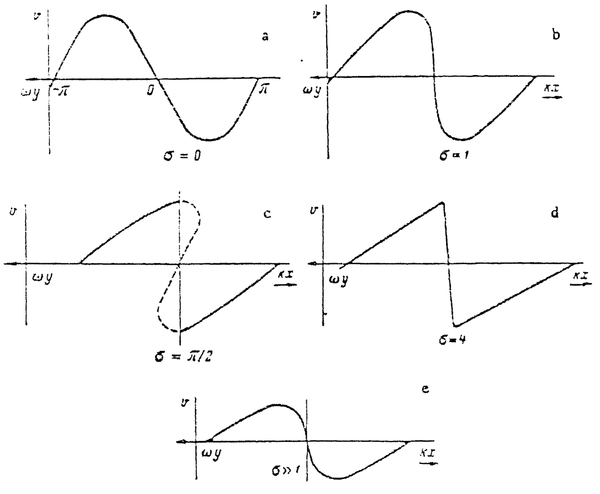


Figure 4. Distortion of the wavefront during propagation (Naugolnykh, 1971) [8].

In the same period, Buys-Ballot [10] in Holland made use of a steam engine in his acoustical research. He placed a group of trumpeters on a flat car on a train and had skilled musicians standing at the edge of the track. When the train went rumbling through (like the old song about Charlie on the MTA – to old Bostonians, the Metropolitan Transit Authority) at thirty miles an hour, the trumpeters sounded a single note, and the musicians were able to detect slight changes in the tone of the music–higher pitch on approach and a lower pitch on departing. This was the first experimental confirmations in acoustics of the effect described for light waves in an astronomical problem by the Austrian, Christian Doppler.

[11] It was a curious mixture of music and engineering, but it was physical acoustics!

Now that I've gotten the subject matter started, let me trace a number of the most important themes of physical acoustics. Towards the end of the nineteenth century, Rudolph Koenig [12]—a German turned Frenchman—was an expert in making tuning forks and other acoustical devices. If you work today at an old college or university, you probably have some of these tuning forks, distinguished by the initials R K on them as his mark of approval. (I found that we have a number of Koenig's forks at Brown.) He then made use of another famous experiment, that of Kundt, which we have all performed in our instructional laboratories in physics, to the misery of our students; we stroke a metal rod in a tube that contains small amounts of fine particles or dust. The stroking produces screeching noises, and the dust piles up at equally spaced intervals, so that we can measure the wavelength of the sound involved. Koenig made smaller and smaller tuning forks in order to achieve higher and higher frequencies (Fig. 6). He achieved frequencies as high as 87 kHz, marking an early appearance of ultrasonics. Clearly, however, Koenig had reached the upper limit with his forks. A new way had to be found to go higher. This was provided a few years later (in the 1890's) by the discovery by Jacques and Pierre Curie [13] that squeezing plates of certain natural crystals produced opposite electric charges on the opposite faces, and that applying an electric field to the plates resulted in a small change in their thickness, making the crystal thinner when the field was applied in one direction, and thicker when the field was reversed (Fig. 7). This was soon called piezoelectricity). At the time, their discoveries were matters of crystallography, but the vast progress that was made in electronics over the next century, including the creation of electronic oscillators, made it possible to use quartz plates for the generation and detection of high-frequency sound. Thus physical acoustics had another child- ultrasonics. A remarkable feature of physical acoustics (as of physics itself) has been its ability to keep splitting off new fields that develop a character of their own—ultrasonics, nonlinear acoustics, shock waves—the list goes on.

I mentioned this earlier theoretical work of Stokes and Kirchhoff on sound absorption. The actual experimental measurement of the sound absorption coefficient was left to the first decade of the twentieth century, and, primarily, to work in the laboratory of the great Russian physicist, Petr Lebedev. One of his students, Altberg [15] used an electric spark as a sound source, containing many frequencies. He then used a Fraunhofer diffraction grating to separate individual frequencies, and was able to produce ultrasonic frequencies as high as 300 kHz.

Following up on Altberg's work, and using some of his apparatus, Neklepaev [16] (Fig. 8) measured the sound absorption coefficient in air at 120-130 kHz and

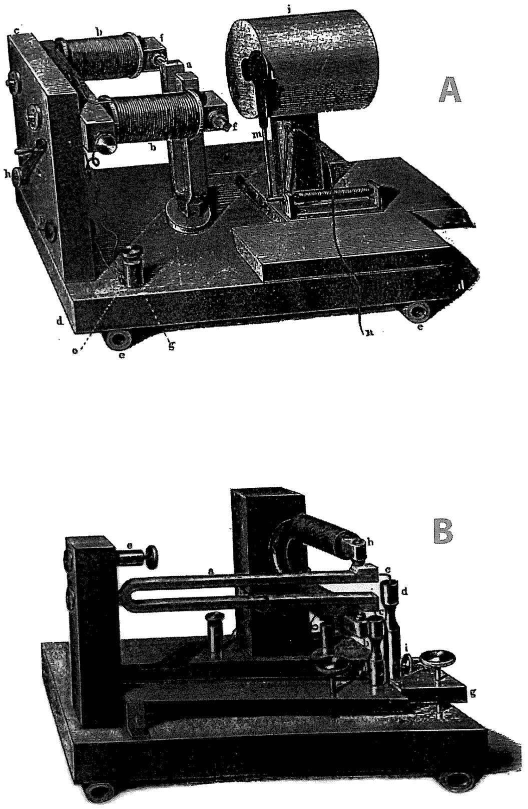


Figure 5. (a) Helmholtz's apparatus for a sustained sound from a tuning fork; (b) his apparatus to produce an alternating current of a given frequency.

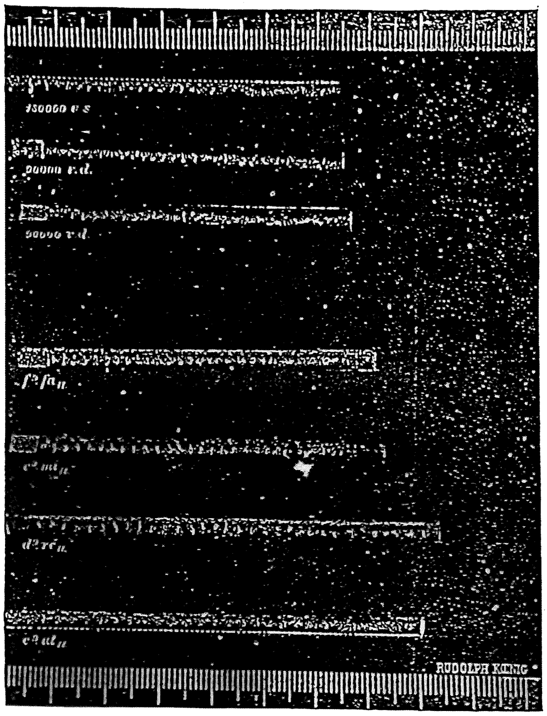


Figure 6. Kundt's tubes patterns for ultrasonic waves.

found that its value was more than twice that predicted by Stokes-Kirchhoff.

What to do? Various theorists, including Sir James Jeans [17] and Albert Einstein [18], developed the idea of thermal relaxation, according to which the equilibrium of the distribution of energy among the internal degrees of freedom of fast molecules would be disrupted by the passage of the sound wave. The attempts of the medium to "relax" to its normal state by collision with other molecules would be impeded by the changing nature of the energy distribution in the sound wave, and that energy would be lost to the sound beam in this process. The phenomenon would also lead to a small amount of velocity dispersion. Einstein [18] suggested applying the idea to the mixture by measurement of the sound velocity, while Jeans applied the ideas to sound absorption (Fig. 9). This process remained a hot topic in physical acoustics for the next forty years and provided a lot of my bread and butter in the period. One of the leaders in the field was Hans Kneser [19] in Germany who, in the early thirties, worked with Vern Knudsen [20] (dare I mention an American name?) in making more accurate measurements of the absorption coefficient (Fig. 10), by measuring the effect on the reverberation time of room models by changing the type of gas contained. Similar measurements were made by Erwin Meyer. [21] (It is of interest that Knudsen performed this research as part of the larger field of architectural acoustics, while Kneser used it as the introduction to the field of ultrasonic absorption measurements in gases.)

The Russian school made further major advances in ultrasonics in the study of electrolytes containing the acetate radical in the 1930's. Spakovskij discovered velocity dispersion in acetic acid, [22] while Bazhulin made significant absorption measurements in ethyl and methyl acetate solutions. [23] At about the same time, the French experimentalist Biquard [24] made many such measurements in various organic liquids.

The development of pulsed systems in radar research during World War II was soon applied in ultrasonics, and led to the study of sound absorption in liquids, first by Pinkerton [25] at Cambridge and then by Tamm and Kurtze [26] at Goettingen. The latter team made many interesting measurements in electrolytic solutions and helped greatly in our understanding the role of relaxation in underwater sound (Fig. 11). [27] The complicated theory of absorption in this area was developed by their associate, Mangred Eigen, [28] who later broadened these studies of what were essentially reaction rate theories to win the Nobel Prize in chemistry in 1967. One of Pinkerton's coworkers, John Lamb, [29] made broad studies of sound absorption in liquids, first at Imperial College and later at the University of Glasgow (Fig. 12).

Another sub field of physical acoustics is opto-acoustics. In the 1920's, the Frenchman Leon Brillouin [30]

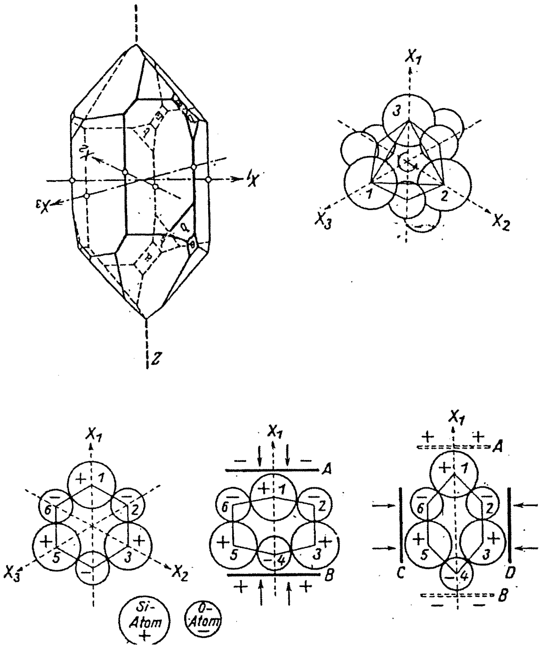


Figure 7. (a) Quartz crystal; (b), (c), arrangements of Si and O atoms in a quartz crystal; (d) effect of compression of a quartz crystal. (Bergman 1935) [14].

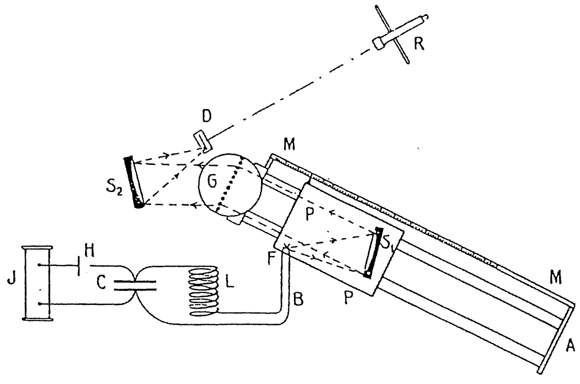


Figure 8. Neklepaev's apparatus for measuring ultrasonic absorption in air (Neklepaev, 1911) [16].

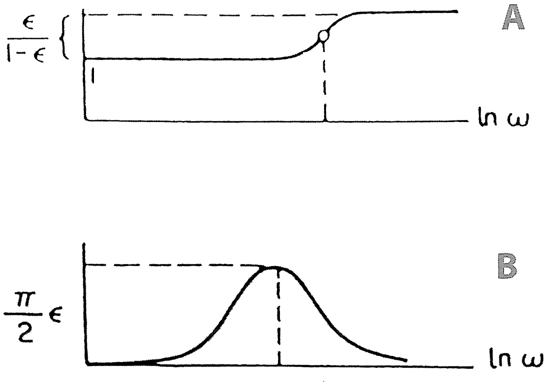


Figure 9. (a) ultrasonic dispersion and (b) absorption coefficient per wavelength for gases. (Jeans, 1925) [17].

studied the Rayleigh scattering of light in liquids. Rayleigh's theory developed, perhaps, to answer the question, "why is the sky blue?" indicated that, at a given viewing angle, the scattered light would be centered about a single frequency. The spectral spread of the frequencies being due to the spread of frequencies and *f* is the frequency of a phonon that has been absorbed or emitted in the light scattering process. In the 1930's and early 40's, Venkateswaran [31] in India attempted to verify these ideas, but his light source had such a broad band that the results were not much more than qualitative in nature (Fig. 13). After the invention of the laser, however, it became possible for researchers to produce much narrower bands of frequencies. A sample of modern Russian work is shown in (Fig. 14) [32] this technique has made it possible to measure both the sound absorption and the dispersion at frequencies up to about 10 GHz. Since Leonard Hall's theory for sound absorption in water (1947) [33] predicted a relaxation frequency in the range 100-600 GHz; we still have work to do.

It has long been a characteristic of physics in general, to reach out to measure the highest, the lowest, the largest, the smallest and physical acoustics has been no exception. We have just described efforts to measure higher and higher frequencies in liquids. Another attempt at extrema has been the measurement of sound absorption and sound velocity when the intensity of the sound wave is increased further and further. Rayleigh published several papers on the subject of nonlinear acoustics, and the English scientist Earnshaw [34] developed an equation describing the effect of the presence of nonlinear terms in the wave equation. Unfortunately, his solution of this equation was an implicit one, and acousticians were not able to unravel it until near the middle of the twentieth century, although the mathematics for its solution had been provided by Bessel nearly one hundred years before, as was pointed out by David Blackstock. [35] Anyway, in 1935, the Italian Eugene Fubini [36] did find the explicit solution, and we had a good description of the developments of harmonics from an otherwise pure sound wave of high intensity as it progresses through a non-viscous fluid. One day, in my own laboratory, I too solved this implicit/explicit problem. Peter Westervelt walked into my lab, looked at my results, and remarked, "that's just what Fubini did twenty years ago," and I said, in a most crestfallen voice, "who's Fubini?" My consolation in this matter has been the fact that, since my work, two or three other acousticians have made the same discovery, without knowledge of either Fubini or me, and that Fubini himself was unaware that Bessel had solved the same problem in astronomy, eighty years before.

The analysis of Fubini did not include dissipation; this lack was corrected by Rem Khokhlov [37] and his students in Russia in the 1960's. His work led to an explosion of work both in Russia and in the U.S.—or, one

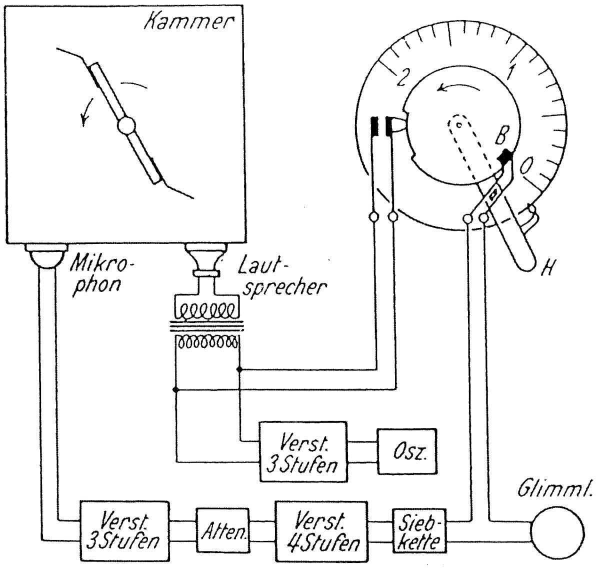


Figure 10. Apparatus for measurement of sound absorption in gases (Kneser and Knudsen, 1934) [20].

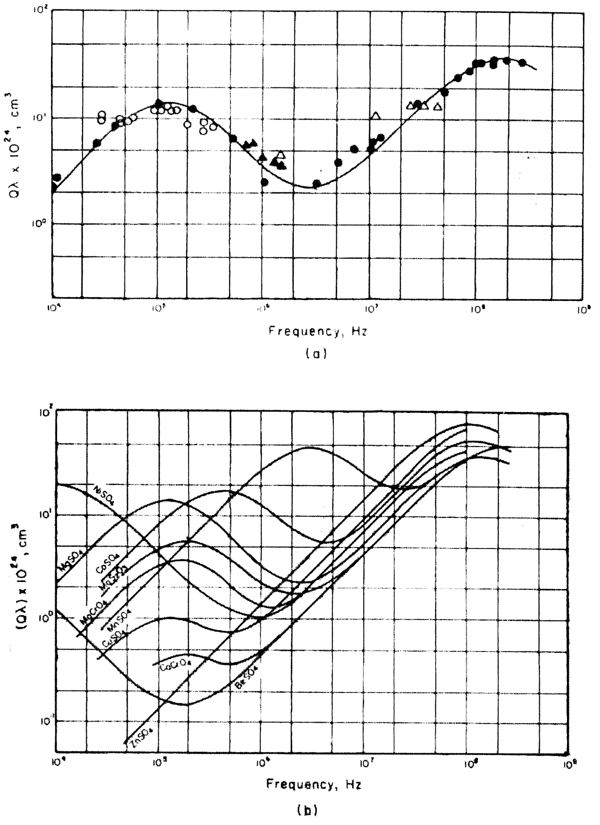


Figure 11. (a) absorption coefficient per wavelength for aqueous solution of MgSO4; (b) chemical reaction taking place (from Stuehr and Yeager, 1965) [27].

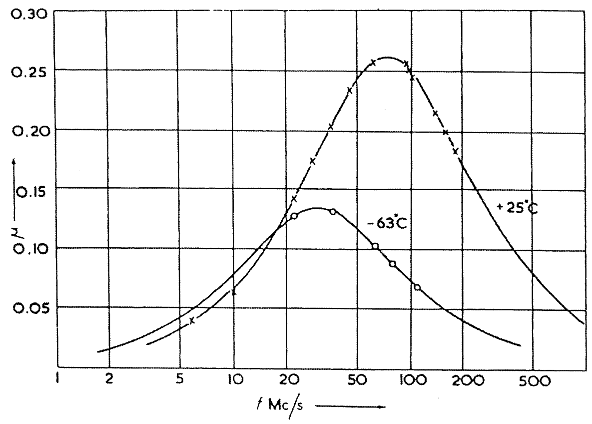


Figure 12. Relaxation of specific heat in carbon disulfide. (Andreae, Heasell and Lamb, 1956)[29].

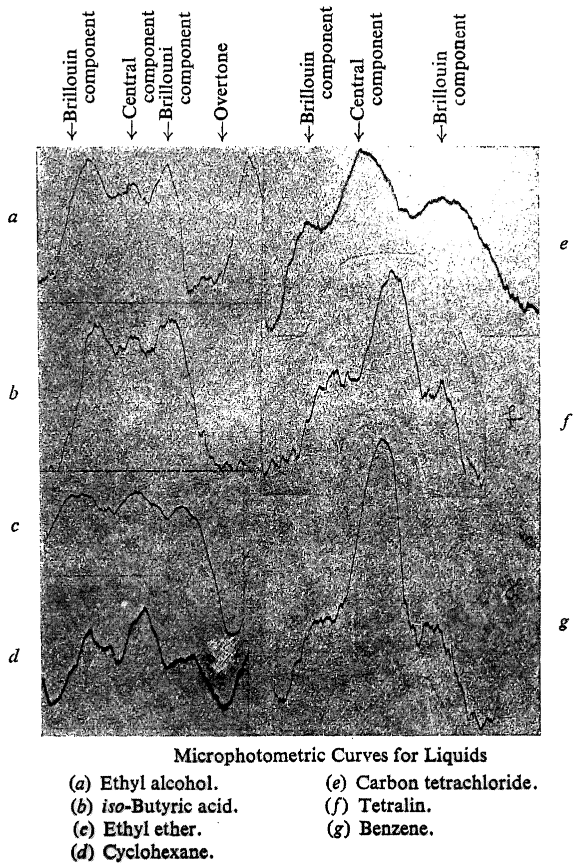


Figure 13. Brillouin scattering (Venkateswaran, 1942) [31].

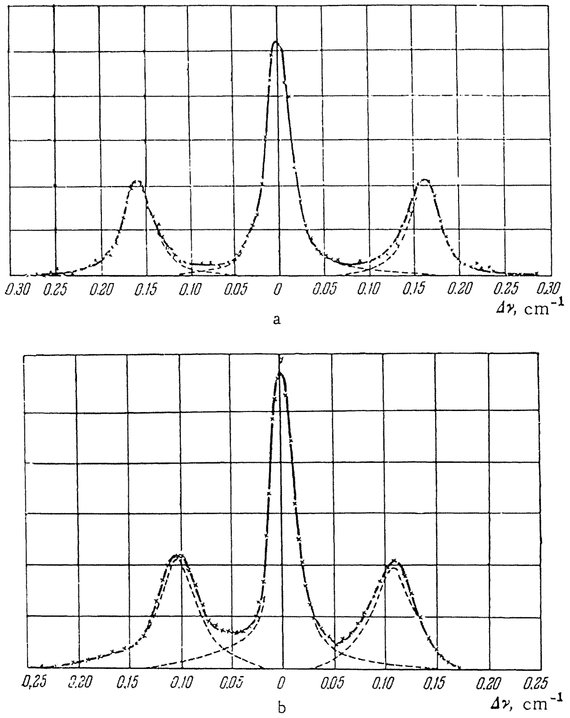


Figure 14. Brillouin scattering in (a) benzene and (b) carbon teterachloride. (Starunov, Tiganov and Fabelinskii, 1966)[32].

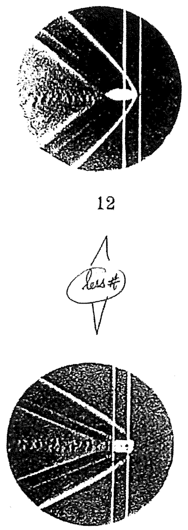


Figure 15. Mach waves from a bullet.(experimental). (Mach and Mach, 1889) [38].

might say, in Russia and in the U.S. and in Texas –the dust clouds have not yet completely settled.

Another manifestation of high intensity is the production of shockwaves. Indeed, a very high intensity sound wave is essentially a periodic series of weak shock waves. Shock waves themselves were first studied by Ernest Mach [38] in Vienna in the 1880's, and we have memorialized him by naming the velocity ratio of particle velocity to sound velocity after him—the Mach number. Examples of his measurements are shown in (Figs. 15, 16).

Another opto-acoustical effect was hypothesized by Peter Debye in 1931. At the time, Debye who was Dutch, was a professor in Berlin but was lecturing in the US. He noted that, in the time it takes for a beam of light to pass through an ultrasonic beam, placed at right angles to the light, the sound wave would move very little. The wave therefore represented an almost stationary set of regularly spaced increases and decreases in the density of the liquid, and therefore of the index of refraction, and could be used for the Fraunhofer diffraction of the light beam. This was at once verified experimentally by Sears at MIT [40], and independently by Lucas and Biquard in France. [41] A detailed theory of the process was worked out by Raman and Nath in India. [42] Finally, to complete this international effort. Otohiko Nomoto in Japan [43] presented a beautiful set of pictures of these diffraction lines, in which he demonstrated that the light in each of the scattered signals depended on a Bessel function the argument of which contained the sound intensity (Fig. 17).

The study of sound in the atmosphere brought forth a number of important discoveries that are part of physical acoustics. In the nineteenth century, both Joseph Henry in the U.S. and John Tyndall in England were busy studying the effect of fog on the transmission of sound through air. Tyndall demonstrated that fog was not a significant absorber of sound but that inhomogeneities of the atmosphere could have a significant effect on sound propagation (Figs. 18, 19). [44, 45] These ideas lead the British mathematician G I. Taylor [46] to hypothesize that large scale vortices in the atmosphere could be responsible of much of the variability of airborne sound. These ideas were given further boost by the work of the Russians Obukhov [47] and Kolmogorov [48] (1941) on the distribution of vortices and turbulence in the air (the famous "two-thirds law" that connects the energy and the scale of the turbulence.

Another significant contribution was that made by the late Sir James Lighthill. [49] Lighthill based his work on Rayleigh's ideas on the scattering of sound by inhomogeneities. In his work, Rayleigh was studying the effect of small inhomogeneities in air on sound propagation. He set up the wave equation with terms involving nonlinearities and inhomogeneities of the medium on the right hand side and linear terms on the left. He then proceeded to neglect the nonlinear terms and studied the effect of the inhomogeneities. Lighthill reversed this procedure by omitting the inhomogeneities of the medium and keeping the nonlinear ones. The result of his analysis was the identification of quadruple sound sources in the inhomogeneities of turbulence. As a result, Lighthill was able to analyze the sound generation in a fluid by turbulence, a work that has had far reaching effects in the study of the noise generated by jet engines, and in the field of nonlinear acoustics.

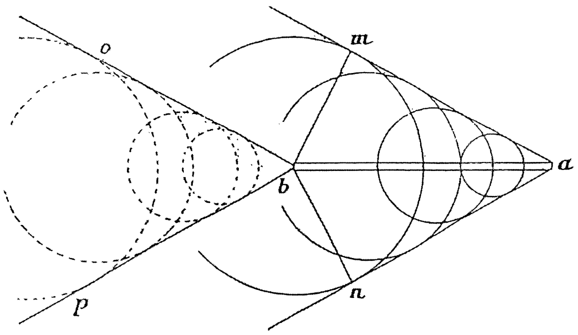


Figure 16. Mach waves from a bullet (theoretical). (Mach and Salcher, 1887)[39].

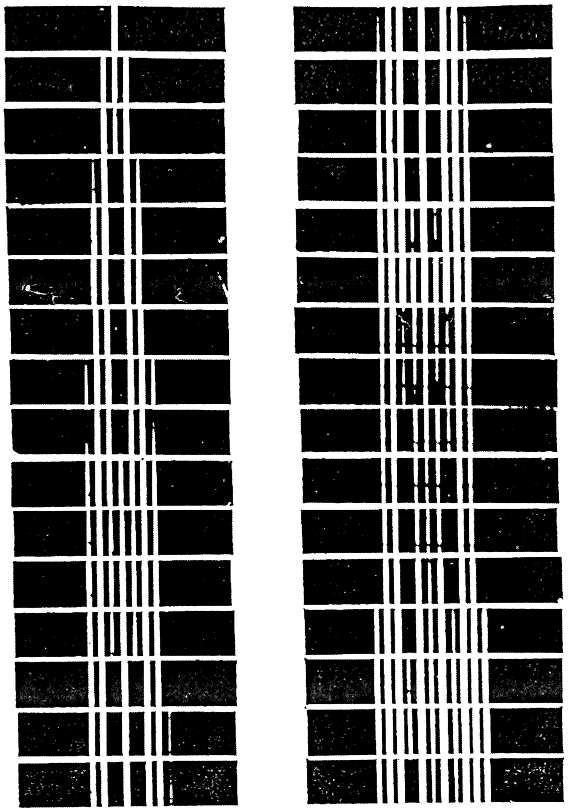


Figure 17. Debye-Sears effect. (Nomoto 1940)[43].

In the second half of the twentieth century, physical acoustics turned its attention to problems on acoustics at very low temperatures. Unfortunately for this article, much of this work has been done by Americans and is, therefore, out of bounds for me. There were, however, some very important European contributions. Second sound—the propagation of waves in superfluid liquid helium, consisting of periodic oscillations of temperature and entropy while the pressure and density remain substantially constant—was discovered by Peshkov in 1944. [50] A few years later, Landau [51] developed his theory of superfluids, making use of the concept of quantized acoustical energy, which had been suggested by Igor

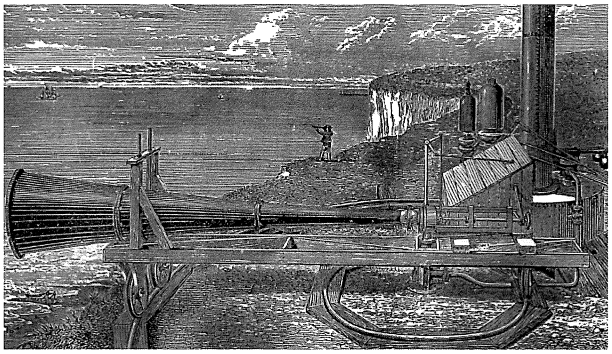


Figure 18. Foghorn at Straits of Dover. (Tyndall, 1867)[44].

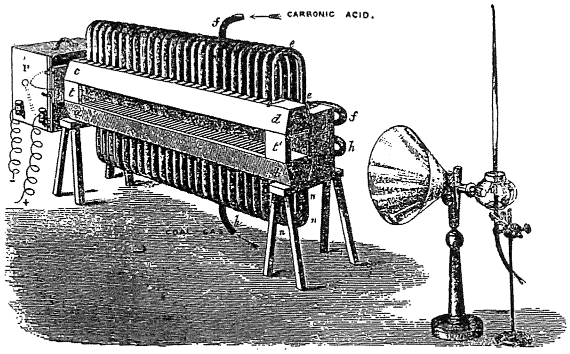
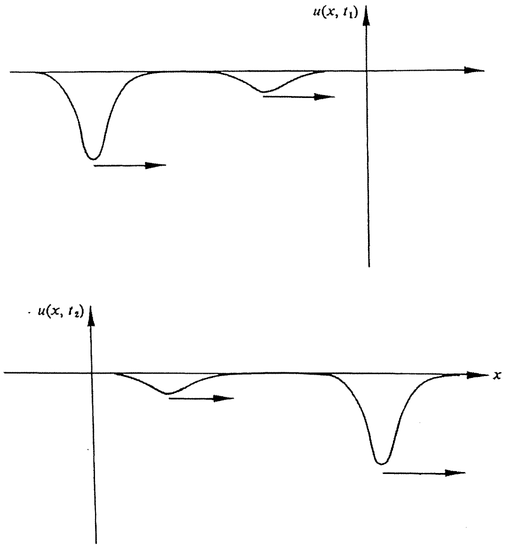


Figure 19. Simulation of scattering from inhomogeneities (Tyndall, 1867)[45].

Tamm [52] in 1930 and given the name of phonons, apparently by Jacob Frenkel [53] in 1931.

This latter work of Tamm and Frenkel pertained principally to solids and the investigation of sound propagation in solids, and experimental measurements of sound propagation in solids, especially in superconductors, were carried out extensively in the fifties and sixties. Here again, I am going out of bounds, because the work was largely done in the U.S., and besides, it's ultrasonics.

In recent times, physical acoustics has been concerned with radiation pressure and levitation, solitons and chaos, cavitation and sonoluminescence. Here again, the American and worldwide scene have been so intertwined that it is difficult to talk about one without taking the other into account. Radiation pressure in acoustics goes back to Rayleigh and to Langevin in the early part of the twentieth century, and discussions as to its nature have often appeared at meetings of the Acoustical Society of America. Most recently, it has come back into style as a mechanism for maintaining a ball or other substance in a "zero-gravity" field that is of importance in space research.



VIII.1. Interaction of solitons ($t_2 > t_1$).

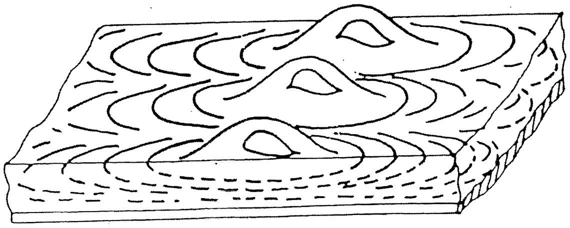


Figure 20. Solitons in water (Wei, et al.) [56].

The concept of solitons—localized disturbances that retain their shape even after interactions among themselves—was recently developed and given its name by Zabuskal and Krustal [54] but the idea goes back to J. Scott Russell [55] who observed such waves in a canal in 1848. Some samples of solitons in water, due to Wei Ronjue, [56] are shown in (Fig. 20).

In studies of cavitations, by Lord Rayleigh and many others, it has long been observed that the process of the formation and destruction of bubbles is accompanied by a noise. One example by Esche is shown in (Fig. 21) [52] This concept has been picked up by Werner Lauterborn at Goettingen. [58] In both cases, the phenomenon of period doubling is evident which provides an entry to the phenomenon of chaos, another very modern subject.

With these final comments, I have completed my tour of the history of physical acoustics outside the United States. I am happy to say that, both at home and abroad, there is much life in the old field yet.

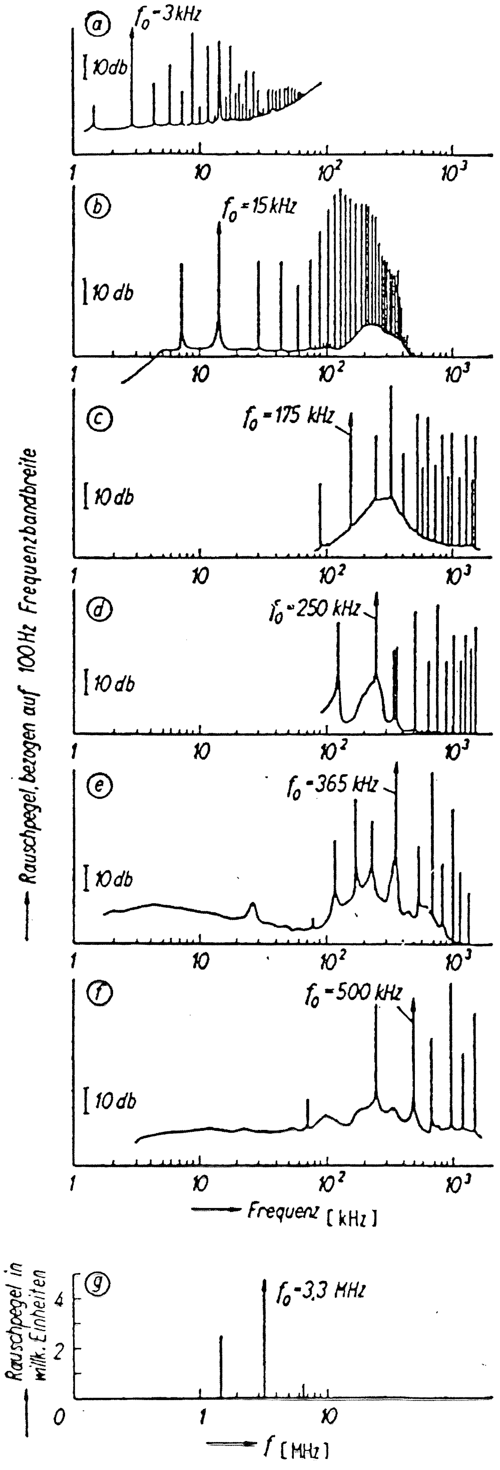


Figure 21. Spectra of acoustic cavitation noise (Esche, 1952) [57].

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Selected Topics In The History of Atmospheric Acoustics in North America 1865-1900

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We have a penchant for celebrating anniversaries. This article began as a paper given in a special session at the Washington, DC, Meeting of the Acoustical Society of America (ASA) in April 1976. The session, "History of American Acoustics." had been organized by Richard K. Cook, National Bureau of Standards (now NIST), to commemorate the American Bicentennial year and was dedicated to Bruce Lindsay.[1] The speakers and their assigned topics were as follows:

Robert S. Shankland	architectural acoustics
Hale J. Sabine	building acoustics
Hallowell Davis	psychological and physiological acoustics
John K. Hilliard	electroacoustics
Harry B. Miller	measurements and instrumentation
David T. Blackstock	physical acoustics
Marvin Lasky	underwater acoustics

My talk was narrowed to a few topics in atmospheric acoustics during the period between the Civil War and World War II. [A] All the talks listed above, except mine, were published in the February 1977 issue of the *Journal of the Acoustical Society of America (JASA).* [3]

Another version of my talk was given at the Columbus ASA Meeting (November 1999) as one of a series of acoustical history talks sponsored by the ASA Archives and History Committee. The series spanned several ASA meetings and forms the basis of the present volume, yet another commemoration, this time of ASA's 75th Anniversary, celebrated at the New York ASA Meeting (2004).

Powered by a steam-driven siren, the magnificent foghorn shown in Fig. 1 is featured as the frontispiece in the 1875 edition of John Tyndall's book *Sound.* [4] Although the setting is the white cliffs of Dover, Tyndall's foghorn was really an American invention. It had been built in the United States and given—or loaned—by the United States Lighthouse Board ("Light-House Board" in some of the literature of the time) to Trinity House in 1873. [5] The British experiments and tests on fog signaling began that year. However, the Lighthouse Board in Washington, under the leadership of Joseph Henry, had begun its experiments on fog signaling in 1865, shortly after the end of the Civil War. The steam siren (Fig. 1) was first tested in the United States in 1867.

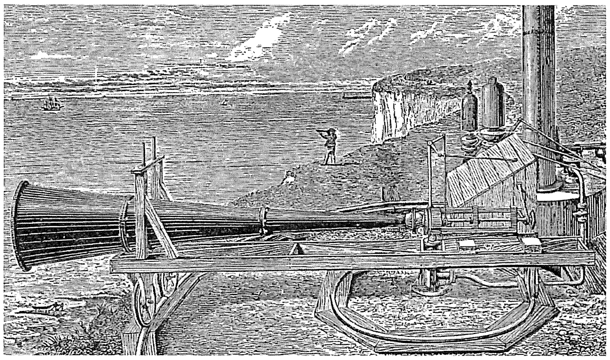


Figure 1. Frontispiece in Tyndall's book Sound. [4] Brown's steam siren produced for the US Lighthouse Board and provided to Trinity House (England) for Tyndall's fog signal experiments.

Figure 2. Joseph Henry (1797-1878). Photo by Matthew Brady, C. 1862.

Joseph Henry (1797-1878), shown in Fig. 2, is best known for his work on electromagnetic induction (though scooped by Michael Faraday, who published first), but made a wide range of contributions to science. [6] He may also have been the nation's first scientific bureaucrat. He was the first secretary of the Smithsonian Institution, which he served from its inception in 1846 for the remainder of his life, and he served as President Lincoln's science advisor during the Civil War. He made two contributions to acoustics, the first on the acoustics of public buildings, [1, 3] the second on sound propagation in the atmosphere. The latter work, described here, extended over several years and grew out of his service on the Lighthouse Board, which was given, incidentally, without salary or fee. His experiments on fog signaling began in 1865, a few months after the Civil War, and continued unabated until his death 13 years later. [7]

On first delving into Henry's papers and reports on sound propagation, I was initially dismayed by the crudeness of the work. Yet the ever-growing pace at which solid results were obtained is impressive. In 1865 coarse tests of sources were made and also the first very crude propagation observations, done with sailing vessels, which having to tack, could not follow a straight-line course. More confident evaluations of sources were carried out in 1867. Well-documented tests and experiments were made by General J. D. Duane in 1871 while Henry was away in Europe and in California. Open sea tests were conducted at four places along the New England coast during the summer of 1873. More detailed experiments, described below, were carried out in 1874, and an impressive array of measurements was made in 1875. Clearly a crescendo was building as the Centennial Year 1876 approached. Then, inexplicably, 1876 was skipped—no report for that year. Reading more carefully, I discovered the reason. Beginning the Report of the Lighthouse Board for 1877, Henry writes [8] "On account of the occurrence of the Centennial Exhibition, which absorbed most of the time of the officers of the Light-House Board..., but few observations were made relative to sound in 1876..." [B]

The main subject of this article is the fog signaling research of Joseph Henry and some later work of others logically related to Henry's research. A second subject is the first-ever measurements of sound absorption in air, by A. Wilmer Duff in 1898 and 1900.

Joseph Henry and Fog Signals

Joseph Henry's contributions to atmospheric acoustics are remarkable, given the lack of sound measuring equipment in his day. Without electronics, microphones, and loudspeakers, scientists largely relied on the ear and made anecdotal observations. False ideas about sound waves abounded. For example, locomotive whistles were mounted in bells because they sounded louder that way. Inventors commonly believed that the source of the sound was the bell, which was set into vibration by the whistle. To prove that the bell simply acted as a "resounding cavity," i.e., a resonance device, Joseph Henry showed that a wooden bell worked as well as a metal one. Another widely held belief was that fog stifled sound. Thus fog signals aren't much use because they are heavily absorbed when one needs them the most. Both Henry and Tyndall soon concluded, however, that fog is not the villain responsible for the capricious behavior of sound over great distances.

One of the first things Henry did (1865) was to develop a mechanical receiver. What he called an "artificial ear" was a conical trumpet for concentrating the incoming sound. The throat of the trumpet was curved upward and terminated by a thin membrane on which sand was sprinkled. At sufficient sound intensity the sand would begin to dance. The comparative "penetrating power" of sound from various sources could be judged by measuring the source-receiver distance at which the sand motion became barely perceptible.

Aided by his artificial ear, Henry and his associates compared various sources—bells, locomotive whistles, and something called a Daboll trumpet, which was a vibrating reed powered by a hot air engine. Experiments were also done with spherical reflectors. It was found that although the reflector strengthened the sound at near distances, say less than 500 yd, at greater distances the reflector provided no benefit. The sound was equally loud with or without the reflector. Indeed it was frequently found that, at a distance, sound behind the reflector was heard about as well as in front. [C] Henry used his findings to avoid wasting time and energy on reflectors. He did, however, find some intrinsic benefit from the use of horns. It was probably a matter of tuning or impedance matching.

The highlight of Henry's early investigations was the steam-siren, invented by a Mr. Brown of New York and tested at Sandy Hook, New York, in 1867. This was an apparatus worthy of note. The drawing for Tyndall's book (Fig. 1) gives us a somewhat exaggerated picture of the device. This particular trumpet was 16.5 ft long, 5 in. in diameter at the throat, and 27 in. in diameter at the mouth. [9] Steam pressures from 20 to 100 psi could be used. The frequency was in the neighborhood of 360 Hz.

Henry had to explain the so-called "abnormal phenomena of sound." First and most obvious of all was the extreme variability of sound transmission. For example, General Duane reported that fog whistles on the coast of Maine could sometimes be heard 20 miles away, sometimes not even as close as two miles away "and this with no perceptible difference in the state of the atmosphere." Second was the lack of reciprocity, illustrated by the following story. Observers on a steamer approaching a lighthouse suddenly stopped hearing the lighthouse fog signal at a distance of three miles. The signal remained unheard until the steamer came within 1/4 mile of the lighthouse. The entire time, however, the lighthouse keeper heard the steamer's whistle. Why? This story also illustrates the third puzzler: the "band of silence," wherein a fog signal is heard nearby and far away but not in between. Fourth was the observation that sound is generally heard better downwind than upwind. In this case Henry had available Stokes's explanation (1858) based on refraction due to wind (discussed in detail below). But in some cases sound was observed to carry extremely well against the wind. How was this to be explained? Fifth, and perhaps the strangest of all, was the aerial echo. Suppose a foghorn is aimed at completely open sea. If the signal is intense enough, a sort of echo comes back from the sea, beginning a few seconds after the direct sound pulse ends, and enduring for several seconds. To the early workers like Henry and Tyndall, especially Tyndall, it was of utmost importance to explain the aerial echo. Yet I have found hardly a reference to it in modern work.

Next consider some of the factors affecting what Henry called the "penetrating power of sound." First, the fog itself, which as already noted, was subsequently discarded as an important barrier to sound. Second, shadowing of structures located near fog signaling devices was found by Henry to be the cause of some of the observed anomalies. Third, elevation of the observer was the subject of an experiment Henry did on Block Island. Observers in a lighthouse atop a cliff, 200 ft above sea level, and at the bottom of the cliff, listened to a boat whistle from a vessel first when the observers were downwind of the vessel, then when they were upwind of it. The observer in the lighthouse heard the upwind traveling signal long after the sea level observer no longer heard it. But sound traveling downwind was heard about the same by both observers. Henry found an explanation for these results in Stokes's argument about refraction due to wind, [10] which we now consider in detail.

For clear illustration of the effect of wind, we jump ahead by about 60 years to B.R. Hubbard's review of fog signaling given in the 1931 volume of JASA. [11] (Figure 3) Hubbard's Figs. 5 and 6 show that rays of sound traveling downwind are bent downward (because wind velocity generally increases with height, the wind-augmented sound speed decreases downward, and rays always seek a region of lower sound speed), giving rise to favorable transmission. Conversely, rays of sound traveling against the wind are bent upward so that at a given distance a silent zone is formed into which no ray can enter. Henry saw that refraction due to wind explains many "abnormal phenomena." For example, if a steamer approaching a lighthouse is upwind of the lighthouse, it can easily be in the shadow zone of the lighthouse fog signal. The lighthouse keeper, however, being downwind of the steamer, has no trouble at all hearing the steamer's whistle. Henry's elevation experiment is also well explained. In the upwind case an elevated observer can hear a sound further than a sea level observer. Downwind, on the other hand, elevation does not favor either observer. The simple model shown here does not explain all the abnormal phenomena, however. For example, it does not explain why upwind propagation is occasionally observed to be quite good. And it gives no clues about the aerial echo.

Figure 4 (Figs. 1-4 in Hubbard's review) shows how refraction by an atmospheric temperature gradient affects sound transmission. A silent zone occurs if temperature drops with height, but audibility is enhanced in the event of an inversion (temperature increase with height). Also shown is how audibility is influenced by source elevation. The role of temperature gradients, not recognized when Henry began his experiments, was explained by Osborne Reynolds in 1874. [12] In 1875 Henry acknowledged Reynolds's contribution but still felt that wind was by far the more important factor.

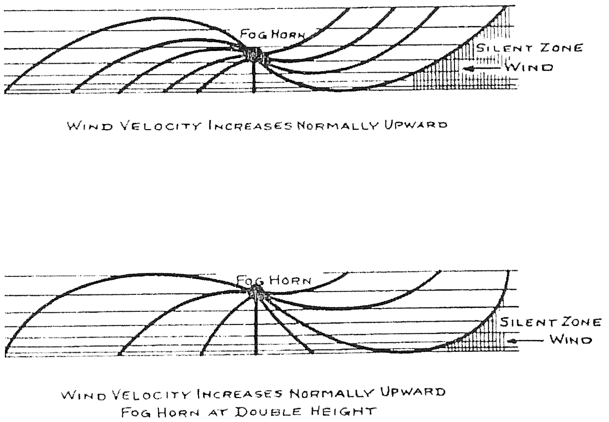


Figure 3. Effect of wind on sound propagation. From Ref. 11.

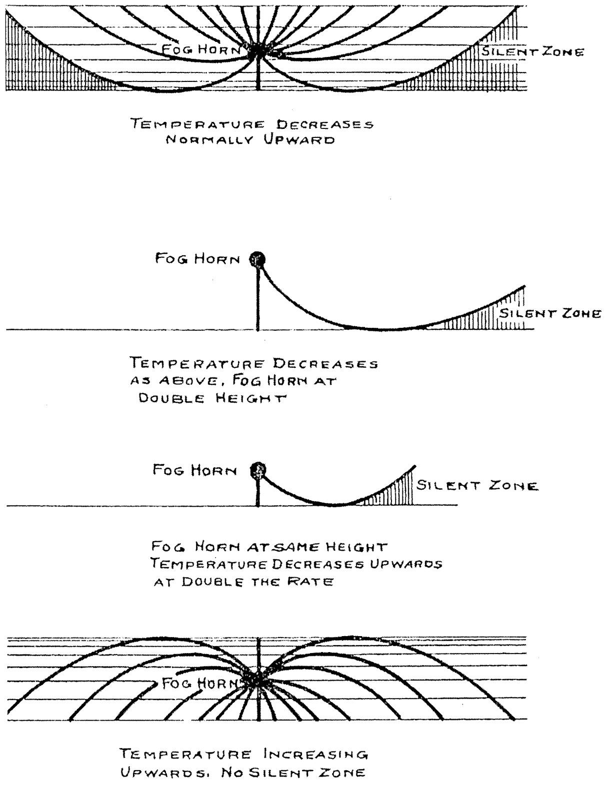


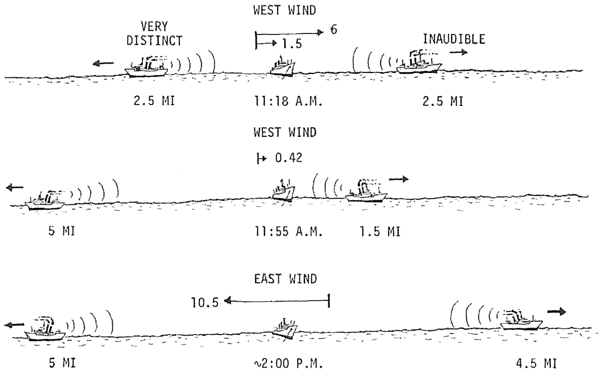
Figure 4. Effect of temperature gradient and source height on sound propagation. From Ref. 11.

Figure 5 shows an experiment Henry carried out in which the "occasionally good" reception upwind was observed. One ship steamed east, one west, each sounding its whistle. Observers on the middle ship, which was anchored, noted the distance at which each source became inaudible. During the morning the west wind (land breeze) gradually died and gave way to an afternoon east wind (sea breeze). Yet all day long the observers on the anchored ship heard the sound coming from the west better than the sound coming from the east. Henry hypothesized that, despite the wind change at the surface of the ocean, at higher levels a westerly wind prevailed throughout the day.

Figure 6 shows the refraction when the wind changes direction with altitude. The upper sketch shows normal downwind propagation. The higher velocity wind at higher altitude causes the rays to be refracted down to the observer [O]. In the second sketch, for upwind propagation, the wind shear results in an upward refraction, which throws the sound upward over the head of the observer, i.e., the observer is in the shadow zone. In the third sketch, the lower wind is unfavorable but the upper wind is favorable. Some of the rays refracted upward by the unfavorable wind are eventually caught by the favorable wind and sent back downward to reach the observer. Henry noted that the belt of silence, or skip distance, could be explained in this way.

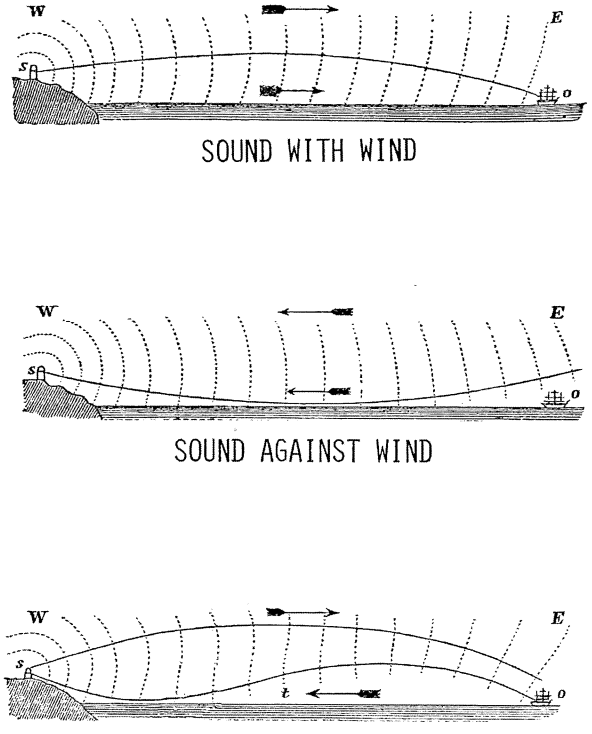
Tyndall (Fig. 7) thought all this refraction by wind business was overrated. To him, Henry seemed to be reaching for straws in postulating an opposite wind at higher altitudes. [13] Besides, how does the sound, once it has gotten up to the favorable wind and been carried by it, "recross the hostile current" below? [D] In the main Tyndall put his faith in the proposition of a flocculent atmosphere, or acoustical clouds—what today we would call atmospheric inhomogeneities. The flocculent atmosphere causes the sound to be scattered about much like light is when it attempts to pass through smoke. Thus it is reflection, not refraction, that limits the penetrating power of sound. The belt of silence about a lighthouse is thus explained by Tyndall as being due to a local acoustical cloud that happens to be passing over the locale. When the cloud has moved on or dissipated, normal sound transmission is restored. Tyndall felt that the aerial echo was the most important clue to the so-called abnormal behavior of sound. Its existence proves that there are acoustical reflectors out there. Given existence of reflectors, reflection is sufficient to explain lack of transmission. The refraction argument is superfluous.

Although Tyndall probably does have the proper answer for the aerial echo, Henry's argument about refraction due to wind cannot be denied. Figure 8 shows what must be deemed a crucial experiment. In this case two ships steam in opposite directions, sounding their whistles as they go. An observer on each ship records the distance of inaudibility of sound from the other ship. The ships go parallel to the wind, at right angles to it, and at odd angles. The measurements are all referred to a common center [C], which is then effectively the location of an omnidirectional source. The egg shaped curve you see is thus the contour of inaudibility, i.e., a directivity pat-



EXPERIMENT AT SANDY HOOK
23 SEPTEMBER 1874

Figure 5. Experiment at Sandy Hook, NY, 23 September 1874.



SOUND WITH WIND

SOUND AGAINST WIND

WIND SHIFT WITH ALTITUDE

FROM REPORT OF THE LIGHT-HOUSE BOARD FOR 1875
DRAWINGS BY WILLIAM B. TAYLOR

Figure 6. Effect of wind and wind shift with altitude. From Report of the Lighthouse Board for 1875; drawings by William B. Taylor.

tern. In the absence of wind it would be a perfect circle. The wind, however, produces the egg-shaped directivity. Can anyone doubt the role of wind in atmospheric acoustics?

Let us finally look at the aerial echo in a little more detail. Observations showed that the aerial echo

1. Was a return from the open ocean, from the direction the source pointed,
2. Began 4-5 seconds after the the direct sound finished,
3. Lasted several seconds, e.g., 8 s,
4. Required a powerful source, and
5. Was observed in all kinds of weather.

Henry was much mystified by the echo. At first he thought it might be due to reflection from waves on the ocean. But Tyndall heard the echo even when the sea surface was a glassy calm, an observation later confirmed by Henry. Property 4 means that the echo was a weak signal, too weak to be heard if the direct sound were not strong enough. As for Property 5, Tyndall asserts that the echo was always observed. Henry had the lighthouse keepers at Block Island and Point Judith record their observations of the echo every Monday for a period of one year in one case, two years in the other. Over the two-year period the echo was heard 106 times out of 113 trials, over the one-year period 50 times out of 57. Moreover, gale winds were blowing at times the echo was not heard, enough to have drowned out any possible echo.

Two of Henry's experiments to investigate the aerial echo are worthy of interest. First, in what he thought would be a crucial test, he pointed the horn of the steam siren upward—no small feat, since the cast iron trumpet weighed 800 pounds. Expecting to receive the echo from above, the observers were surprised to find that the return seemed to come instead from all points on the horizon. This experiment was carried out several times, always with the same result. Apparently, Tyndall's acoustical clouds were deep horizontally but not vertically. Second, Henry sent observers on a vessel in the direction of the echo. They found that the echo was still there but weakened as they traveled toward it. At the same time the duration of the echo increased.

Well, what about the aerial echo? I have seen little about it in modern literature. L. V. King, whose foghorn measurements made in 1913 [14] I could not, regretfully, include in this report, recorded echoes of 20 seconds duration in one case. But the people at the National Oceanographic and Atmospheric Administration, who use atmospheric sounders, do not, to my knowledge, observe the echo. [15] Admittedly their sounders are at a much higher frequency and are much more directive than the fog signals used by Henry and by Tyndall. Still it seems odd that the effect should be so little known today. A speculation is that the aerial echo is what underwater sound people call volume reverberation, except that the scatterers are Tyndall's inhomogeneities instead of fish and other material bodies.

Figure 7. John Tyndall (1820-1893).

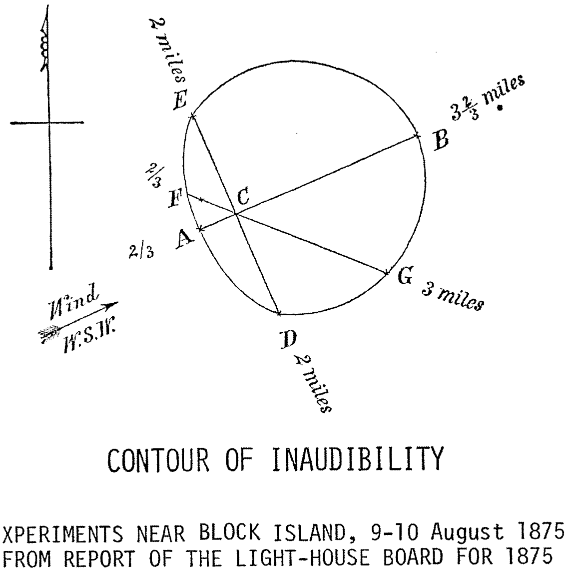


Figure 8. Experiments near Block Island, 9-10 August 1875. From Report of the Lighthouse Board for 1875.

B. Absorption of Sound in the Atmosphere

Let us leave fog signaling now and turn to the first-ever measurements of absorption of sound in air. These measurements were made in 1898, and repeated in 1900, by A. Wilmer Duff in open air at "a quiet place on the River St. John" in New Brunswick. [16,17] Duff (Fig. 9) was born in New Brunswick and received his Ph.D. in physics in Edinburgh, Scotland. He taught physics at Purdue from 1893 until 1899, when he was hired as head of the Physics and General Science Departments at Worcester Polytechnic Institute (WPI). He served WPI until 1936, won the American Association of Physics Teachers Oersted Medal in 1939, and died in 1951. [18] Like W. C. Sabine, Duff used the ear as a detector in his experiments. To measure the absorption of sound (in 1898), he used eight whistles, all at essentially the same frequency, about 7000 Hz. First, he blew two whistles and an observer moved to a distance at which the sound became inaudible. Then all eight whistles were blown and the new inaudibility distance determined. If the sound attenuation were due to spherical spreading, the second distance would be twice the first. In fact, because of sound absorption it was much less. Knowledge of the two distances allows one to determine the absorption. Duff found that the measured absorption was about six times greater than that due to viscosity and heat conduction. Because of the quiet, but varied, conditions under which the experiment was done, he did not ascribe the extra attenuation to refraction or to Tyndall's acoustical clouds. Lacking anything else, he attributed it to heat radiation and used his measurements to calculate a value for the heat radiation coefficient. Lord Rayleigh read Duff's article, which was published in the 1898 *Physical Review*, and immediately fired off an article to the 1899 *Philosophical Magazine*. [19] He didn't believe heat radiation was the explanation. He speculated that there might be absorption due to exchange of molecular energy between translational and rotation forms. Aha, the birth of the relaxation theory! But neither Rayleigh nor anyone else did any more with his remarkable suggestion. It all had to be thought out again 20 or 30 years later. In the meantime, Duff impressed by Rayleigh's surprise at the magnitude of the absorption, made another measurement, again at the River St. John in New Brunswick, in 1900. [17] This time the frequency was 4000 Hz. Figure 10 shows Duff's two values plotted on Evans, Bass, and Sutherland's 1972 graph of sound absorption in air. [20] On hearing this story at breakfast before I gave the talk in 1976, a colleague looked at Fig. 10 and commented "It's nice to see the Evans, Bass, and Sutherland curves confirmed!"

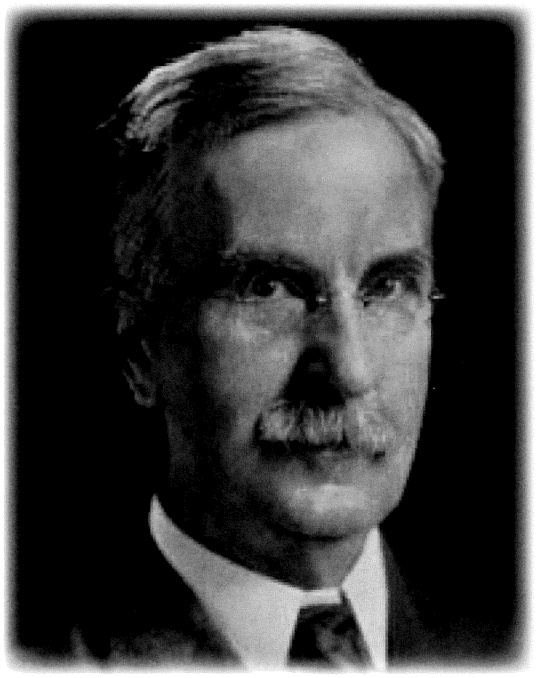


Figure 9. A. Wilmer Duff (1864-1951).

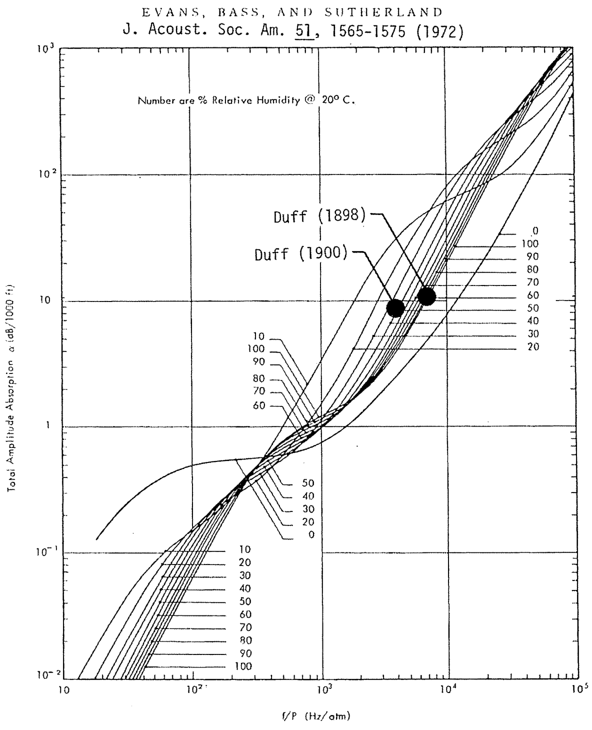


Figure 10. Duff's absorption measurements plotted on the 1972 version of the air absorption curves of Evans, Bass, and Sutherland (Ref. 20).

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19. Lord Rayleigh, "On the cooling of air by radiation and conduction and on the propagation of sound," Phil. Mag. (Ser 5) 47, 308-314 (1899).

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A. The original subject was a history of physical acoustics in North America, covering the following topics: (1) the rise of ultrasonics (undoubtedly the most important technical development), (2) finite-amplitude sound (my own field), (3) atmospheric acoustics, (4) some elements of radiation and scattering, and (5) certain special topics such as interaction of sound and light. Eventually realizing, however, that justice could not be done to all these topics, I decided to concentrate on a few developments, particularly those apparently not then widely known or appreciated, and let the rest go. For the other topics the reader is referred to the Benchmark Volume on Physical Acoustics compiled by the honoree of the 1976 Session, Bruce Lindsay. [2]

B. In the oral version of this paper given at the Washington ASA Meeting in 1976, I wondered aloud whether the many acoustical laboratories in the Washington area found history repeating itself on the occasion of the American Bicentennial that year.

C. The results cannot be blamed on too small a reflector; in modern terms the value of ka was at least 5, perhaps even 10 or greater. Diffraction from the edge of the reflector seems a more likely cause. For example, to explain the strong signal far behind the reflector, consider diffraction by a disk. The shadow cast by the disk is effective everywhere but on the axis, where the edge wave is highly correlated (scattered signals from all points on the edge arrive simultaneously) and produces a signal as strong as though the disk were not present. Relying on two ears, however, a human listener would not be able to emulate a point receiver and would thus perceive only the shadow zone. On the other hand, as separation between disk and receiver increases, the diameter of the high correlation zone increases. At sufficient distance, therefore, the human becomes a point receiver and therefore hears the edge wave strong and clear.

D. Actually Tyndall could have answered his own question by tracing a few rays; the lower current can be recrossed at plenty of angles.

Physical Acoustics Timeline

550 BC	550 BC Pythagoras relates length of vibrating string to pitch.
1400's	(late) Leonardo da Vinci identifies an early form of the principle of superposition, shows that sound has a finite velocity, and uses a tube to listen to underwater sound.
1638	(circa) Galileo explains the relation of pitch to frequency, consonance, dissonance, the frequency ratios corresponding to musical intervals, vibratory resonance, sympathetic vibrations, and the quantitative dependence of a the frequency of a vibrating string on it length, diameter, density, and tension.
1654	(circa) von Guericke and later Boyle & Hooke show that sound does not propagate in a vaccum.
1686	Newton characterizes sound as pressure pulses transmitted through neighboring fluid particles. Computes the speed of sound in a gas by assuming condensation is proportional to pressure with the result being lower than the correct value by around 16%.
1765	Euler publishes model equation for finite-amplitude waves.
1808	Poisson finds an exact solution to describe the propagation of finite-amplitude waves.
1816	Laplace correctly computes the speed of sound in a gas by assuming adiabatic conditions.
1845	Stokes relates attenuation of sound to the viscosity of fluids.
1859	Rijke studies heat-driven acoustic oscillations in tubes with flow.
1860	Helmholtz publishes the theory of the resonator that now carries his name.
1868	Kirchhoff finds the spatial absorption for sound in a viscous, heat-conducting gas.
1870	Rankine publishes fundamental equations describing shock wave propagation (later also published by Hugoniot in 1889 and partially derived earlier by Stokes).
1877	The first edition of Rayleigh's *The Theory of Sound* is published.
1880	Brothers Curie discover the piezoelectric effect.
	A. G. Bell uses photoacoustic effects to transmit sound by modulation of light.

Physical Acoustics Timeline

1898 •••• A. W. Duff publishes "The attenuation of sound and the constant of radiation of air," Phys. Rev. (Ser. 1) 6, 129-139 (1898). Following a comment by Lord Rayleigh "On the cooling of air by radiation and conduction and on the propagation of sound," Phil. Mag. (Ser 5) 47, 308-314 (1899), Duff reports a second set of measurements in "The attenuation of sound," Phys. Rev. (Ser 1) 11, 65-74 (1900).

1911 •••• Love describes propagation of elastic waves in a layered half-space and identifies the horizontally-polarized shear horizontal wave later to bear his name.

1927 •••• Wood and Loomis describe in detail their ultrasound studies including heretofore unfamiliar phenomena such as some chemical and thermal effects, acoustic production of emulsions and fogs, and biological effects.

1933 •••• Vern Knudsen makes the first accurate measurements of atmospheric absorption using vacuum tube technology in a reverberation room.

H.O. Kneser develops the first theoretical model of the molecular relaxation part of atmospheric absorption considering only oxygen relaxation.

1934 •••• Discovery of sonoluminescence by Frenzel and Schules.

1937-39 L. Landau, G. Rumer, and A. Akheiser, the beginning of theory for attenuation of ultrasonic waves in solids due to interaction with thermal phonons.

1944 •••• Peshkov observes second (thermal) sound in superfluid helium.

1947 •••• Isadore Rudnick publishes the pioneering work on sound propagation from a point source over a locally reacting acoustic impedance plane based in part, on prior research on propagation losses of EM waves by Sommerfeld (1909), van der Pol (1935) and Norton (1937).

1948 •••• M. Greenspan tracks propagation in gas from the hydrodynamic to the collisionless regime.

1950's •• Noltingk, B.E. and Neppiras, E.A. develop theory for cavitation bubble in ultrasound field.

1951 •••• A. Kastler, the theory of interaction between ultrasonic waves and nuclear spins published.

Wulff, Fry, Tucker, Fry, and Melton produce ultrasonic effects on nerve activity and show that temperature increase is not responsible.

1952 •••• Hueter reveals the much greater absorption exhibited by bone and its different frequency dependence, compared with soft tissues.

Lighthill founds the study of aeroacoustics.

Physical Acoustics Timeline

***1953* ••••**	Carstensen, Li, and Schwan, in studies with blood and various blood proteins in solution, show that a major fraction of the absorption in biological materials occurs at the molecular level.
***1954* ••••**	H. Bömmel and, independently, L. Mackinnon observe effect of superconductivity on ultrasonic attenuation. Results in accord with BCS theory.
***1955* ••••**	(circa) R. K. Cook uses infrasound to detect California surf at the Bureau of Standards in Washington, DC.
***1956* ••••**	A.V. Granato and K. Lücke, vibrating string model of dislocation damping in solids.
	Biot's theory on a porous medium.
***1959* ••••**	Wiener and Keast observe refractive shadow zones for propagation near the ground.
1959-61	E. H. Jacobsen, E. B. Tucker, M. E. Browne, W. I. Dobrov, the interaction between electron spins and phonons observed.
1959-62	Zverev and Kalachev develop transmitters and receivers based on nonlinear sound-sound interaction (in USA-parametric antennas) (done in parallel with Westervelt in USA but declassified and published later in 1970).
***1963* ••••**	Tiersten publishes studies on thickness vibrations and wave propagation of piezoelectric plates.
	Westervelt publishes theory of the parametric array.
***1964* ••••**	L. E. Hargrove, R. L. Fork, and M. A. Pollack introduce acousto-optic mode locking of lasers.
***1965* ••••**	Shapiro and Rudnick observe fourth sound in superfluid saturated porous media.
	White and Voltmer invent the interdigital transducer for generation of surface acoustic waves.
***1968* ••••**	Nyborg details the biophysical action of a single bubble vibrating under the influence of an ultrasonic field.
***1969* ••••**	Pickar and Adkins observe third sound in atomically-thin films of superfluid helium.
	Joe Piercy defines the role of nitrogen molecular relaxation in atmospheric absorption.
***1970* ••••**	Rooney demonstrated "single-bubble hemolysis"; i.e., hemolysis produced by micro-streaming near a single vibrating bubble.

Physical Acoustics Timeline

1971 •••• Zabolotskaya, Khokhlov, and Kuznetsov develop the equation for nonlinear acoustic beams with dissipation, now called the KZK equation.

H. H. Demarest and O. L. Anderson make breakthrough advances leading to Resonant Ultrasound Spectroscopy.

1978 •••• Daigle, Piercy, and Embleton observe turbulence-induced decorrelation of direct and ground-reflected sound energy outdoors.

1979 •••• J. D. Maynard, G. A. Williams, S. J. Putterman, and I. Rudnick discover Fifth sound in superfluid helium.

1980 •••• Crum measures the growth of bubbles by rectified diffusion.

N. Rott publishes his theory of thermoacoustics.

1983 •••• Patent on first thermoacoustic refrigerator issued to Wheatley, Swift and Migliori.

Raspet, et al. adopt the FFP program to propagation in a layered atmosphere over an impedance plane.

Full understanding of wave interaction with ground surface evolves from several investigators including Attennborough, Bass, Raspet, Lee, Hayek, etc.

J. D. Maynard and E. G. Williams patent Nearfield Acoustic Holography.

1984 •••• H.E.Bass, L.C. Sutherland, J. Piercy and L. Evans publish the detailed theory of sound absorption supported by an extensive review of available laboratory and field measurements.

1984 •••• Junru Wu, Robert Keolian and Isadore Rudnick observed "nonpropagaing hydrodynamic solitons".

1986 •••• Suslick publishes first determination of temperature during sonochemical reaction.

1988 •••• Discovery of stable single-bubble sonoluminescence by Felipe Gaitan.

Moldover et al. at NIST use a spherical, argon-filled acoustic resonator to re-determine the universal gas constant R with a standard uncertainty of 1.7 parts per million. CODATA recommends their result in 1998.

Marston gives a geometrical theory of diffraction (GTD) for elastic wave contributions to the scattering by smooth elastic objects in water.

Physical Acoustics Timeline

1989 ••••	White and Gilbert introduce numerical solution of the parabolic equation to atmospheric acoustics.
1990 ••••	Suslick and Grinstaff report sonochemical preparation of protein microspheres, a synthesis of ultrasonic echo contrast agents.
1991 ••••	Putterman and Barber observe picosecond flashes from stable single-bubble sonoluminescence.
1999 ••••	Moldover et al. at NIST combine acoustic and microwave resonances to measure the errors of the International Temperature Scale of 1990 from 217 K to 303 K with a relative standard uncertainty of 2.5x10^-6.
	Backhaus and Swift publish thermoacoustic-Stirling engine.
2002 ••••	Taleyarkhan et al. report in *Science* evidence of nuclear emissions during acoustic cavitation in deuterated liquids. To date, unconfirmed.

Past and Present Chairs of the Technical Committee on Physical Acoustics

1960-61	Theodore Litovitz
1961-63	Isadore Rudnick
1963-64	Robert T. Beyer
1964-66	Herbert J. McSkimin
1966-67	Hans E. Bommel
1967-68	Ronald K. Eby
1968-71	Mack A. Breazeale
1971-73	Bill D. Cook
1973-75	Osman K. Mawardi
1975-77	Frederick H. Fisher
1977-79	Robert E. Apfel
1979-84	Walter G. Mayer
1984-87	Anthony J. Rudgers
1987-90	Gilles A. Daigle
1990-93	Wayne M. Wright
1993-96	Anthony A. Atchley
1996-99	James M. Sabatier
1999-02	Robert M. Keolian
2002-	Thomas J. Matula

Recipients of the Silver Medal in Physical Acoustics

1975 - Isadore Rudnick - For his definitive contributions to many areas of physical acoustics, and particularly for his ingenious experimental investigations of third and fourth sound in superfluid helium.

1977 - Martin Greenspan - For his experimental and theoretical contributions to physical acoustics, particularly of sound in gases and liquids.

1979 - Herbert J. McSkimin - For his contributions to science and engineering through research in physical acoustics.

1985 - David T. Blackstock - For contributions to our understanding of the propagation of finite amplitude sound through the use of the Burgers equation and weak shock theory and for national and international leadership in nonlinear acoustics.

1988 - Mack A. Breazeale - For pioneering work on nonlinear phenomena in ultrasonic wave propagation in solids and liquids.

1991 - Allan D. Pierce - For many significant contributions to acoustics: Its basic principles and applications.

1994 - Julian D. Maynard - For contributions to the thermodynamics of He II and to Anderson localization; to nearfield acoustic holography and acoustic spectroscopy.

1997 - Robert E. Apfel - For contributions to the understanding of acoustic cavitation, acoustic radiation pressure, and the bioeffects of medical ultrasound.

2000 - Gregory W. Swift - For theoretical and experimental contributions to the development of thermoacoustic engines.

2003 - Philip L. Marston - For contributions to generalized ray theories for acoustical scattering, and the acoustical manipulation of fluids to study fundamental phenomena in fluid mechanics and optics.

Recipients of Interdisciplinary Silver Medals

Silver Medal in Theoretical and Applied Acoustics

1983 - Eugen J. Skudrzyk - For his extensive contributions to the advancement of acoustics through his tireless multifaceted activities as author, researcher, and teacher.

Silver Medal in Physical Acoustics and Bioresponse to Vibration

1990 - Wesley L. Nyborg - For technical contributions in the application of physical acoustics to biology and medicine.

Silver Medal in Physical Acoustics and Engineering Acoustics

1993 - Steven L. Garrett - For leadership in transferring fundamental concepts of fiber optics and thermoacoustics into practical applications.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Engineering Acoustics and Physical Acoustics

1997 - Gerhard M. Sessler - For contributions to electret transducers and the understanding of sound propagation in gases.

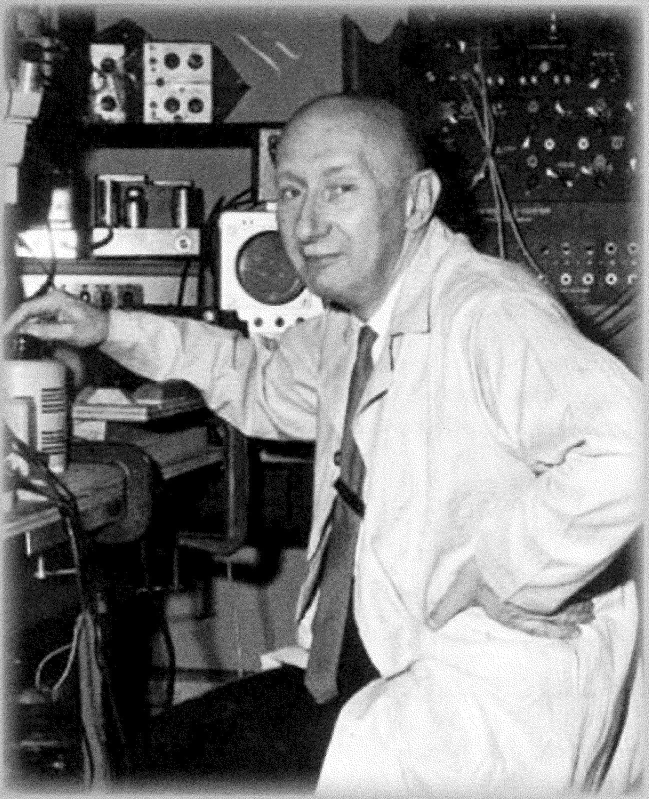
Helmholtz-Rayleigh Interdisciplinary Silver Medal in in Physical Acoustics and Biomedical Ultrasound/Bioresponse to Vibration

2000 - Lawrence A. Crum - For advancing the understanding of the physical, chemical, and biological effects of acoustic cavitation and of high-intensity ultrasound.

Chapter 12

Psychological and Physiological Acoustics

Viginia M. Richards, Chapter Editor
History Lectures, Ira J. Hirsh & Murry B. Sachs



Psychological and Physiological Acoustics

Introduction

The scope of the Psychological and Physiological Acoustics Technical Committee of the Acoustical Society of America includes "the investigation and the dissemination of information about psychological and physiological responses of man and animals to acoustic stimuli." This statement encompasses the essence of the study of hearing the study of what we hear and how we hear it. The ensuing research, scholarship, and educational efforts bridge many disciplines associated with the hearing sense. Moreover, the Psychological and Physiological Acoustics Technical Committee is not isolated within the Acoustical Society of America; there is cross-fertilization between a number of sub areas, including Animal Bioacoustics, Architectural Acoustics, Noise, and Speech Communication.

To provide an overview of the history of the important technical, theoretical, and even practical aspects of the study of the psychology and physiology of hearing is a daunting, if not impossible, task. In their reviews, Professors Ira J. Hirsh and Murray B. Sachs provided well researched, and at times charming, historical reviews of the research questions, the theoretical approaches, and the progress researchers have made answering fundamental questions about how we hear. Concordant with research published in the Journal of the Acoustical Society of America through the past seventy-five years, the current reviews emphasize basic questions concerning auditory perceptions and the anatomy and physiology of the peripheral auditory system. Both chapters also look to recent advances; one needs only to consider recent research concerning hearing loss and deafness in order to appreciate the import of the foundational work successfully completed during the past seventy-five years. Also of note are the descriptions of the how changes in electronic technology, and now biotechnology, have impacted on the evolution of hearing research. In his chapter, Dr. Hirsh (who gratefully acknowledges the editorial help of Neal Viemeister and Dennis MacFadden) organizes the history of psychological acoustics by linking together research on fundamental questions concerning auditory perception what is absolute sensitivity for most human listeners, how well can listeners determine the location of a sound source, etc. Dr. Sachs, on the other hand, organizes his chapter on physiological acoustics by starting with a current model of the peripheral auditory system, and then describing the variety of work that has led to our current understandings. As the chair of the Psychological and Physiological Acoustics Technical Committee,

I extend a heartfelt thank you to Drs. Hirsh and Sachs for their efforts, and the resulting chapters.

Viginia M. Richards, Chair
Technical Committee on Psychological
and Physiological Acoustics

Psychoacoustics and The Acoustical Society Of America

Ira J. Hirsh, Washington University &
Central Institute for the Deaf

What follows is a bird's-eye view of psychoacoustics, with chief emphasis on the relation between that field and the 75 years of this Acoustical Society of America. The limitations of a single viewer of all the research that could be included are enormous. I can describe matters that seem to this bird major steps along the way. For many of these matters the reader will be referred to secondary sources where the subject is summarized well. Areas of research of great interest to others may not be well represented here.

In 1929, this Society was founded, and the first *Journal of the Acoustical Society of America* (JASA) was published. In fact, the first few volumes of "acoustics" was largely about "hearing," a subject matter that is now of principal concern to only one or two of many Technical Committees within the Society.

This Society's first President, Harvey Fletcher, also had a regular day job at the Bell Telephone Laboratories (BTL). He assembled a remarkable group of scientists and engineers whose names are well known for fundamental papers on auditory capacities in the 1920s and 1930s. The goal, the design of the best telephone system that could be produced, was based in part on characteristics of listeners. The principal features concerned the minimum acoustic energy for hearing at different frequencies, the magnitude of the smallest change in frequency and in intensity that was noticeable, and the masking effects of one sound on another. An early summary of this aspect of psychoacoustics, along with much about speech and speech perception, appeared in Harvey Fletcher's *Speech and Hearing* (1929).

I mention Fletcher first, in part because of his great contributions and that of his group, and in part because of the context of this "acoustical society." In this chapter we are concerned with "psychological acoustics," the psychological aspect of acoustics, or more simply "psychoacoustics." If we flip the coin, then we could as well refer to the "acoustic" or "auditory" aspect of psychology, represented in laboratories and books of experimental psychology, especially in chapters on "hearing." Such early work is found in Helmholtz's *Lehre von den Tonempfundingen* (1863). By that year, we also had the beginnings of psychophysical methods from G.T. Fechner, and sensitivity to differences from E.H.Weber. Robert Woodworth's *Experimental Psychology* (1938) contains, in its chapter on hearing, a great summary of what was known. More detailed information on both psychological and physiological acoustics was published in the same year (1938) in *Hearing* by S.S. Stevens and H. Davis, a classic for students in psychology, acoustics, and, more recently, audiology.

Auditory Sensitivity - Absolute and Differential

Absolute threshold

How much acoustic energy must be delivered to the ear for a listener to respond that he heard something? Does that energy depend on the frequency of a tonal signal? Such questions were important, not only for the designers of telephones, but also for describing a capacity of human listeners and the assessment of hearing loss, or degree of hearing impairment. Sivian and White (1933) published their results in JASA. That early work was followed by hearing surveys and reports from other laboratories. Licklider (1951) put several different results together and eventually there were agreements across national borders, principally through the International Organization for Standardization (ISO).

The availability of these measures of thresholds for tones of different frequencies permitted an increase of serious measures of hearing loss. Eventually international standards, contributed largely by members of this Society and its Committee on Standards, were agreed.

Differential sensitivity for intensity and frequency

Given that a sound is heard, what do we know about differences between different sounds? The reports of Shower and Biddulph, in 1931, followed the earlier report of Knudsen (1923) on the smallest noticeable difference or change in frequency. Just-noticeable differences (JNDs) for intensity were reported by Riesz in 1928.

These early reports on both absolute and differential sensitivity, as well subsequent reports covering a large corpus, are well summarized in Green (1988).

Masking

Discriminating between two tones of different frequency or of different intensity is not far from discriminating between a noise and that same noise with a tone in it. Thus masking can be regarded as another example of discrimination.

The classic paper on the masking of tones by tones was by Wegel and Lane (1924), who showed that low-frequency tones can mask higher-frequency tones better than the higher on the lower. There were also clear dependencies on frequency, and also peculiar discontinuities in the functions, presumably due to beats near the coincident tones (the masked and masker). The wrinkles were ironed out by Egan and Hake (1950), who used a narrow band of noise instead of the masking tone. Here the masking functions were simpler.

In 1940, Fletcher proposed that when a white noise masked a pure tone, only a narrow band of noise around that tone was effecting [sic] the masking. He suggested further that this "critical band" at any frequency was that band whose total energy was equal to that of the tone being masked. But a "critical band" was used by Zwicker, Flottorp and Stevens to describe loudness integration as bands were enlarged. Many authors favored use of "critical ratio" as a term better associated with the masking experiments.

Binaural masking

Somewhat more complicated was the masking of tones or speech by noise delivered to both ears. One had to take into account the phase or time relations between signals and noises at the two ears (Hirsh, 1948). The effects were robust and challenged simple notions of masking at the periphery only. (Yost and Trahiotis have had copied or reprinted a large number of relevant articles in "The MLD: A collection of seminal papers.")

Psychological Attributes of Sounds

Most listeners can describe the degree of loudness or of high or low pitch in common parlance. The earliest goal of the new psychophysics (1850) was to establish a relation between the psychological aspect of subjective dimensions and the pertinent aspect of the physical (in this case the acoustic) stimulus.

Decades of studies with listeners' estimations of the loudness of sounds, fractionation and matching procedures, have yielded solid relations between loudness and intensity, pitch and frequency and applied scales like "perceived noisiness" (Miller, 1974). Indeed, these procedures have been extended to other sensory domains like vision and touch (see Stevens, 1951).

Pitch and frequency analysis have been the key to emphasize the association with a biological mechanism, like "place" along the cochlea or among nerve fibers. (See especially, Moore, 1993.)

Method and Theory

Signal detection

Psychophysical procedures, formalized by Fechner in 1860, and with newer varieties, were used by psychologists, engineers and physicians to explore the sensory characteristics of humans. In general those classical procedures yielded results on sensitivity that contained information not only about sensitivity but also about factors related to listener's criteria in listening tasks. Then, about 100 years later, application was made from the theory of signal detectability (TSD) to psychophysical investigations in which one could separate detectability from other aspects of decision-making. Reviews of much of the work as applied to auditory psychophysics can be found in Green and Swets (1966), and in Tanner and Sorkin (1972). TSD has been important in psychophysical theory, not only in sensory science, but also in more general decision tasks. We learned, or were reminded, that a listener brings to the task of discrimination a variety of factors other than those associated with a barrier or assumed "threshold" in the auditory mechanism itself—expectations, degree of attention, costs and rewards.

Auditory processing

Throughout the 75 years of the ASA, and before, scientists have sought to know how the hearing system does what it does. There have been explanatory theories or models based primarily on biological mechanisms. These have been alluded in Murray Sachs' companion chapter on Physiological Acoustics in this monograph. Other schemes have been rational, often mathematical, systems that may be purely formal, or explanatory through a physical, often electronic, model. If we can describe such a system that behaves in the same way, as do listeners, then we have a theoretical model in physical terms.

Temporal processing

For some time in this history, the stimulus dimensions studied concerned the spectrum: intensity, frequency, bandwidths, etc. It has been clear, however, that the acoustical message in any sound must also describe how the message evolves in time. The oscillogram gives a spatial display of long-time and short-time temporal changes. The former is a major aspect of speech and musical sounds. The latter describe the fine temporal grain within brief signals. A fine summary of theories concerning such time varying changes is given by Viemeister and Plack (1993). Identification of longer signals and signal sequences is treated by Hirsh (1988).

Auditory perception

Psychoacoustics has sometimes been characterized as the esoteric aspects of auditory processing, especially cochlear mechanisms, the details of psychophysical procedures, the relevance for theories of auditory processing. It has not, until recently, been closely associated with the auditory perception of speech, of natural sounds, or of music.

The limitation of the stimulus properties to be studied was really a limitation of the instruments available at any given time. Sound-level meters, wave analyzers, and filters served well the steady state. But music had a time pattern, often laid out in a space on a score. Speech sounds were displayed in Fletcher's 1929 book by oscillograms, and were later rescued by the sound spectrograph. Now we could think about temporal grain and the minimum interval between two sounds, and about order in which elements in an auditory display followed each other (Hirsh, 1959, 1974; Bregman, 1990). These were some of the now available dimensions to expand the repertoire of studied sound patterns.

Auditory perception of space

The localization of sound sources in a listener's environment is one of the oldest subjects in psychoacoustic research. Studies in the late 19th century had already established that the judgment of the laterality of a sound source was related to differences in intensity or in time of arrival of the sounds at the two ears. A summary of experiments of these dependencies is given by Wightman and Kistler (1993). In addition, there are other contributions of the particular individual distributions of the sound pressure at the eardrum from sounds emanating from different azimuths (Shaw, 1965; Wightman and Kistler, 1993). Human listeners show a remarkable ability to focus on the earliest of a series of reflections in a room—the precedence effect. An early synthesis with earphones was reported by Wallach, Newman and Rosenzweig (1949) and clarified many of the limits.

Perception of speech

Fletcher's group at the Bell Labs explored auditory psychophysics to assist in predicting the intelligibility of speech through different telephone systems. How to validate the relation? In characteristic manner, that group created a variety of syllables, words, and sentences to be used in listening tests, where the most frequent measure was 'percentage correct.' Much of that early work was summarized in Fletcher's 1929 book and was extended by Egan at Harvard's Psychoacoustic Laboratory, by the group at Northwestern University, and by Hirsh at Central Institute for the Deaf.

The relevance of measures of sensitivity to differences in pure-tone frequency or in intensity for predicting speech intelligibility was not clear then, and is really not very clear now. But of course the basic levels of intensity and bandwidths of a transmission system were clear and were useful in telephone and radio communication. In fact, those two principal dimensions form the basis of an Articulation Index for just such predictions of new designs (French and Steinberg, 1947) and later was applied to hearing-aid design and selection.

A scheme that relates speech perception to the frequencies and intensities in a transmission system is important in designing such systems. But as a theory of sound-to-speech, the spectrum is not sufficient. Students of speech perception are going beyond characteristics of the spectrum and even the temporal features of syllables to aspects of the ensemble of words and still larger units, and include aspects of the listener's language history. Perhaps such characteristics go beyond acoustics, but they are coming to occupy readers and speakers at ASA meetings and publications.

Applications

Noise

One theme that runs throughout the history of this Society is noise—an interest for several of our Technical Committees. The simple physical definition of noise is its non-regular repetition, its random character. The subjective annoyance aspect of noise was treated by Laird in Vol.1 of JASA. As it grew to affect working environments, schoolrooms, communities around airports and highways, annoyance was studied, calculated in various schemes—especially during the last 50 years.

The many-faceted problems around noise were a great fit for this Society. The problems required the talents of physicists, noise-control and machine-design engineers, psychologists, audiologists, otolaryngologists, and land-use planners. Technical symposia and Society committees were at work, in parallel with efforts in, for example, the National Research Council (NRC) that profited from the model of this Society in bringing these specialties together in the Committee on Hearing and Bioacoustics and Biomechanics (CHABA) under the NRC, along with our own Standards Office. In this enterprise, Edgar Shaw, Henning von Gierke, William Galloway, Karl Kryter, Ken Eldred and many others provided the breadth that was necessary to bring measurements, psychological scales, community surveys and principles of noise reduction together.

Studies that related spectrum, level, intermittency and other predictors of masking played an important role in estimating how much interference with speech communication could result from ambient noise. In addition, a serious health problem was the loss of hearing from exposure to high levels and durations of noise, particularly important in noisy workplaces. The attendant literature is huge. A concise summary of these various effects of noise is the report by Miller (1974). It was not just our literature, but also our societal responsibilities that came to the fore—in our own standards program, in our participation in international standards and cooperation with other societies and governmental agencies. These efforts showed the strength of having an Acoustical Society that involved various specialties from physics and engineering, from biology and psychology, and from medical and legal points of view. Agencies within our government as well as from other countries have followed similar patterns.

Retrospective

During the 75 years of ASA's existence, psychoacoustics has evolved from studies of sensory capacities to bridge parallel development in physiology and in communication theory within this hospitable Society, which accommodated varieties of specialties. The development of theory in several lines has enhanced our ability to understand and explore complex perceptual and artistic domains.

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The History of Physiological Acoustics

Murray B. Sachs, Johns Hopkins University

When Neal Viemeister asked me to give a lecture on the history of physiological acoustics, I was reminded of a time when I was playing ball with my sons and their friends. One of the kids picked up my Stan Musial mitt and asked innocently "who is Stan Musial?" The question went right through me. Who wouldn't know about my childhood hero! Recently a graduate student in our lab had the temerity to ask, "who is Jerzy Rose?" That question struck even deeper, for I had only idolized Stan the Man from afar, but I had known Jerzy "up close and personal." The crowning blow came when a postdoc in our department told me he had thought that Nelson Kiang was my first student! Of course nearly the inverse was true—I was one of Nelson's early students. I realized that we were failing to pass on the rich historical perspective of our field to the next scientific generation, and so with some trepidation I accepted the invitation to give the lecture.

The first two papers that I could find in JASA that might be called "physiological acoustics" appeared in Volume 2 in 1930 and in more or less direct ways they portend the future of the field. A paper by Smith and Laird (Smith and Laird 1930) on effects of noise on stomach contractions could be considered an early precursor of the rapidly growing literature on cross-modality interactions in the system (Kanold and Young 2001). Firestone's analysis of interaural acoustic differences for tones in the same volume (Firestone 1930) gives rise to an enormous literature on this topic. The next paper was an invited talk by Hallowell Davis at the 1934 Meeting of the Society

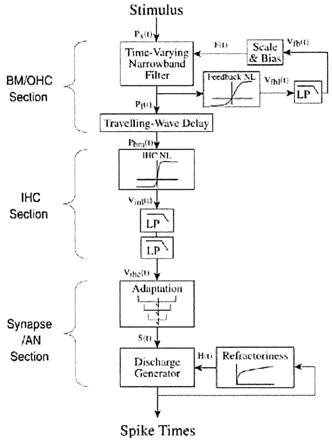


Figure 1. Model of stimulus processing in the peripheral auditory system. From (Carney 1993).

in Pittsburgh, published the next year in Volume 6 (Davis 1935). Davis presented some of his seminal observations on cochlear electrophysiology.

Throughout the history of the Society the primary focus of the *Journal* in physiological acoustics has been on the on the peripheral auditory system. In this review we focus on three parallel thrusts in the history of our understanding of the peripheral system. Figure 1 shows Laurel Carney's recent model of the peripheral system (Carney 1993). The first part of the review will look at the history of how the various stages of such a model have been fleshed out. The second part will focus on the neural encoding of sound in the auditory nerve (the output of the model), and the last will address how that code influences discrimination.

Unraveling Cochlear Mechanisms

The auditory nerve has long been considered a window on the biophysical mechanisms of cochlear transduction. The most carefully characterized aspect of the responses of single fibers has been the tuning curve, which is a plot of threshold versus frequency for tonal stimuli. The first tuning curves were reported by Galambos and Davis in 1943 (Galambos and Davis 1943), but they subsequently reported that they were probably recording from secondary cochlear nucleus neurons (Galambos and Davis 1944). The first tuning curve from an auditory-nerve fiber was probably the one reported by Tasaki in 1954 and shown in Fig. 2A (Tasaki 1954). Later, Yasuji Katsuki, in Japan(Katsuki, Sumi et al. 1958) and Nelson Kiang in Boston (Kiang, Watanabe et al. 1965; Kiang, Sachs et al. 1967) published tuning curves from many auditory-nerve fibers as shown in Fig.2B.

Perhaps the most intensively studied question in auditory theory is: "What are the cochlear mechanisms underlying the shapes of these tuning curves?" This question can be traced as far back as Helmholtz in the middle of the 19th century (Helmholtz 1863; Helmholtz 1954). It was originally less about auditory-nerve tuning curves and more about pitch discrimination. Georg von Békésy phrased the question in a 1956 paper in *Science* titled "Current status of theories of hearing" (Békésy 1956): "The words "theories of hearing" as commonly used are misleading...Theories of hearing are usually concerned with answering the question, how does the ear discriminate pitch? (But) we must know how the vibrations produced by a sound are distributed along the length of the basilar membrane before we can understand how pitch is discriminated and therefore theories of hearing are basically theories of the vibratory patterns of the basilar membrane and the sense organs attached to it."

As we all know, Georg von Békésy was the first to measure those patterns and he was awarded the Nobel Prize in 1961 for this work. A Physiological and Psychological Acoustics medal of this society bears his name.

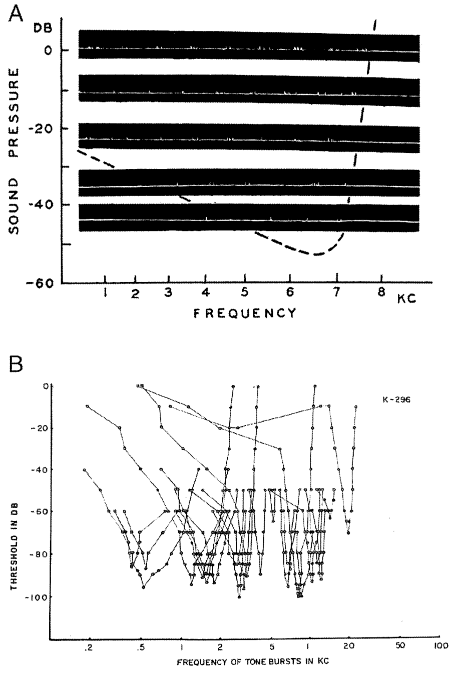
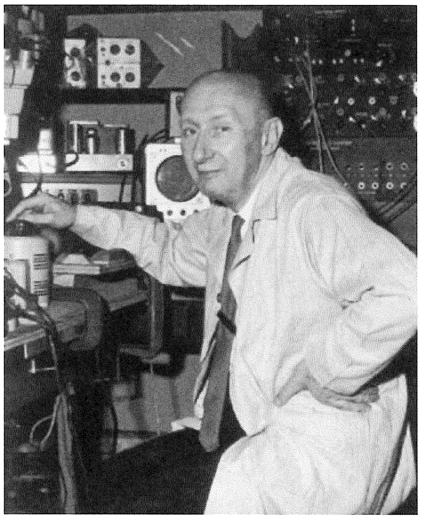


Figure 2. Auditory-nerve fiber tuning curves. A. from (Tasaki 1954); B: from (Kiang, Watanabe et al. 1965).



Georg von Békésy

Figure 3. A. Photo of Georg von Békésy scanned from The Georg von Békésy Collection. (Békésy 1974). B. Basilar membrane model is a metal band with a slit cut in the shape of the basilar membrane and covered with an elastic membrane. From (Békésy 1960).

As illustrated in Fig. 3 Békésy was himself a great model builder, in the traditional sense of "builder," often simulating vibratory patterns on scaled up physical models of the cochlea. This model is a metal band with a slit cut in the shape of the basilar membrane and covered with an elastic membrane. When he got the thickness just right Békésy showed that intense sound caused circumscribed damage to the membrane at points progressively farther from the base as the frequency decreased. Figure 4A shows what may be the most famous of Békésy's observations, the traveling wave pattern along the basilar membrane of a human cadaver. It shows a wave whose amplitude grows as it travels toward the point of maximum displacement and decays rapidly beyond.

One of Békésy's many ingenious modeling efforts shown in Fig. 4B displays such a traveling wave pattern (Békésy 1960). In his own words from his Nobel Lecture (Békésy 1961): "...the final version of the model consists of a plastic tube filled with water, and a membrane 30 cm in length; when it is stimulated with a vibration it shows traveling waves of the same type as those seen in the normal human ear...I decided to go one step further and make a model of the inner ear with a nerve supply...so I simply placed my arm against the model. To my surprise, although the traveling waves ran the whole length of the membrane with almost the same amplitude, and only a quite flat maximum at one spot...I had the impression that only a section of the membrane 2-3 cm long was vibrating...Thus the century old problem of how the ear performs a frequency analysis—whether mechanically or neurally—could be solved; from these experiments it was evident that the ear contains a neuromechanical frequency analyzer, which combines a preliminary mechanical frequency analysis with a subsequent sharpening of the sensation area." Keep these words in mind as we survey the subsequent 40 year history of this idea.

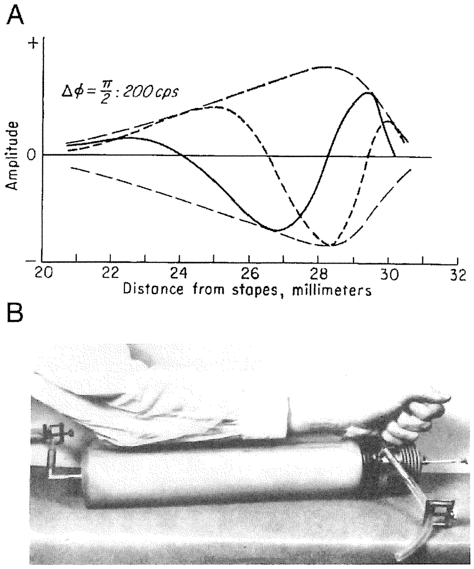


Figure 4. A. Traveling wave patterns on the basilar membrane. From (Bekesy 1960). B. Mechanical model of the inner ear. From (Békésy 1961).

Figure 5 (Békésy 1960) shows the tuning of the basilar membrane in the form of displacement versus frequency plots for four positions along the basilar membrane of guinea pig. In addition to his monumental work as a scientist, Békésy was also a serious collector of art and the inset is a 19th century Japanese print from the Békésy collection (Békésy 1974). These results of von Békésy stimulated a generation of basilar-membrane modelers, none more notable than Joe Zwislocki, (Fig. 6),

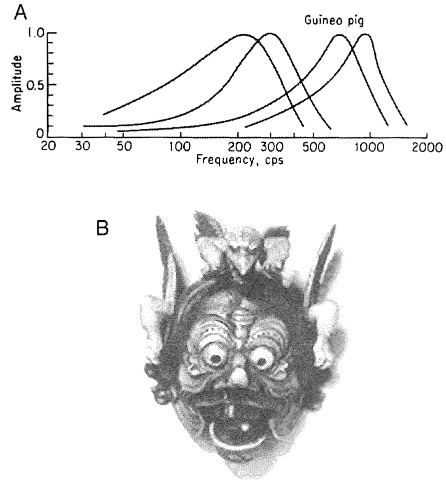
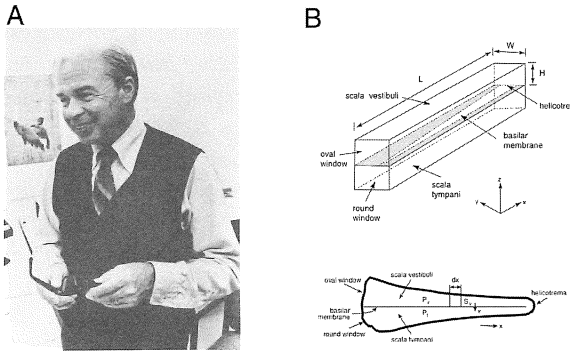


Figure 5. A. Displacement versus position functions for guinea pig basilar membrane. From (Bekesy 1960). B. Inro and netsuke, 18th-19th century, Japan. Selected objects from the collection of George von Békésy bequeathed to the Nobel Foundation. Edited by Jan Wirgin. Copyright © 1974 by The Nobel Foundation, Stockholm.



Josef John ("Joe") Zwislocki

Figure 6. A. Photo of Josef J. Zwislocki. From Abstracts of the 1988 Midwinter Meeting of the Association for Research in Otolaryngology. B. Geometry of Zwislocki model of basilar membrane motion. From (Zwislocki 1965).

who was awarded the first von Békésy Medal by this Society in 1985. Until the 1970's models of basilar-membrane mechanics represented all cochlear structures as linear and passive. The motion of such a system is governed by the laws of classical fluid dynamics. In the late 1940's Zwisloski developed the prototype model based on these concepts of fluid dynamics, and the idealized model of cochlear geometry shown in Fig. 6. The model has been widely applied and with the advent of modern computing the model has been made progressively more precise with regard to cochlear structure (Sondhi 1978; Steele and Taber 1979).

Although such models can reproduce the Békésy data very well, they by no means answer the question of what determines the shapes of auditory nerve tuning curves. Figure 7A from a paper by Pat Wilson from the University of Keele in 1974 (Wilson 1974) compares mechanical and neural tuning curves in guinea pig. The dashed curves are the resonance curves from Békésy, and the dotted curve is a mechanical tuning curve from guinea pig from J.P. Wilson and J.R. Johnstone (Wilson and Johnstone 1975). The mechanical tuning is much broader than the neural tuning curves. In particular, the mechanical curves lack the sharp tips seen in the neural curves.

This discrepancy between neural and mechanical tuning led to one of the most exciting and controversy-filled times in the history of physiological acoustics. Barely noticeable in Fig. 7A, but of enormous importance, are mechanical tuning curves for squirrel monkey measured by Bill Rhode (Rhode 1971). In 1971, Rhode published a paper that was to reverberate throughout the auditory research world for years. Figure 7B shows that resonance curves for the basilar membrane in the squirrel monkey can be considerably sharper than had been thought. But as the level of tone used to measure the contours increases the tuning broadens and at the highest level the displacement function takes on the low-pass filter shape seen in the guinea pig data of Wilson and Johnstone (Fig. 7A). This broadening reflects a strong nonlinearity in the basilar membrane mechanics. At and just above the best frequency the functions are highly compressive, that is, as stimulus level increases the ratio of displacement to stimulus level decreases.

These data are the first indication of a non-linear basilar membrane and really set the community on its collective ear. Quoting from a 1952 paper by Békésy (Békésy 1952): "When the traveling waves along the cochlear partition were first observed, it was possible to show that a decrease of the stimulus to half its magnitude did not alter the pattern of vibration. The cochlea therefore is a linear system." Linear or non-linear became a central question of auditory research and controversy raged well into the 1980's, when it would become clear that the basilar membrane is highly non-linear.

In the early 1970's, when issues of basilar membrane tuning were still very much unresolved, Ted Evans and his colleagues at the University of Keele in England proposed a so-called second filter between basilar membrane motion and auditory nerve discharges. In a review paper Ted, shown in Fig. 8 with the then Minister of Health of the UK Patrick Jenkin, says: "On occasions when recordings were made under conditions where the cochlear blood supply was impaired... the (neural) tuning curves obtained had high thresholds, were broadly tuned and resembled the basilar membrane curves...These findings suggest that the sharpening of the frequency selectivity of the cochlea may be vulnerable to certain deleterious influences such as anoxia." (Evans 1975) The data in Fig. 8 show that the normal low-threshold sharply tuned segment of the neural tuning curve can be lost after a few minutes' respiration in 5% O^2. Again quoting Evans: "It seems unlikely that the mechanics of the basilar membrane would be so severely affected by brief periods of hypoxia". However, more recent studies by Shyam Khanna and his colleagues (Khanna and Leonard 1982) have shown that basilar membrane mechanics are extremely sensitive to subtle metabolic influences.

Early on, some thought was given to the idea that sharpening of neural tuning may involve the innervation patterns of the auditory nerve fiber endings in the cochlea. In 1933 Lorente de No, then at the Central Institute for the Deaf in St. Louis, published a paper (Lorente de No 1981) that was for thirty years the accepted view of cochlear innervation (Fig. 9). Lorente describes the now familiar radial and spiral fibers. Over the course of the next thirty years there were numerous attempts to find a correlation between these two types of afferent fibers and the response patterns of auditory-nerve fibers (Goblick and Pfeiffer 1969). For example, Nelson Kiang's 1965 monograph (Kiang, Watanabe et al. 1965) shows that fibers with the same best frequencies may have very different thresholds. Tasaki (Tasaki 1954) suggested that fibers connected to inner hair cells may have higher thresholds

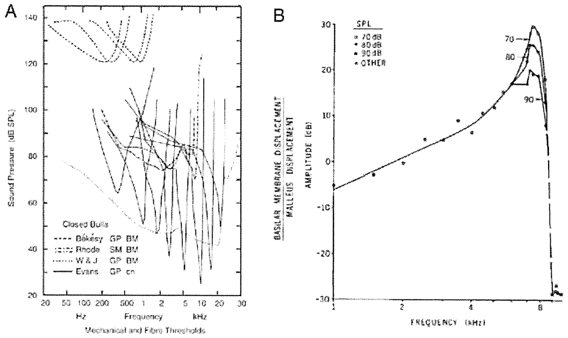
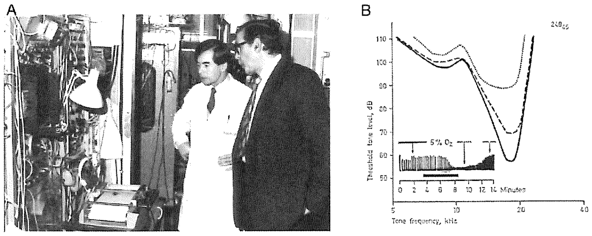
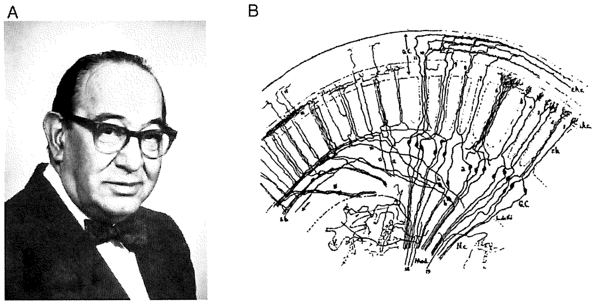


Figure 7. Comparison of neural and mechanical tuning curves. From (Wilson 1974). B. Basilar membrane displacement functions from squirrel monkey. From (Rhode 1971).



E. F. Evans

Figure 8. A. Photo of E.F. (Ted) Evans (in white lab coat). Courtesy Dr. Evans. B. Effects of hypoxia on auditory-nerve fiber tuning curves. From (Evans 1978).



Raphael Lorente de Nó

Figure 9. A. Photo of Raphael Lorente de No. From Abstracts of the 1986 Midwinter Meeting of the Association for Research in Otolaryngology. B. Innervation patterns in the cochlea. From (Lorente de No 1981).

than fibers connected to outer hair cells which sit on a place on the basilar membrane that appears less firmly attached to bone. With vintage (and I should say often appropriate) Kiang skepticism, Kiang says of Tasaki's and other hypotheses: "Our own data do not support any of these previous suggestions. It might be prudent to defer speculation on this topic until some unsettled anatomic questions have been answered, for example, "what are the relative numbers of radial and spiral fibers? Do the spiral fibers innervate hair cells all along their course after crossing the tunnel of Corti?" (Kiang, Watanabe et al. 1965) A landmark paper by Hendrik Spoendlin (Spoendlin 1968) answered these and many other questions about the afferent innervation. Spoendlin showed (Fig. 10) that 90% of the afferents are radial and innervate a single inner hair cell. Spiral fibers are unmyelinated and form synapses with 10-20 outer hair cells. Because of their small size and number there are few if any documented recordings from these spiral fibers. It is no surprise, then, that no real correlations were found between anatomical and physiological response types.

In an elegant series of papers in the late 70's and early 80's Charlie Liberman and his colleagues did demonstrate a correlation among the radial afferents with wide ranging implications (Liberman 1978). Liberman focused on spontaneous rate as a parameter and subdivided fibers into three groups: low, medium and high spontaneous rate fibers (Fig. 11A). One of Liberman's most important observations was that spontaneous rate is correlated with fiber threshold, that is low spontaneous fibers have the highest thresholds at any BF and high spontaneous fibers have the lowest thresholds. Taking advantage of newly developed techniques for marking neurons (Fig. 11B) Liberman showed that all radial fibers innervate only one inner hair cell, that low and high spontaneous rate units actually innervate different sides of the same hair cell and that details of the synaptic endings of the two spontaneous classes are different (Liberman 1982). We will return to the functional implications of these classes of fibers later.

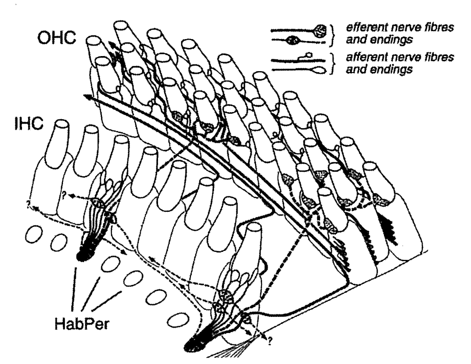


Figure 10. Innervation patterns in the cochlea. From (Spoendlin 1978).

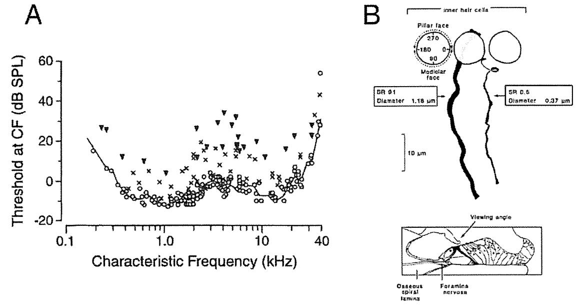


Figure 11. A. Threshold versus best frequency for auditory-nerve fibers categorized by spontaneous rate: circles, triangles and x's correspond to high, medium and low rates respectively. From (Liberman 1978). B. Hair cell innervation pattern of a high and a low spontaneous rate fiber. From (Liberman 1982).

So, most of the afferents innervate inner hair cells. Then what is the function of outer hair cells? Figure 12 shows that by the mid-1980's the question of basilar membrane tuning had been largely resolved. As shown by the superimposed mechanical and neural tuning curves Mario Ruggero and others (Robles, Ruggero et al. 1986) showed that basilar membrane and neural tuning

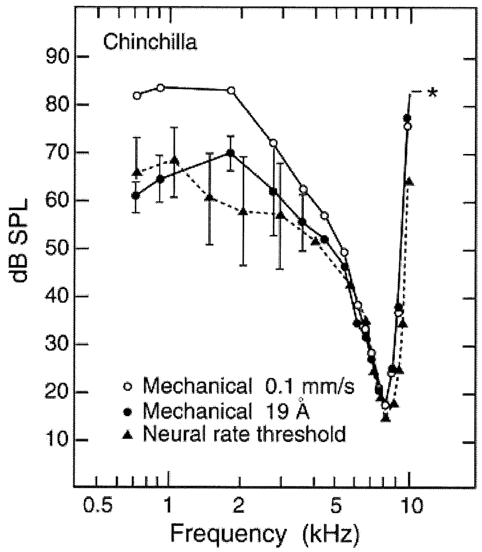


Figure 12. Comparison of neural and mechanical tuning curves. From (Robles, Ruggero et al. 1986).

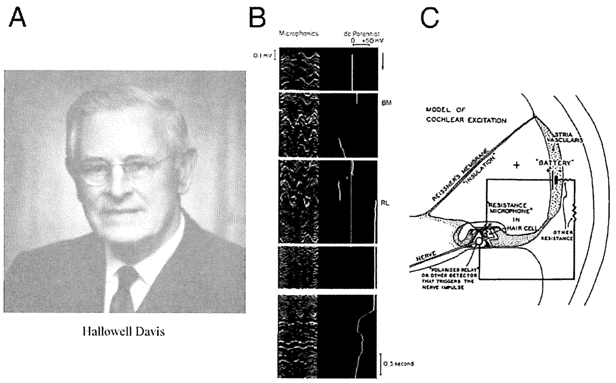


Figure 13. A. Photo of Hallowell Davis. From Abstracts of the 1982 Midwinter Meeting of the Association for Research in Otolaryngology. B. DC (right) and AC (left) potentials recorded as a microelectrode is advanced from scala tympani through scala media into scala vestibuli. From (Tasaki, Davis et al. 1954). C. The "Davis model" of cochlear electroanatomy. From (Davis 1965).

were at least very similar. For reasons that we will explore later, at about this time the idea that outer hair cells might play a role in sharpening basilar-membrane tuning began to emerge.

But the quest to find a role for the outer hair cells really begins much earlier. I quote from The Professional Memoirs of Hallowell Davis (Davis 1991): " the new era in auditory physiology really began in 1930 with the publication by E.G. Wever and C.W. Bray of a paper in *Science* "Auditory Nerve Impulses." "In 1929 he (Wever) undertook to determine the frequency of impulses in the cat's auditory nerve with an instrument capable of dealing with high audio frequencies. The instruments chosen were the telephone and the ear of an observer. A rather large electrode was placed on the auditory nerve in the internal auditory meatus of a decerebrate cat in a quiet experimental room and another member of the team listened to the signals in a telephone in a distant quiet room. Voices of the experimenters could not be heard directly, but in the telephone the listener could hear clearly any words spoken near the cat. Transmission ceased with the death of the animal." Wever and Bray had launched a new era of cochlear electrophysiology, and Davis and his colleagues carried it forward. Hallowell Davis (Fig. 13), born in 1896, was a giant in this society and keenly active virtually until his death at age 96 in 1992. He was awarded the Society's gold medal in 1965 and the National Medal of Science in 1975.

Continuing to quote from the Davis memoirs: "In 1933 Derbyshire and I submitted for publication our definitive study of the electric response of the cochlea, based chiefly on recordings from the round window of cat. The cochlear response differs fundamentally from the action potential of nerve and muscle: It shows no characteristic wave form of its own, but reproduces that of the stimulus. We have also confirmed that this response is absent in albinic cats which on histologic examination are found to lack the organ of Corti. We have ventured the hypothesis that the sensory cells of this organ are responsible for the electrical change". i.e., they had described the cochlear microphonic and correctly hypothesized its source.

Techniques for differential recording between scala vestibuli, scala tympani and scala media later allowed for the measurement of highly localized cochlear potentials. Figure 13B from a 1954 paper by Tasaki and his colleagues (Tasaki, Davis et al. 1954) shows both dc and ac potentials as a microelectrode is advanced from scala tympani through scala media into scala vestibuli. Note that as the electrode penetrates the reticular lamina there is a positive jump in the DC potential, corresponding to the endocochlear potential that had first been identified by Békésy in 1952 (Békésy 1952) and the phase of the ac component (the CM) reverses. This strongly suggested to Tasaki that the source of the CM is at the reticular lamina, i.e., at the hair-bearing end of the hair cells. We will see that this hypothesis was confirmed later by Jim Hudspeth (Hudspeth 1982).

On the basis of measurements like these, Davis (Davis 1965) proposed what has become known as the Davis variable resistance model (Fig. 13C). In the model the transducer channel is represented by the ciliary displacement-dependent conductance and current through it is driven by the endocochlear potential. Virtually all cochlear transduction models start with some variation on this Davis model.

Detailed studies of cochlear potentials in the 50's,

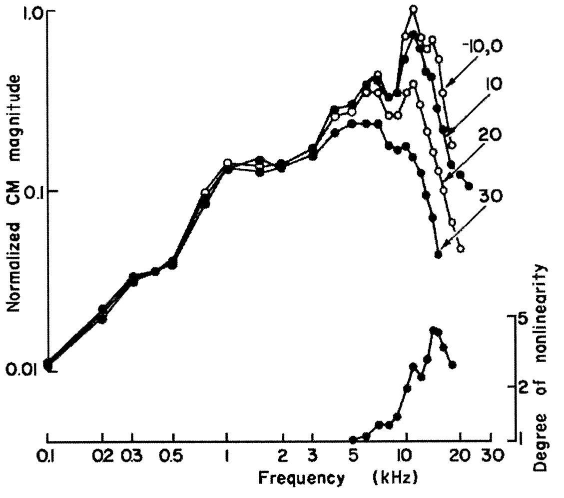


Figure 14. Cochlear microphonic potential versus frequency showing nonlinear behavior at and above the best frequency. From (Dallos, Cheatham et al. 1974).

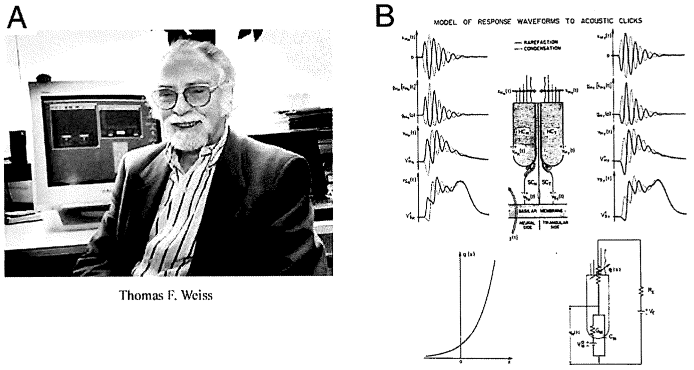
60's and into the 70's led to a detailed picture of the electroanatomy of the cochlea. Certainly among the most quantitative of these came from Peter Dallos and his colleagues (Dallos 1973). For example, Fig.14 (Dallos, Cheatham et al. 1974) shows nonlinear behavior in cochlear microphonic (CM) that is similar to the mechanical nonlinearity of Rhode. Dallos cautions that while "it is tempting to associate the pronounced frequency dependent nonlinearity of the CM with the somewhat similar nonlinearity that Rhode has observed in the basilar membrane motion, militating against this temptation are numerous observations supporting the claims that the dominant CM nonlinearity arises from hair cell processes" (Dallos, Cheatham et al. 1974). It became clear later that these two nonlinearities were at the very least intimately related. In this regard, it is important that Dallos has shown that most of the cochlear microphonic is generated by the outer hair cells.

To this point, the nature of hair cell function had to be inferred from recordings of extracellular potentials like the CM. The first direct recordings from hair cells came not from the mammalian cochlea but from the amphibian lateral line in 1970 by Harris, Frishkopf and Flock (Harris, Frishkopf et al. 1970). The first auditory hair cell recordings were from the auditory papilla of the alligator lizard by Tom Weiss and his colleagues at MIT in 1974 (Weiss, Mulroy et al. 1974). Some aspects of this end organ make it especially attractive for studies of hair cell function. For example, as illustrated in Fig. 15 hair cells on opposite sides of the dorsal region of this organ are morphologically polarized in opposite directions (as defined by the eccentric position of the kinocilium). On the basis of responses to clicks, Weiss and his colleagues developed a detailed version of the Davis model in which motion of the cilia toward the kinocilium causes a large nonlinear increase in the hair cell conductance (Fig. 15B, bottom left). In the model, the opposite morphological polarization of hair cells on two sides of the papilla leads to the opposite polarity click responses as observed experimentally in these cells (waveforms at bottom of left and right columns). These results confirm the hypothesis relating morphological polarization and response polarity put forth by Flock and Wersall in 1962 on the basis of microphonic recordings from the lateral line organ of fish (Flock and Wersall 1962).

In 1977 Jim Hudspeth mechanically stimulated ciliary bundles on individual bullfrog saccular hair cells while recording intracellularly within the same cell, as in Fig. 16 (Hudspeth and Corey 1977). His results confirmed that displacement toward the kinocilium leads both to a hair cell depolarization as well as an increase in conductance. The input/output functions for the cells were highly rectifying (Fig. 16B).

Then in 1984 Jim Pickles discovered tip links shown in Fig. 17 (Pickles, Comis et al. 1984; Hackney, Fettiplace et al. 1993), fine strands that connect the tops of a shorter stereocilium with the lateral wall of its taller neighbor. Hudspeth had demonstrated in 1982 that transducer current flowed through the stereocilia tips (Hudspeth 1982).

Figure 15. A. Photo of Thomas Weiss. (Courtesy Dr. Weiss.) B. Hair cells morphologically polarized in opposite directions produce oppositely polarized response to clicks. In detailed version of the Davis model motion of the cilia toward the kinocilium causes a large nonlinear increase in the hair cell conductance. From (Weiss, Mulroy et al. 1974).



Thomas F. Weiss

These two discoveries led to the currently accepted notion of a spring-loaded trapdoor mechanism of hair cell excitation (Gillespie 1995). Changing tension in the tip link is hypothesized to change the conduction probabilities of a cation-conducting channel.

In 1978 Ian Russell and Peter Sellick at the University of Sussex published results of the first intracellular recordings from inner hair cells in the mammalian (i.e., guinea pig) cochlea (Russell and Sellick 1978). Subsequently Dallos and his group were able to record from outer hair cells (Dallos, Santos-Sacchi et al. 1982; Dallos 1985). Both inner and outer hair cells are sharply tuned and have tuning curves very similar to that of the basilar membrane at the same place in the cochlea. But, as Geisler emphasizes in his recent book *From Sound to Synapse* (Geisler 1998), "... it would be wrong to assume that hair cells in the mammalian cochlea are simply passive recorders of basilar membrane vibrations. They are not." One line of research that led to this conclusion involves the efferent innervation of the cochlea, which had been carefully described in 1946 by Grant Rasmussen (Rasmussen 1946) and further characterized by Bruce Warr, John Guinan and their colleagues in the late 1970s (Rasmussen 1946; Warr and Guinan 1979), who showed that the efferents that Spoendlin shows terminating on outer hair cells (Fig. 10) have a separate brainstem origin from those that synapse on the afferent neurons under the inner hair cells. In 1956 Bob Galambos, then at Walter Reed Medical Center, had demonstrated that stimulating the efferents where they cross the midline of the brainstem suppresses the whole nerve action potential recorded from the auditory nerve (Fig. 18, Galambos 1956). Figure 19 from Mike Wiederhold's work in the late 1960's shows the strong suppression effect in single auditory nerve fibers (Wiederhold and Kiang 1970). There is very strong evidence that stimulating in the floor of the fourth ventricle activates only the efferents that innervate the outer hair cells (Brown, Nuttall et al. 1983). But recall that Spoendlin had shown that almost all of the auditory-nerve fibers innervate the inner hair cells. Thus we have a crucial anomaly: the afferent fibers, from which virtually all of our recordings come, innervate only inner hair cells and yet stimulating efferents that go only to the outer hair cells affects auditory nerve responses in a major way.

In the late 1970's evidence began to mount that the outer hair cells might play a role in an active, energy-

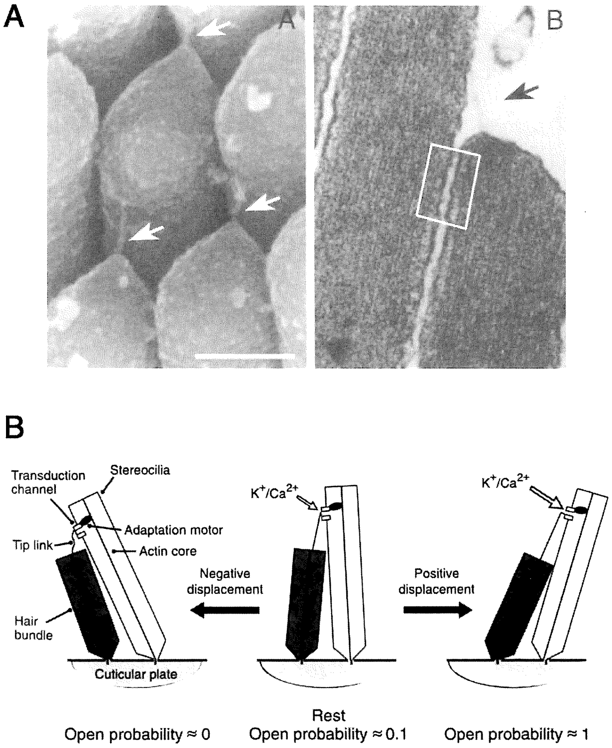


Figure 17. A. Electron micrographs showing tip links (arrows). From (Hackney, Fettiplace et al. 1993). B. Spring-loaded trapdoor mechanism of hair cell excitation. From (Gillespie 1995).

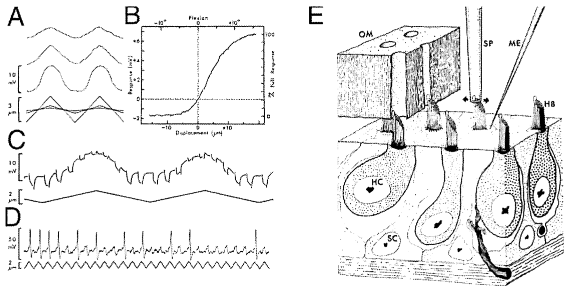
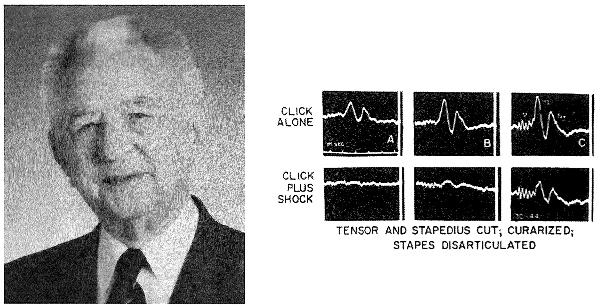


Figure 16. Effects of stimulating ciliary bundles on individual bullfrog saccular hair cells while recording intracellularly within the same cell (as in E). Displacement toward the kinocilium leads both to a hair cell depolarization (A and B) as well as an increase in conductance as measured with constant current pulses (C). Spikes are generated in innervating fibers on the depolarizing phase (D). From (Hudspeth and Corey 1977).



Robert Galambos, M.D., Ph.D.

Figure 18. A. Photo of Robert Galambos. From Abstracts of the 1998 Midwinter Meeting of the Association for Research in Otolaryngology. B. Suppression of whole nerve-action potentials by stimulation of efferent fibers to the cochlea. From (Galambos 1956).

generating mechanism in the cochlea—the so-called cochlear amplifier. The first clue to the identity of the cochlear amplifier came in 1975 when Ryan and Dallos (Ryan and Dallos 1975; Dallos and Harris 1977) showed that destruction of outer hair cells in chinchillas drastically elevated behavioral thresholds and thresholds of auditory-nerve fibers. In 1978 David Kemp, reported that faint sounds could be recorded coming out of human ears being stimulated with acoustic clicks (Kemp 1978); these so-called otoacoustic emissions were assumed to be generated actively by the basilar membrane (Zweig and Shera 1995). Then in 1980 David Mountain showed that stimulating the COCB or changing the endocochlear potential could alter the otoacoustic emissions (Mountain 1980). Both of these results argued for electrical feedback from outer hair cells onto the basilar membrane.

In 1985 Bill Brownell and his colleagues made one of the most far-reaching observations in the modern history of physiological acoustics (Brownell, Bader et al. 1985). While on sabbatical in Switzerland Brownell developed an *in vitro* isolated hair cell preparation and showed that when outer hair cells are electrically stimulated they are capable of mechanical deformations at acoustic frequencies. They suggested that this so-called electromotility was the connection between outer-hair cell membrane potential and cochlear mechanics. They argued on the basis of the microanatomy of the cochlea shown in Fig. 20 that a decrease in outer hair cell length results in a decrease in the separation between the basilar membrane and the reticular lamina. The past 15 years have seen this electromotility characterized in detail from the level of the whole cell to the level of the so-called molecular motor that drives the motility. Recently Dallos and colleagues have isolated the putative motor protein, which they designated prestin (Zheng, Shen et al. 2000).

Exactly how the electromotility influences basilar membrane motion is unknown at this time but so-called micromechanical models have been very helpful in advancing our understanding. In these models the microstructures in the cochlear partition are driven by the macromechanical motion of the basilar membrane and in turn, via electromotility feed back energy into the macromechanical motion to sharpen tuning. A key aspect of the micromechanical processes is the conversion from macromotion of the basilar membrane into radial shear on the inner hair cell stereocilia as was originally envisioned by ter Kuile in 1900 as illustrated in Fig. 21A from Hallowell Davis (Davis 1965). Over the past 15 years, many detailed models of the micromechanics have been produced. Jont Allen considered the simplified model of the cochlear duct shown in Fig. 21B (Allen 1977, 1980). Both Zwislocki and Allen advanced the idea that the tectorial membrane has a resonance of its own near the resonant frequency of the basilar membrane and represented by the mass, spring and dashpot shown here (Zwislocki and Kletsky 1979; Allen 1980; Zwislocki 1990). The effect of this resonance is to place a zero just below the best frequency in the resonance curve of the stereocilia. Such models do produce sharp tuning in the stereocilia, and thus act as a second filter. However, the macromotion of the basilar membrane is unaffected and feedback from hair cells to basilar membrane displacement must be incorporated to produce sharp basilar-membrane tuning. Several investigators have shown directly that electrical stimulation of the cochlea can produce motion of the basilar membrane (Xue, Mountain et al. 1995; Nuttall, Guo et al. 1999). A general schematic of this feedback system is shown in Fig. 21C (from (Geisler 1998)). Cochlear partition forces deflect the cilia, which produces a transducer current and a corresponding change in outer hair cell membrane potential. This outer hair cell membrane potential change is reverse-transduced into an electromotile force on the cochlear partition.

We have toured the history of this outer hair cell feedback model of basilar membrane motion and we have touched on the transduction mechanisms of the inner hair cell in non-mammalian species. More direct measurements of input/output functions of cochlear hair cells by Dallos, Russell and others confirm the halfwave

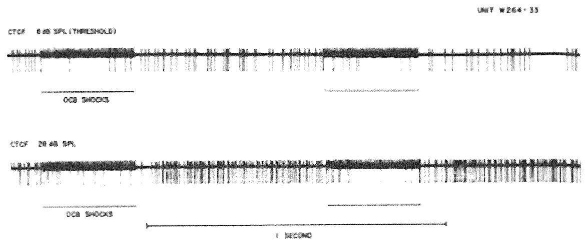


Figure 19. Suppression of activity in single auditory-nerve fibers by stimulation of efferent fibers to the cochlea. From (Wiederhold and Kiang 1970).

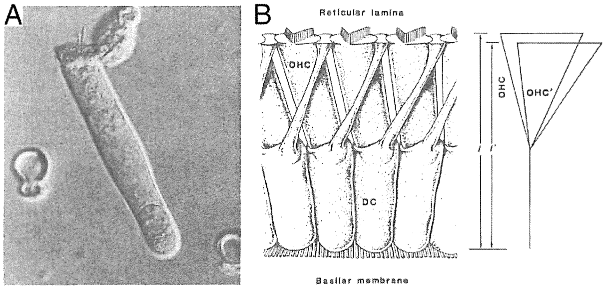


Figure 20. A. An isolated outer hair cell. B. Drawing of cochlear partition geometry showing how shortening of outer hair cells could cause a decrease in the separation between the basilar membrane and the reticular lamina. From (Brownell, Bader et al. 1985).

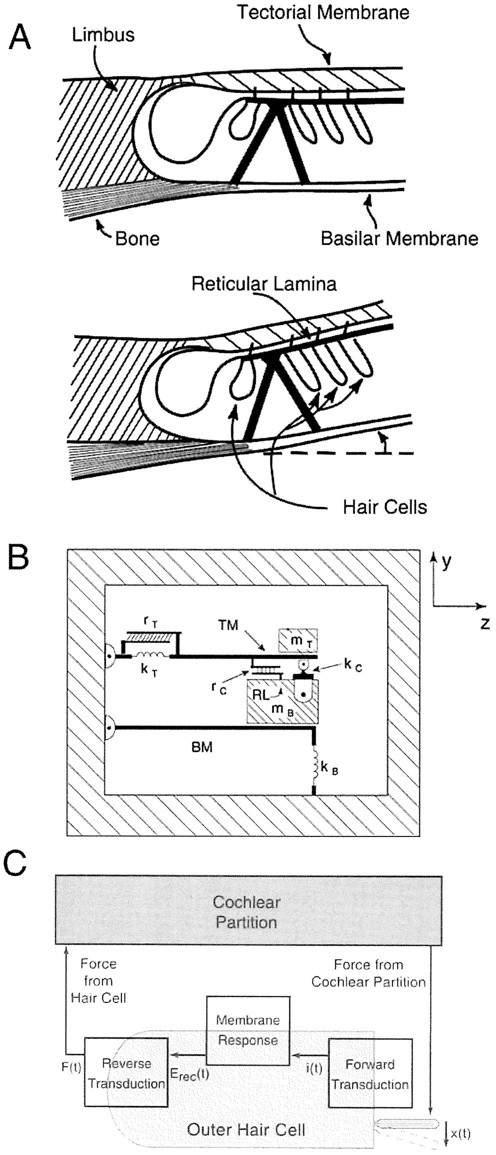


Figure 21. A. Conversion from macromotion of the basilar membrane into radial shear on the inner hair cell stereocilia as was originally envisioned by ter Kuile. From (Davis 1965). B. Diagram of model for cochlear micromechanics. From (Allen 1980). C. Schematic diagram of conceptual model for outer hair cell feedback onto the cochlear partition. From (Geisler 1998).

rectifying nature of the transduction process in both inner and outer hair cells as shown in Fig. 22 from a 1986 paper by Dallos (Dallos 1986). Also shown here is another contribution of the Dallos group to this Society—the Bekesy medal, which Peter won in 1995, was designed by Peter's wife Joan.

The final stage in the peripheral model of Fig.1 is synaptic transmission from the inner hair cell to the innervating auditory nerve fibers. The basis for our current models of this stage are found in the extensive and detailed studies of adaptation in the auditory nerve fiber responses to tones by Bob Smith and his colleagues at Syracuse University (Smith and Zwislocki 1975; Smith and Brachman 1982). As illustrated in Fig. 23 (Geisler 1998), the underlying principle of synaptic models is that neurotransmitter flows into a reservoir at a steady rate and stored for release to the afferent neuron at a rate determined by the membrane potential.

Stimulus encoding in the auditory nerve

So much for the cochlear mechanisms underlying the response properties of auditory-nerve fibers. There has been an intimately related but parallel history of our knowledge of how those patterns represent the information in an acoustic stimulus. Because the inner hair cell acts as a half-wave rectifier, we expect that there should be an ac component of the auditory nerve fiber responses to tones. Jerzy Rose and his colleagues Joe Hind, David Anderson and John Brugge studied this ac component in a landmark paper in 1967 (Rose, Brugge et al. 1967). The photo in Fig. 24 shows their team during an early auditory nerve recording session. In addition to the notable people in the photo we see one of the great technologi-

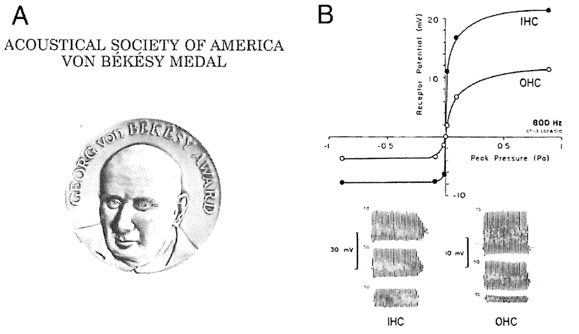


Figure 22. A. The Georg von Bekesy Medal in Physiological Acoustics. B. Input/output functions for inner and outer hair cell. From (Dallos 1986).

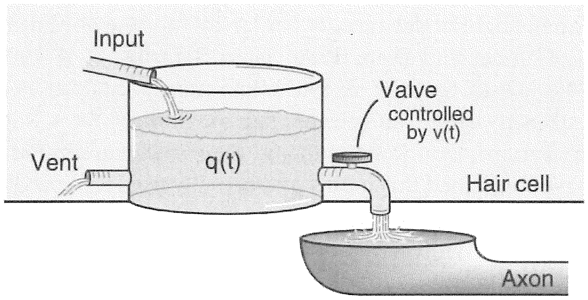


Figure 23. Representation of a model for hair cell synaptic transmission. From (Geisler 1998).

cal leaps forward in neurophysiology. The equipment rack contains an original LINC computer assembled by Joe and Dan Geisler at MIT as part of an NIH sponsored project that brought on-line computing to neurophysiology. Among other things, the LINC permitted on-line display of the ac component of the auditory nerve response in the form of a period histogram. The a.c. or so-called phase-locked response is shown by the peaks in the period histograms. Phase locking has been studied in great detail by many investigators since this early work of the Rose group. An interesting aspect of this body of work is that it involved some important advances in statistical estimation theory, which have since found applications in a number of other fields including medical imaging (Miller and Mark 1992; Johnson 1996).

The dc component of the inner hair cell receptor potential produces changes in average rate of innervating auditory-nerve fibers as is shown by the PST histogram in Fig. 25 from Kiang's 1965 monograph (Kiang, Watanabe et al. 1965). The photo shows Nelson, Walter Rosenblith and Bill Peake, taken at about the same time. Walter founded the Communications Biophysics Group at MIT, which spawned many eminent auditory physiologists, including Peake and Kiang. A standard question in doctoral qualifying exams is "why use tones to study the auditory system?" The obvious answer is that sinusoids are useful in describing the responses of linear systems. But we have seen that the cochlea is highly nonlinear at virtually every level and there are many auditory-nerve reflections of cochlear non-linearities, perhaps the simplest of which is the saturation of discharge rate with sound level, first demonstrated by Katsuki (Katsuki, Sumi et al. 1958) and Kiang (Kiang, Watanabe et al. 1965). In 1974 Sachs and Abbas (Sachs and Abbas 1974). showed that low threshold fibers saturate completely over about a 30 dB range of sound levels but that high threshold fibers do not saturate completely at reasonable sound levels, and rate can continue to increase over a range of more than 80 dB (Fig. 26A). In the same paper, they showed that this behavior is easily reproduced by a simple cochlear model in which the non-linear basilar membrane is followed by a simple saturating hair cell/synapse complex (Fig. 26B). Although this model was subject of controversy at the time in light of debate over basilar-membrane nonlinearity (Palmer and Evans 1980; Sachs, Winslow et al. 1989; Sokolowski, Sachs et al. 1989), in a more recent series of extremely careful and elegant papers, Graham Yates, Robert Patuzzi, Don Robertson and their colleagues in Perth have confirmed this model and actually used it to predict basilar membrane displacement functions in the guinea pig (Yates, Winter et al. 1990).

This relatively simple picture sometimes breaks down at very high stimulus levels. Kiang and his colleagues showed (Fig. 27) that in some instances the functions have a saturating low level component separated from a high level component by a sharp notch (Kiang, Liberman et al. 1986). A sharp shift in the phase of the response is associated with the notch. Kiang and his colleagues and others have attempted to associate the two components with interactions between inner and outer hair cells.

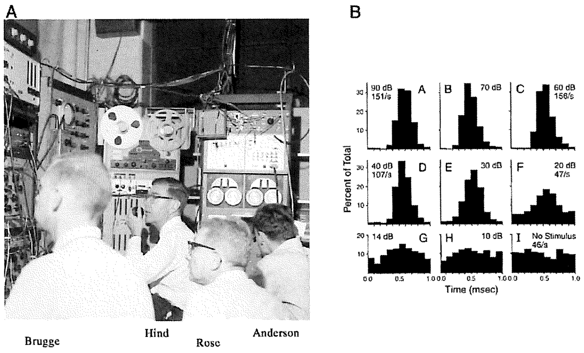


Figure 24. A. Rose, Hind, Anderson and Brugge team. (Courtesy Dr. Brugge.) B. Period histograms showing auditory-nerve fiber phase-locked responses to tones. From (Rose, Brugge et al. 1967).

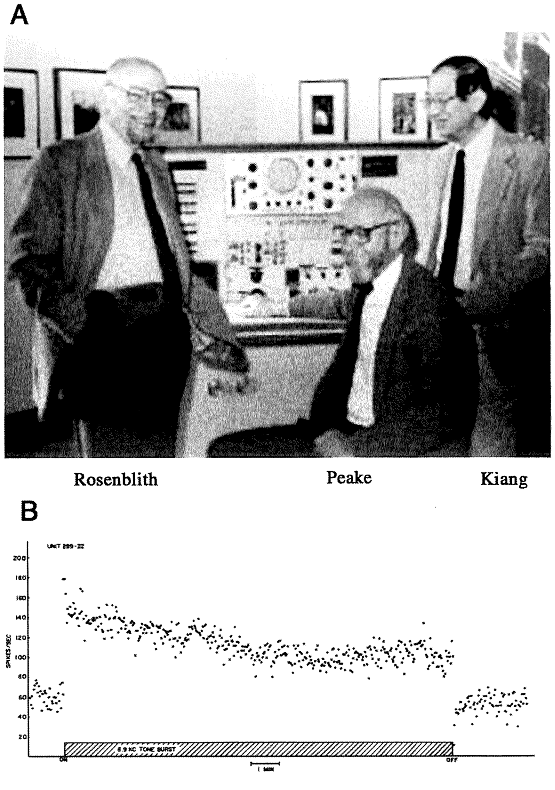


Figure 25. A. Photo of Walter Rosenblith, Bill Peake and Nelson Kiang. B. Post stimulus time histogram showing rate response of an auditory-nerve fiber. From (Kiang, Watanabe et al. 1965).

Studies with two-tone stimuli demonstrate even

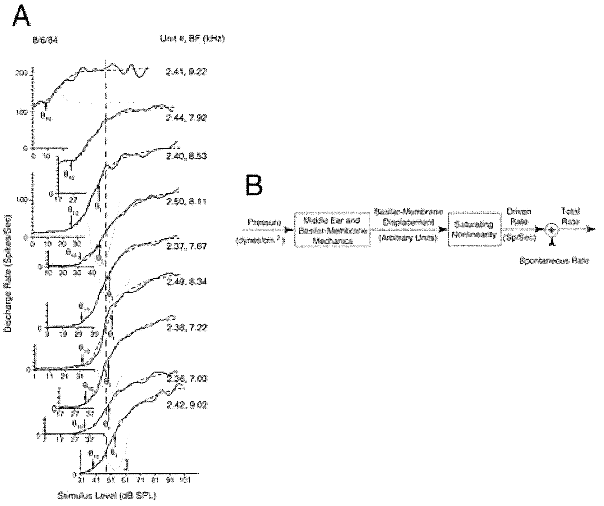


Figure 26. A. Rate versus level functions for auditory-nerve fibers with similar best frquencies. From (Sachs, Winslow et al. 1989). B. Model relating discharge rate to basilar membrane displacement that is the basis for the dashed curves in A. From (Sachs and Abbas 1976).

more dramatically the nonlinear behavior of the auditory-nerve encoding process. A phenomenon called two-tone suppression is shown in Fig. 28 by the decrease in rate to a BF tone by simultaneous presentation of another tone (Sachs and Kiang 1968; Arthur, Pfeiffer et al. 1971). The general characteristics of two tone suppression are often displayed in the form of suppression areas. Two-tone suppression has been characterized in great detail by numerous groups and there is very strong evidence that suppression is a reflection of a basilar membrane nonlinearity similar to that first observed by Bill Rhode and studied extensively by Mario Ruggero and his colleagues at Universities of Minnesota and Northwestern (Robles, Ruggero et al. 1991; Rhode and Cooper 1993). Non-linearities are also evident in the phase-locked responses to two tones as was shown by the Wisconsin group in 1969 (Brugge, Anderson et al. 1969). For example, the phase-locked responses to one tone can be suppressed by the simultaneous presentation of a second tone.

In 1971, at the time of the publication of Rhode's results, Russ Pfeiffer proposed a model that has influenced the thinking about the nature of the cochlear nonlinearity ever since (Pfeiffer 1970). Russ (photo in Fig. 29A) was Nelson Kiang's student before moving to Washington University in the late 60's. He became associate editor of JASA and made numerous creative contributions to Physiological Acoustics before his tragic death in an automobile accident in 1975. Central to the model is the basilar membrane compressive nonlinearity (Fig. 29B). It

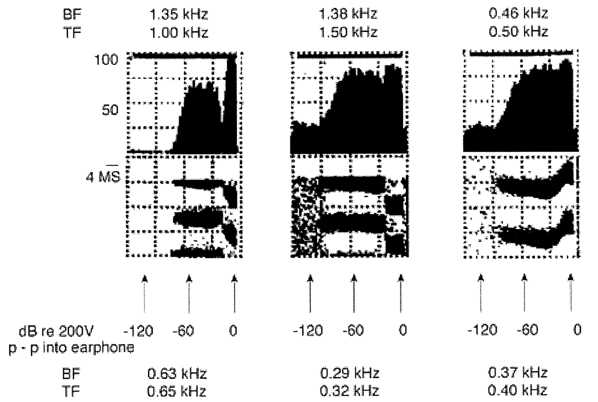


Figure 27. Rate-level functions (top) and corresponding phase plots for three auditory-nerve fibers, showing notches and phase shifts at high levels. From (Kiang, Liberman et al. 1986).

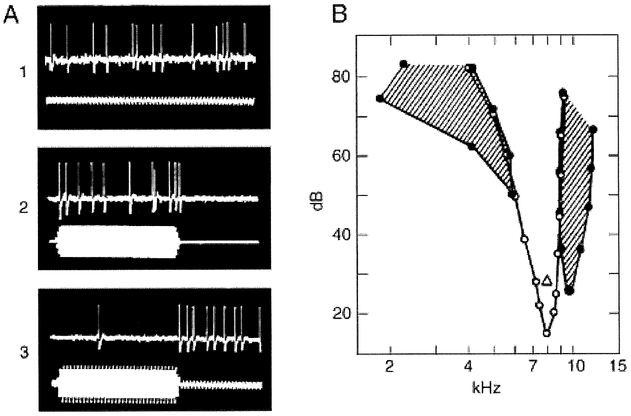


Figure 28. A. Suppression of responses to BF tones by off-BF tones. B. Suppression areas for a single auditory-nerve fiber. From (Arthur, Pfeiffer et al. 1971).

is trivial to show mathematically that such a nonlinearity can generate combination tones and that it produces suppression of the ac response at one frequency by simultaneous presentation of a second frequency. However the compression may not produce the equivalent of rate suppression, i.e., a decrease in the rms value of the signal output, because of a strong output response component at the suppressor frequency. In order to produce rate suppression Pfeiffer used a bandpass nonlinearity, as shown in Fig. 29C. The first filter in this model determines the suppression area boundaries, the compressive nonlinearity produces the suppression and the narrow second filter tuned to BF reduces the output component at the sup-

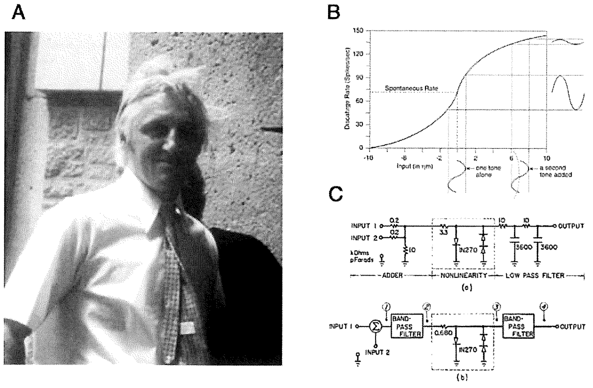


Figure 29 A. Photo of Russ Pfeiffer. (Courtesy Dr. D.O. Kim.) B. Saturating nonlinearity showing suppression of ac response component to a high frequency tone bya addition of a lower frequency tone of greater amplitude. From (Geisler 1998). C. Bandpass nonlinearity model for two tone suppression. From (Pfeiffer 1970).

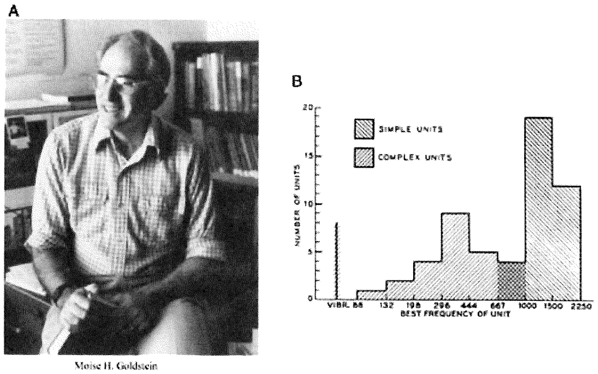


Figure 30. A. Photo of Moise Goldstein. (Courtesy Dr. Goldstein.) B. Histogram of best frequencies in bullfrog auditory nerve. From (Frishkopf and Goldstein 1963).

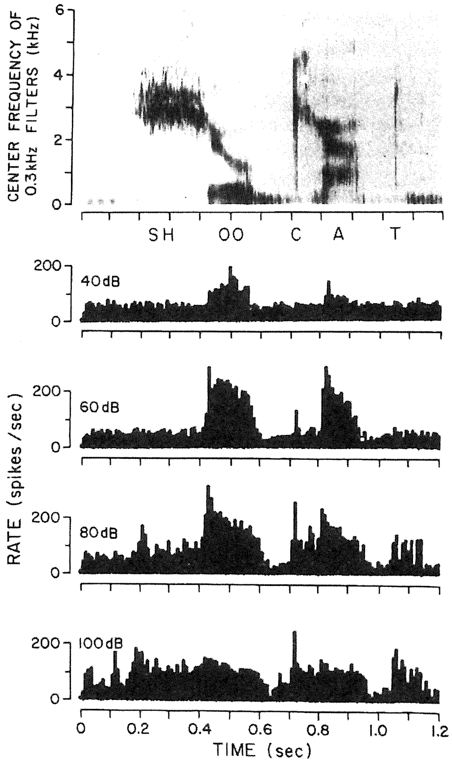


Figure 31. Spectrogram and corresponding PST histograms of auditory nerve responses for the phrase "shoo cat". From (Kiang and Moxon 1974).

pressor frequency, thus allowing rate suppression to occur. The BPNL model in its various realizations provides a qualitatively reasonable representation of many aspects of auditory nerve two-tone responses (Goldstein 1990).

Success in describing the detail the responses of auditory nerve fibers to tones and combinations of tones led several groups in the late 70's and early 80's to look at the neural encoding of speech. Earlier, animal communication sounds had been studied in a number of animals (Frishkopf and Goldstein 1963; Konishi 1969; Hoy 1978). For example, Larry Frishkopf and Moise Goldstein showed in 1963 (Frishkopf and Goldstein 1963) that there are two populations of fibers in the frog's auditory nerve coming from different end organs (Fig. 30) The BFs of the two populations correspond to two peaks in the vocal spectrum of the frog. While these and numerous other studies have important implications for animal communications, their specialized nature limit the possible extrapolations to human speech.

Perhaps the most catchy speech stimulus was used by Kiang and Moxon in their 1974 paper where they show (Fig. 31) PST histograms of single cat auditory-nerve fiber responses to the phrase "Shoo cat" (Kiang and Moxon 1974). However, it is clear that in studying the encoding of sounds as complex as speech, we need to consider not the responses of single fibers but the responses of the whole population of auditory-nerve fibers. In another of his innovative contributions, Russ Pfeiffer in a 1975 paper with Duck Kim provided the tool we needed to look at populations of fibers (Pfeiffer and Kim 1975). As shown in Fig. 32 over the course of several days they recorded responses to the same tones from several hundred single fibers in the same cat and plotted the responses as a function of characteristic frequency. The result was their estimate of the traveling-wave envelope for these tones, both in amplitude and phase. In an elegant series of papers Kim, Charlie Molnar and their colleagues (Kim and Molnar 1979) applied this population technique to describe the cochlear distribution of responses to one and two-tone stimuli, and in doing so laid the groundwork for population studies of the encoding of speech. Charlie, who died in 1996, was a close friend and colleague of Russ, both at MIT and Washington U. and a scientist of enormous breadth and creativity. He was one of the developers of the LINC computer.

In 1979 Eric Young and I published the first population studies of speech coding (Sachs and Young 1979; Young and Sachs 1979). We showed that for a vowel with a formant structure as shown in Fig. 33 plots of discharge rate versus BF, called rate-place profiles, reflect the presumed distribution of basilar membrane amplitude and therefore provide a beautiful representation of the speech spectrum. A potentially more precise spectral representation results if instead of rate we plot a measure of the phase-locked response to speech as in Fig. 34 (Young and Sachs 1979). The principle underlying the so-called temporal representation is that, because of basilar membrane filtering, fibers phase-lock to stimulus energy near their BF. The temporal representation is so precise, in fact that Alan Palmer showed that two vowels with different pitches can be separated on the basis of the representation (Palmer 1990). Several groups have pursued both rate and temporal representations of speech over a wide range of speech stimuli (Delgutte 1980; Sinex and Geisler 1983; Geisler 1988).

We would be remiss in not paying tribute to another of this Society's giants. Ken Stevens, who by the way is alive and as active as ever. Ken earned both the Gold Medal of the Society and the National Medal of Science.

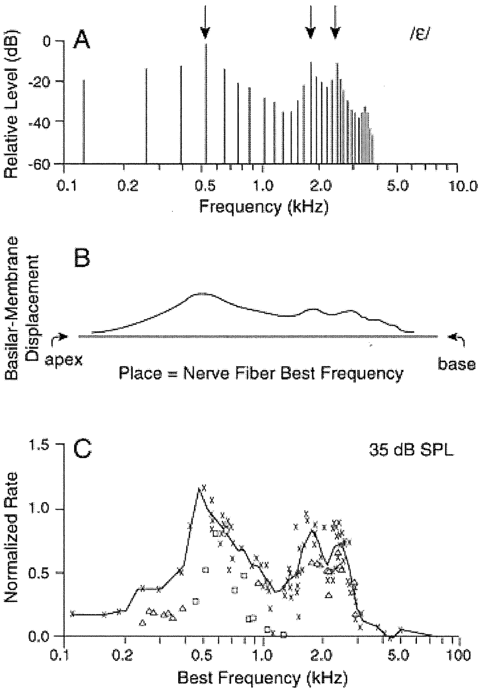


Figure 33. Rate versus best frequency for a population of auditory-nerve fibers (C). Stimulus is vowel / Σ / whose spectrum is shown in (A). Hypothetical basilar membrane displacement shown in (B). From (Sachs and Young 1979).

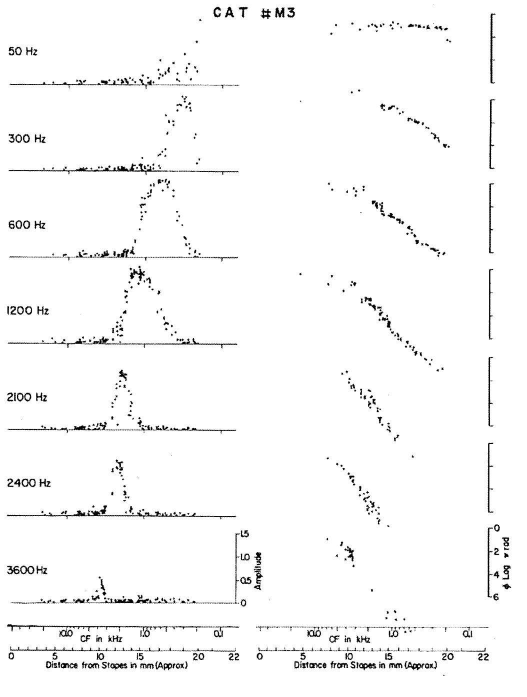


Figure 32. Amplitude and phase of response plotted versus best frequency for a population of auditory-nerve fibers for 7 tone frequencies. From (Pfeiffer and Kim 1975).

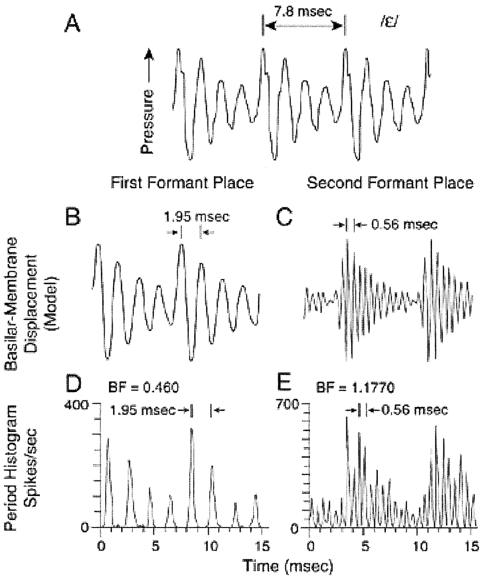


Figure 34. A. Time waveform of vowel / Σ /. B. Response to / Σ / of basilar membrane model at the 512 Hz (= first formant) place. D. Period histogram for response to / Σ / for auditory-nerve fiber with best frequency near the first formant. C. and E. Same foor second formant. Data replotted from (Young and Sachs 1979).

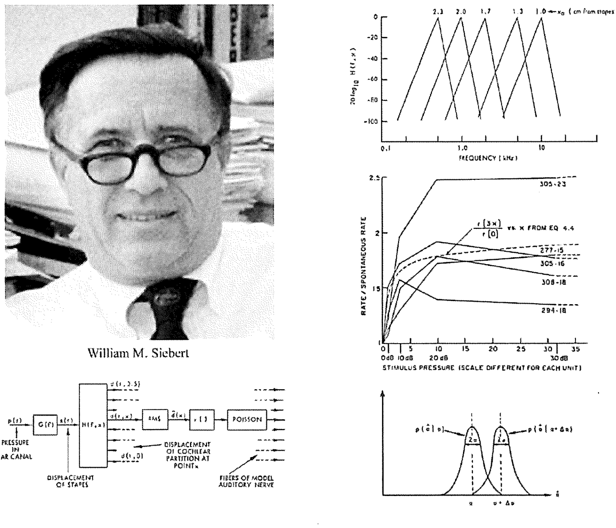
His monumental work in all aspects of speech had an enormous impact on those of us who studied the encoding of speech in the auditory system.

Models of auditory discrimination

An unanswered question in auditory theory is whether the brain actually uses the rate-place code, the temporal code or some combination. The search for answers to this question has been the focus of another thrust of physiological acoustics, namely the relationship between patterns of spike trains in the auditory nerve and human performance in auditory detection and discrimination tasks. This thrust has been the glue that has bound Physiological and Psychological Acoustics together in one technical committee of the Society. In 1968 Bill Siebert at MIT first articulated a framework that became the prototype that still finds wide applications not only in auditory research but also in other sensory systems (Siebert 1968). He began by noting that there are certain fundamental limitations on the precision with which auditory-nerve fibers can transmit stimulus information. These limitations come about because of the noisy (stochastic) nature of the auditory-nerve fiber spike trains and because of resolution limits in the cochlear mechanisms that generate the spike trains, e.g., limited frequency resolution of the cochlear filters and limited dynamic range of auditory-nerve spike rates.

Siebert introduced an extremely simple model (Fig. 35), which is remarkable in the depth of the insights that it provided despite the simplicity. In the model, the displacement of the stapes is converted into basilar-membrane displacement by an array of linear filters. The tuning curves of the basilar membrane are linear in log-log coordinates and the slopes are taken to approximate auditory-nerve tuning. In order to avoid dealing with phase-locking in this early model, Siebert converts the rms value of displacement into the average rate of a Poisson model of the auditory nerve spike trains via a highly simplified expression for the measured rate-intensity functions. Siebert analyzed this model in terms of signal detection theory and statistical estimation theory. Associating the jnd with the standard deviation of the model estimate of intensity or frequency, Siebert obtained jnd vs. sound level functions that were similar to those that had been measured psychophysically at the time. One of the striking features of these functions is that for high stimulus levels the jnds are independent of level. Siebert shows that because of rate saturation this level independence in the model depends on the rate changes at the edges of the stimulated region of the cochlea.

But subsequent psychophysical results shed some doubt on this idea that the central processor must use responses of off-frequency fibers in frequency or intensity discrimination at high stimulus levels. For example, Neal Viemeister showed (Fig. 36) that subjects do quite well at intensity discrimination in a background of notched noise where presumably the off-frequency fibers with BFs outside the notch are saturated by the noise (Viemeister 1983). Bill Shofner showed that one way around this dilemma lay in the low spontaneous high threshold units, which are not saturated by the background noise (Shofner and Sachs 1986; Delgutte 1990). Viemeister, Ber-



William M. Siebert

Figure 35. Photo of Bill Siebert (Courtesy MIT Research Laboratory of Electronics). Siebert's peripheral auditory system model. From (Siebert 1968).

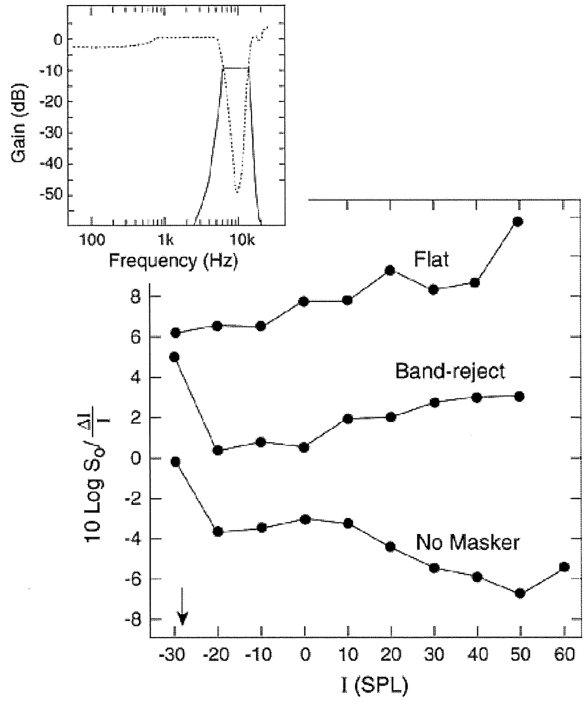


Figure 36. Tone detection in masking noise. From (Viemeister 1983).

trand Delgutte and others have shown that combining rates of low, medium and high spontaneous rate fibers in a Siebert-like model does go a long way to explaining intensity discrimination in situations where spread of excitation is eliminated (Viemeister 1988; Delgutte 1990).

There is another way around the saturation problem that was explored by Siebert in a 1970 paper (Siebert 1970). There he developed a similar model based on auditory nerve phase-locking responses and showed that frequency jnds could be explained on the basis of only a few fibers tuned to the stimulus frequency, independent of stimulus level. Although in the intervening years there have been numerous models based on Siebert's phase-locking ideas including models for interaural phase discrimination by Steve Colburn and his colleagues (Colburn 1973; Goldstein 1973) and speech and frequency discrimination by Julius Goldstein and his colleagues, it is fair to say that the question of whether the brain uses the simple rate-place code, the temporal code or some combination remains largely unanswered.

Summary

We have followed the histories of three related themes in Physiological Acoustics as they have evolved throughout the history of this Society. At this point I had intended to summarize the progress we have made by picking a few titles from each of the Society's three quarter-centuries. Much to my initial surprise the topics have not changed very much in those 72 years but the substance has changed significantly. For example, we saw an article on the acoustics of the external ear in volume 2 of JASA in 1930 and again the same topic appears in 1990. Not that there hasn't been progress. The 1930 paper reports rather crude measurements on human ears, while the 1990 paper presents extremely precise measurements of the head related transfer function in the cat, which has stimulated a whole new direction of research in the peripheral and central mechanisms of sound localization (Musicant, Chan et al. 1990; Rice, May et al. 1992).

So instead of summarizing what I have said about the past 75 years, I will give my limited vision of the next quarter of the Society's first century. What might the next 25 years hold?

Clearly although the topics might not change all that much we are going to know a lot more about them. Our models of the peripheral auditory system will be informed by all that modern genetics, molecular biology and sensor technology has to offer us. We will undoubtedly know in detail the molecular mechanisms of electromotility and its effect on basilar membrane mechanics. We will fully understand how the hair cell functions. As a result we will be able to construct cochlear models at a level of biophysical precision unimaginable not only when Bekesy and Zwislocki were first building models of cochlear mechanics, but even 30 or 40 years later.

And the applications of this knowledge and these models are potentially breathtaking. From designing new generations of hearing aids based on cochlear mechanisms, to optimizing the application of stem cell technology and hair cell regeneration to cure rather than treat deafness, the quantitative, mechanisms-oriented approach that characterizes the vast majority of the work that appears in JASA is going to make the future even richer than the past. I hope that we all enjoy its full potential.

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Psychological and Physiological Acoustics Timeline

1928 ••••	Founding meeting of ASA.
1929 ••••	First volume of JASA.
1930 ••••	Measurement of "auditory impulses" (Wever and Bray).
1931 ••••	Estimate of just detectable changes in frequency (Shower and Biddulph).
1933 ••••	Estimate of absolute threshold (Sivian and White).
1938 ••••	Pitch of the Residue: evaluating the role of temporal analysis in pitch perception (Schouten).
1943 ••••	Physiological tuning curves (probably cochlear nucleus, Galambos and Davis).
1948 ••••	Binaural Unmasking (Hirsh).
1953 ••••	**Elucidation of the "Cocktail-party" problem (Cherry).**

Psychological and Physiological Acoustics Timeline

1961	Georg von Békésy awarded Nobel Prize in Medicine "for his discoveries of the physical mechanism of stimulation within the cochlea."
1965-68	Measurement of auditory nerve fiber responses and cochlear nonlinearity (Kiang, Rose, Sachs, Goldstein).
1966	Estimate of head-related transfer function (human, Shaw).
	Signal Detection Theory emerges as an important experimental psychology tool (e.g. Green and Swets).
1968	Afferent innervations of inner ear described (Spoendlin).
1970	First direct recording from hair cells (Weiss et al.).
1971	**Measurement of basilar membrane resonance curves (Rhode).**
1972	**Psychophysical evidence for spectral suppression (Houtgast).**
1975	**Standardization of loudness calculation procedures (ISO 532).**
1978	**Measurement of otoacoustic emissions (Kemp).**
1985	**Demonstration of electromotility (Brownell et al.).**
2000	Elucidation of the mechanism of outer hair cell electromotility (Zheng et al.).

Past and Present Chairs of the Technical Committee on Psychological and Physiological Acoustics

1960-61	William D. Neff
1961-62	James P. Egan
1962-64	Jozef J. Zwislocki
1964-67	John A. Swets
1967-69	Moise H. Goldstein
1969-71	David M. Green
1971-73	Peter J. Dallos
1973-75	Irwin Pollack
1975-77	Juergen Tonndorf
1977-79	Joseph L. Hall
1979-81	Charles S. Watson
1981-84	Joseph E. Hind
1984-87	Frederic L. Wightman
1987-90	Donald C. Teas
1990-93	William A. Yost
1993-96	Ervin R. Hafter
1996-99	Donna L. Neff
1999-02	Neal F. Viemeister
2002 -	Virginia M. Richards

Recipients of the von Békésy Medal

1985 - Jozef J. Zwislocki - For landmark contributions to our knowledge of the hydromechanical, neurophysiological, and perceptual mechanisms of the auditory system.

1995 - Peter J. Dallos - For contributions to the understanding of cochlear processes.

1998 - Murray B. Sachs - For contributions to understanding the neural representation of complex acoustic stimuli.

Recipients of the Silver Medal in Psychological and Physiological Acoustics

1977 - Lloyd A. Jeffress - For extensive contributions in psychoacoustics, particularly binaural hearing, and for the example he has set as a teacher and scholar.

1981 - Ernest Glen Wever - For establishing the field of cochlear electrophysiology and advancing knowledge of middle and inner ear function.

1987 - Eberhard Zwicker - For prolific contributions to the understanding of fundamental auditory properties and for environmental, technological and clinical applications.

1990 - David M. Green - For outstanding experimental and theoretical contributions to hearing research and its methodology.

1994 - Nathaniel I. Durlach - For pioneering contributions to research concerning binaural hearing, intensity perception, hearing aids, tactile aids, and virtual reality.

2001 - Neal F. Viemeister - For contributions to the understanding of temporal and intensive aspects of hearing.

2002 - Brian C. J. Moore - For contributions to understanding human auditory perception, especially the perceptual consequences of peripheral frequency analysis in normal and impaired listeners.

Recipients of Interdisciplinary Silver Medals

Silver Medal in Psychological and Physiological Acoustics, Musical Acoustics, and Noise

1991 - W. Dixon Ward - For furthering knowledge of auditory perception in psychological and musical acoustics and increasing the understanding of the etiology of noise-induced hearing loss.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Psychological and Physiological Acoustics, Architectural Acoustics and Noise

1999 - Jens P. Blauert - For contributions to sound localization, concert hall acoustics, signal processing, and acoustics standards.

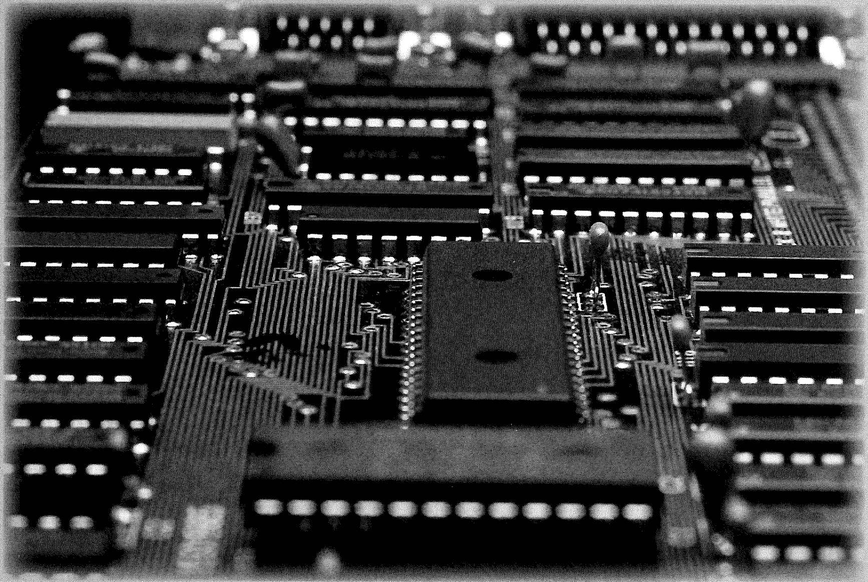
Helmholtz-Rayleigh Interdisciplinary Silver Medal in Musical Acoustics, Psychological and Physiological Acoustics and Architectural Acoustics

2001 - William M. Hartmann - For research and education in psychological and physiological acoustics, architectural acoustics, musical acoustics, and signal processing.

Chapter 13

Signal Processing in Acoustics

Charles F. Gaumond, Chapter Editor
History Lecture, David I. Havelock



Signal Processing in Acoustics

Introduction

Signal processing is a relatively recent term in acoustics. When I took a course in history of science, acoustics was summed up by a single paragraph in the text, "In the study of sound, the [establishment on a mechanical basis] was entirely successful and it suffices to mention the great work of John William Strutt …, *The Theory of Sound*, which appeared in 1877-8. The phenomena of sound in practical completeness are interpreted in terms of longitudinal mechanical waves ..." After this entire success and practical completeness, one might wonder what people in acoustics have been doing since Lord Rayleigh and Helmholtz. One of the activites was and continues to be what we today call signal processing.

Signal processing papers were often cataloged under the term applied acoustics in the 30's to 50's. Applications of acoustics were important to the Society from the beginning; the first organizing meeting in 1929 had thirty-one attendees from industry and seven from academia. The industrial interests included telephony, noise-reduction, radio and music reproduction. In 1931 Franklin Hunt discussed the limits of "sound pictures" and setting the upper frequency response to 5 kHz to decrease the perception of noise. This is clearly signal processing. The modern analogs of the earliest interests, namely, communication, sound reproduction, and noise-reduction continue to be of great commercial interest. As in 1931, the ASA continues to be a middle ground for cross fertilization between basic researchers in diverse scientific areas with applied researchers in signal processing for our novel telephones, compressed music, undersea defense and thrilling theaters lined with speakers. Clearly signal processing will continue to be be an integral component in the ASA in the twenty-first century.

The History of Signal Processing in Acoustics was presented by David I. Havelock, who has been active in the ASA Technical Committee on Signal Processing in Acoustics since its inception. He participated in the creation of the predecessor Interdisciplinary Technical Group and was Chair from 1995-1998. David Havelock has worked in signal processing, mostly in acoustical applications, since 1976 and is currently a Senior Research Officer in the Acoustics and Signal Processing Group at the National Research Council, Canada.

Charles F. Gaumond, Chair,
Technical Committee on Signal Processing in Acoustics

Signal Processing in Acoustics

David I. Havelock, National Research Council

Although signal processing is a young field it is very broad, impacting not only every part of acoustics but, increasingly, permeating every human endeavor. The Technical Committee on Signal Processing in Acoustics (TC-SP) is the youngest Technical Committee in the Acoustical Society. It was created by conversion from an Interdisciplinary Technical Group (itself, formed only in 1994) in December 2000.

This article begins with a brief sketch of the evolution of the use of signals from early to modern times. This is followed by a summary of Signal Processing in JASA, the process leading up to the formation of the TC-SP, and the activities of TC-SP. In its 75-year history, members of the Acoustical Society of America have made innumerable contributions to signal processing and have advanced acoustics through innovative use of signal processing methods and a few illustrative examples are presented here. The historical articles by Victor Anderson, [1, 2] provide further information as do the books of Frederik Nebeker, [3, 4]which provide a concise treatment of the history of Signal Processing from an IEEE perspective. The IEEE History Center has material tracing the development of signal processing, and the ASA is prominent in these accounts. For example, conversations with notable individuals, many of which are distinguished members of the ASA, can be found at the History Center web site by searching under the a keyword such as acoustics. [5] An historical account of audio processing can be found in the IEEE Signal Processing Magazine. [6]

The Nature of Signals

A concise and broadly satisfying definition of signal processing is elusive. Oppenheim and Shafer, in their second book on digital signal processing [7], provide a definition in terms of signals: "Signal processing is concerned with the representation, transformation, and manipulation of signals and the information they contain."

Their accompanying definition of signals, however, is less satisfying: "Signals are used to communicate between humans and between humans and machines…"

While this describes how signals are used (excluding communication between machines), it does not define what a signal is.

Nebeker [3] defines a signal as "...a time-variant quantity that conveys information," which is a somewhat restrictive definition that does not embrace the more liberal perspective needed, for example, to include the non time-invariant set of inputs to a neural net target classifier or images, obtained through acoustic techniques, that serve to communicate between humans and machines.

Dictionaries define signal in various ways, such as "A modulation of an electric current, electromagnetic wave, or the like by means of which information is conveyed...[8]," "A speech sound... that communicates meaning...[9]," or "a detectable physical quantity or impulse... by which messages or information can be transmitted.[9]" No matter what definition of signal one prefers, it is most often the case in modern times that signal processing, as defined by Oppenheim and Shafer, is applied to a digital representation of "it," or something derived from it. In times not long past, however, signals took on many varied forms and were not so easily manipulated.

Early Signals and Processing

We often analyze signals in terms of their frequency content. This may be justified on the basis of the mathematical convenience of doing so but the importance of cycles and periodicity to our understanding and use of signals goes deep into our history. In his account of the history of electrical and magnetic measurements, Joseph F. Keithley writes [10] : "Initially, life was thought to be a succession of recurring cycles, and there was no concept of history. The cycles were based on correlations of natural events..."

Natural events, such as the seasons, migrations, and the cycles of the sun and moon, were the important signals to ancient mankind. Keithley goes on to say that a more linear or evolving view of time developed only much later, such as with the constant flow water clocks of 250 BC. The importance of these early interpretations of signals is underscored by S. L. Marple, Jr. [11] : "Cyclic, or recurring, processes observed in natural phenomena have instilled in humans, since the earliest times, the basic concepts that are embedded to this day in modern spectral estimation."

In the sixth century BC, Pythagoras attempted to establish a simple relationship between the tones of a vibrating string and numbers associated with the length of the strings. This was not a physical model for the source of the sound so much as a means of providing an abstract representation for them. Philolaus of Crotona expressed the need for such a representation in the fifth century BC: "Actually, everything that can be known has a Number; for it is impossible to grasp anything with the mind or to recognize it without this [number]." [12]

Over two thousand years later, in Newton's time, signals were commonly expressed as functions and, as Oppenheim and Shafer write in the second edition of their landmark textbook on Digital Signal Processing: "Since the invention of calculus in the 17th century, scientists and engineers have developed models to represent physical phenomena in terms of function of continuous variables and differential equations."

These abstract models, in the presence of modern computational capabilities, can easily be cast into the form of digital signals. Indeed, by the time Bernoulli derived the solution to the wave equation, in 1738, signals were commonly analyzed in the form of mathematical functions. This abstraction was necessitated not only by the limited range of transducers available at that time to provide real-world signals and data, but by the difficulty of working with volumes of data. Problems such as tidal prediction and celestial mechanics were tackled by manipulating tables of numbers. These calculations were done by hand and it is difficult now to appreciate the painstaking efforts that were involved.

Compared to our computational abilities today, scientists of Bernoiulli's era could do little more with their elaborate representations of the physical world, it seems, than could Pythagoras with his numerical representation of tones. Nevertheless, important theoretical and practical contributions were made for numerical procedures to calculate harmonic coefficients long before Fourier finally put Harmonic Analysis on a solid footing in 1822 with this famous paper. [13]

The 19th century produced many ingenious devices to represent and analyze signals through analog techniques. This was likely brought about by frustration with the tedium of numerical calculations. The Koenig Analyzer (c. 1876), referred to as the "clang analyzer," is a particularly elegant example of such devices. [14] It produced a visual image of the harmonic components of complex sounds using a set of Helmholtz resonators to modulate the gas flow to a set of burners. A rotating mirror was used to help display the modulation. This device converted sound into a visual signal representation, performing optical, mechanical, and, in some sense, even chemical signal processing.

Alexander Graham Bell's "Phonautograph" (1874) [15] presented signals in a different way. Exemplifying the interdisciplinary nature of signal processing, he co-developed the device with Clarence Blake, a Boston ear specialist, to provide a visual representation of speech to deaf people. The device contained a detailed scale-model of the middle-ear bones to convert sounds at a mouthpiece to vibrations at a stylus, which etched a pattern onto smoked glass. Later, Bell applied this device to electrical transmission of signals in the invention of the telephone.

Graphical means were often used to represent measured data but it was, and still is, difficult to analyze and process signals in this form. A family of analog computers, such as the Henrici-Coradi Harmonic Analyzer (1894) [16] was developed to trace curves of plotted data and deduce their harmonic components. These devices were able to do mechanical integration to compute the first few harmonic coefficients for applications such as tidal predictions.

In the 20th century many devices were created to record or reproduce signals, especially audio signals (although other signals, such as bat cries [17], were also of interest.) For example, an elaborate music synthesizer and recorder by Olsen and Belar (1955) [18] treated details of music synthesis such as attack rate, decay and vibrato with complicated analog mechanisms controlled by punched paper tape. This system lined the walls of a large room but, compared to the Teleharmonium of Thaddius Cahill (c.1900) [19], which was 60 feet long and weighted 200 tons, it was a compact and efficient device.

The Dawn of Modern Signal Analysis

Although real world signals were represented and analyzed by many ingenious means in early history the representations were not realistic in that they lacked the noise and randomness normally present in nature. In 1894, Sir Arthur Schuster showed how data with irregular fluctuations should be handled to understand the underlying periodicities. [20] He pointed out how prior techniques were incorrect and could result in erroneous results—which must have been terribly disappointing to those who had spent time toiling at endless calculations on huge tables of numbers to obtain those results. Small consolation might have been found in his comment that his computational approach "would involve an almost prohibitive labor." He coined the term periodogram, which is still a fundamental tool for spectral power estimation today.

The analysis of noisy signals was put on a firm analytical basis by the Yule-Walker equations (1927) and the Wiener-Khintchine theorem (1930). These equations relate the autocorrelation function of noisy data, which can be directly and easily calculated (in principle), to an autoregressive representation (Y-W) or to a power spectral representation (W-K). Following on the work of Fourier, which laid down the theory for spectral representations of signals, these equations showed how the representations could be applied to real data. They set the stage for sophisticated and rigorous signal processing that would await the power of digital computers to be fully realized.

As digital techniques developed, methods for signal processing were more easily implemented and evolved quickly. For example, array beamforming theory was brought to practice by the DIMUS [22] system for underwater sonar, and psychoacoustics models of hearing were applied to digital speech coders [23]. As noted by Schroeder [24], digital computers made it possible to simulate signals and processing methods, opening up the domain of digital simulation and computer modeling. Digital computers were also used to automate control of experiments, such as in the psychoacoustic measurement techniques of Levitt [25]. Music was an early application of signal processing and by 1969 there were already two books on computer music. [26, 27]

Table I. The development of fast Fourier transform techniques. Gauss developed the principles of the familiar Cooley-Tukey algorithm in 1805 but the result was not well known. Others re-discovered the technique for various applications. In the 1800s the work concentrated on computing only the first few Fourier coefficients but more general solutions appeared later. MF indicates 'multiple factors;' RFP indicates 'relative prime factors.' (Following Heideman, et al. [28])

C.F. Gauss	1805	Interpolation of orbits, (MF)
F. Carlini	1828	Barometric pressure (12 coefficients)
A. Smith	1846	Compass deviations on ships (5 or 9 coeff.)
J.D. Everett	1860	Underground temperatures (5 coefficients)
C. Runge	1903	Sequences - $2^n k$
K. Stumpff	1939	Sequences - $2^n k$, $3^n k$
Danielson & Lanczos	1942	X-ray diffraction, sequences - 2^n
L.H. Thomas	1948	Sequences - (RPF)
I.J. Good	1958	Sequences - (RPF)
Cooley & Tukey	1965	Sequences - (MF)
S. Winograd	1976	Sequences - (RPF)

In many respects, the FFT heralded the dawn of the age of digital signal processing, even though much of the theory for signal processing was established well before the time the FFT was popularized in 1965. Ironically, the famous mathematician Carl Fredrich Gauss [28, 29], developed the FFT, which we usually credit to Cooley and Tukey [30], in 1805 but Gauss' work did not get wide distribution or appreciation at the time. Numerous people recreated his work in varying ways over the years (see Table I). The independent re-discoveries were motivated by the desire to obtain Fourier coefficients (usually just the first 3-7 coefficients) for a variety of applications such as: celestial mechanics, barometric pressure predictions, corrections to compass deviations, analysis of geothermal data, and x-ray diffraction. Although acoustics does not stand out amongst these applications, once Cooley and Tukey presented their fast algorithm, acoustic signal processing became practical and acoustics became prominent in the signal processing community.

Whereas computers prior to the end of the 20th century were restricted to signal analysis, system modeling, and (non real-time) simulation, they eventually became powerful enough for real-time processing in acoustic applications. General purpose digital signal processing (DSP) systems proliferated and have evolved toward embedded DSP systems which can be fully integrated into products and other systems. With modern high performance computing, sophisticated algorithms and realistic model-based solutions can be performed in real-time.

Ubiquitous communications systems are bringing new challenges to acoustic signal processing and the tools available are evolving from the general-purpose digital computer and DSP card to programmable logic devices (FPGA, CLD) and custom integrated circuits (ASIC) with high level programming and design tools. Examples of emerging technologies, such as integrated MEMS devices [31, 32] (micro-electro-mechanical systems), opto-electronic devices suggest a continuation of new opportunities and challenges for Signal Processing in Acoustics.

Signal Processing in JASA

In March 1963, V.C. Anderson was appointed the first Associate Editor of the *Journal of the Acoustical Society of America* (JASA) for Signal Processing in acoustics. At that time, Signal Processing in Acoustics was a sub-topic of the technical area on Underwater Sound but in January 1964 a new subject classification for Acoustic Signal Processing was introduced (slightly in advance of the formation of the Digital Signal Processing Technical Committee of the IEEE, which was formed under the Professional Group on Audio and Electroacoustics in 1965.)

Underwater Acoustics and Speech were the major areas for signal processing. Speech was dominated by the IEEE, which was newly formed in 1963 and rapidly developed a very active committee in this area. As Nebeker [4; p. 34] says in reference to a communication with Daniel Martin (past JASA Editor): "The Acoustical Society, however, was not as receptive [as the IEEE] to this rapidly growing area, and in the 1960s many papers on speech processing were rejected by the speech editor of the *Journal of the Acoustical Society of America*, perhaps because they were seen as too technological."

Nevertheless, many papers and letters on signal processing have been published in JASA over the years (see Fig. 1), with Underwater Acoustics being the dominant subject matter. The Editors and Associate Editors in Signal Processing for JASA are listed in Table II.

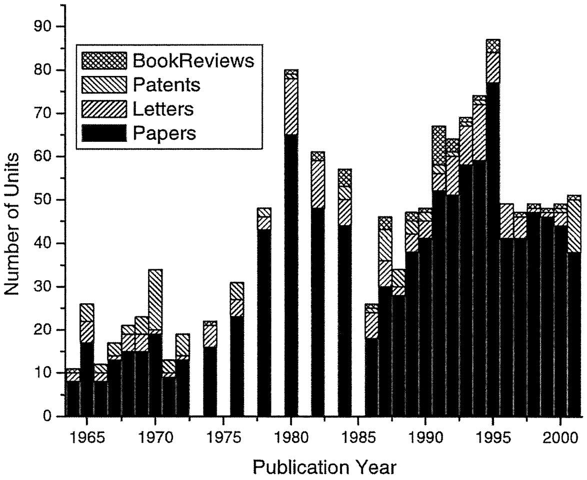


Figure 1. Publications on Signal Processing in Acoustics in JASA, excluding abstracts from ASA meetings. Each bar represents one year of JASA, which may span two volumes. (Data from some odd-numbered years are missing.)

Table II. The JASA Editors in Chief, Associate Editors for Signal Processing in Acoustics, and changes to the subject classification index.

1929 - 1939	Floyd Watson, Chair
1939 - 1956	Floyd Watson, Editor
1956 - 1957	Floyd Watson, Editor in Chief
1957 - 1985	R. Bruce Lindsay, Editor in Chief
1963 - 1966	**V.C. Anderson**, AE Signal Processing (Underwater)
1964	New Subject #15: Acoustic Signal Processing
1966 - 1969	**Theron Usher**, Jr., AE Signal Processing
1969 - 1995	**W.A. Von Winkle**, AE Signal Processing
1974	PACS 43.60 Adopted
1985 - 1999	Daniel W. Martin, Editor in Chief
1995 - 1997	**J.L. Krolik**, AE Signal Processing
1997 -	**J.C. Burgess**, AE Signal Processing
1999 -	Allan D. Pierce, Editor in Chief

Formation of TC-SP

Although signal processing has been an integral part of acoustics research since the mid-1960s it was not until 1994 that a technical group dedicated to signal processing was created within the ASA. To some extent this was due to the higher level of activity in this area within the IEEE, which was perceived to be broad enough to cover all applications, and the sense that each of the ASA Technical Committees was addressing its own signal processing needs.

In 1987 a survey [33] of ASA membership revealed strong support for three new technical areas of interest, namely, Signal Processing, Aeroacoustics, and Medical Ultrasonics. In response to this interest, the ASA Rules were changed in 1988 to define Technical Specialty Groups (TSG) [34] and the TSG on Animal Bioacoustics was formed shortly thereafter. (Acoustical Oceanography followed suit in 1993 but the Technical Committee now known as Biomedical Ultrasound/Bioresponse to Vibration was formed as a 'Provisional Technical Committee' in 1985, prior to the rule changes.) All the TSGs have since been converted to Technical Committee status.

Following the 1987 survey and the ASA Rule changes, a petition for the formation of a TSG on Signal Processing in Acoustics was circulated and submitted to Executive Council in 1992 with 52 signatures. After much debate, perhaps more debate than on any single issue in recent ASA history, the petition was narrowly defeated, even as the number of signatures on the petition continued to grow toward 100. A few days later, Executive Council requested further input from the proposed TSG and from Technical Council so that it could reconsider the petition. A revised proposal for the TSG was prepared, identifying the inherent interdisciplinary nature of the proposed group. The proposal was not well received by Technical Council but in Executive Council, following further extensive debate on the revised proposal, a motion was passed [35] to create the new TSG and to further modify the rules of the ASA to define Interdisciplinary Technical Groups. Interestingly, following the vote that created Signal Processing in Acoustics, on 10 June 1994, two more motions were introduced to re-name and limit the authority of the newly formed Group but both were defeated.

The first meeting of the new Group was called to order by interim Chair Jim Bartram in Austin, Texas, November 1994. Soon after, the necessary ASA Rule changes were completed and the Group became known as the Interdisciplinary Technical Group on Signal Processing in Acoustics (ITG-SP) and its Chair became a non-voting member of Technical Council with the 12 other Technical Committees and Technical Specialty Groups. The Technical Committee on Speech Communication changed its session designation from SP to SC to allow Signal Processing to use SP.

After a few ASA meetings the ITG-SP was sponsoring and co-sponsoring about 10% of the technical sessions at ASA meetings (Fig. 2) and interacting with all of the other Technical Committees (Fig. 3). (In 1998 Technical Liaisons were appointed to interact with each of the other Technical Committees.) In its short history, the ITG-SP pursued numerous technical initiatives, including the Gallery of Acoustics and the Student Challenge Problem. Attendance at technical sessions has ranged from less

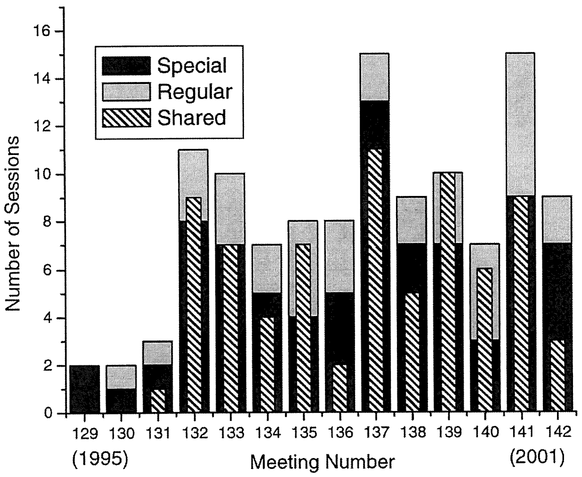


Figure 2. Technical sessions sponsored by Signal Processing in Acoustics (SP) or co-sponsored (shared) with other Technical Committees. Special sessions are structured with invited and contributed papers. Regular sessions contain contributed papers only. The median number of SP sessions represents about 10% of the sessions at ASA meetings.

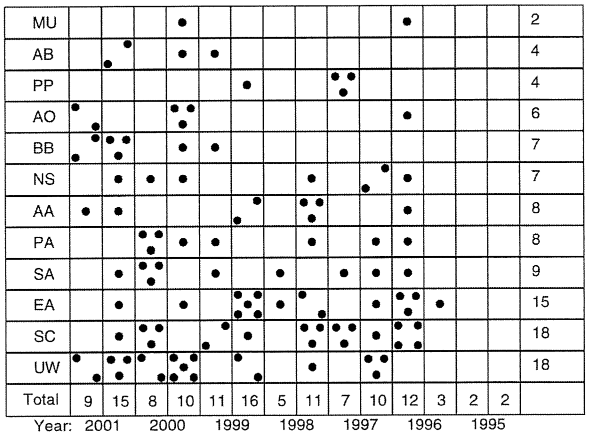


Figure 3. Sessions co-sponsored with other Technical Committees. Each co-sponsored session is represented by a dot. The totals along the bottom and right edges indicate the number to TC-SP shared sessions at each ASA meeting and the number shared with each Technical Committee, respectively.

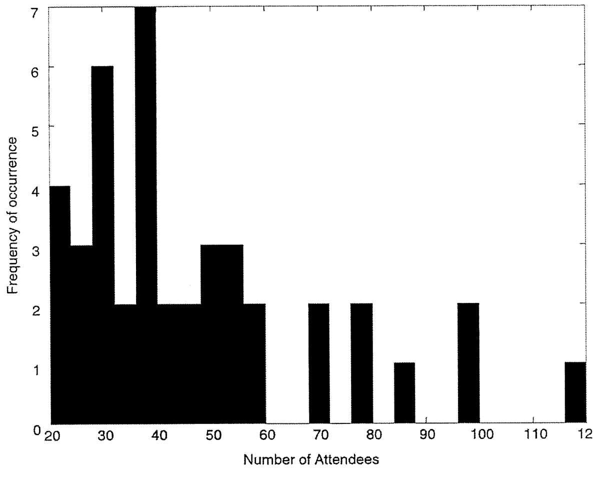


Figure 4. Distribution of audience sizes at Signal Processing in Acoustics technical sessions. The data are based on available session Chair reports up to May 2000.

than 20 to more than 120, with most sessions having 20-50 attendees (Fig. 4). Table III shows the number of ASA members with technical interests in Signal Processing in Acoustics and the numbers indicate that interest in SP has been increasing within the ASA.

In 1999 Gabi Weinreich introduced the "Inclusivity Index" to display the extent to which a particular technical area has significant interest beyond its own dedicated Technical Committee members. Figure 5 shows the Inclusivity Index for the Technical Committees, sorted by their Index for 2002 (wide bars). According to this measure, Signal Processing in Acoustics has the greatest breadth of interaction within the Society.

After several years of successful activities and interaction with the Technical Committees of the ASA, the ITG-SP applied to Technical Council in December 2000 to be designated a Technical Committee. The application was readily accepted by Technical Council and subsequently approved by Executive Council, creating the Technical Committee on Signal Processing in Acoustics (TC-SP).

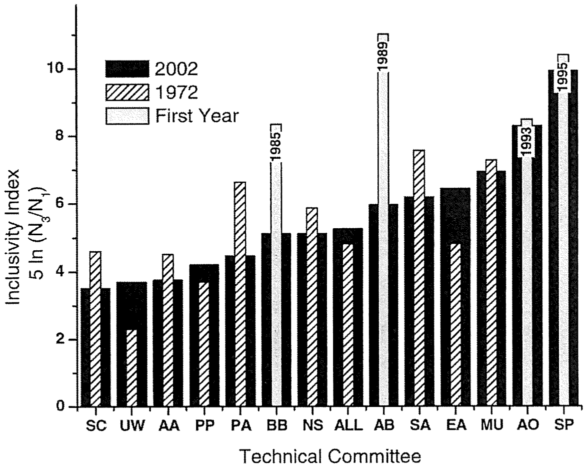


Figure 5. Inclusivity Index for ASA Technical Committees. Gabi Weinreich introduced the Inclusivity Index in 1999 to indicate the extent to which a particular technical area has significant interest beyond its own dedicated Technical Committee members. The Index is defined as 5 ln (N_1/N_3), with N_1 and N_3 being the number of members indicating that the Technical Committee is within their "1st" and "3rd" area of technical interest (see Table III, for example), respectively. The Technical Committees are ordered by their 2002 Index value. The inset bars indicate the Index in 1972 or the first year of the Committee.

Table III. ASA members with technical interest in Signal Processing in Acoustics. The number of ASA members indicating that SP as their first (1st), their first or second (2nd), or their first, second or third (3rd) technical area of interest are tabulated for the available years surveyed. The number in the "1st" column is also shown as a percentage of ASA membership (1st %) and the number in the "3rd" column is also shown ranked against the corresponding numbers for all other Technical Committees. The data indicate an increasing interest in Signal Processing in Acoustics within the ASA.

	1st	**2nd**	**3rd**	**1st %**	**3rd rank**
1995	119	438	915	1.8%	#10
1997	215	803	1650	3.1%	#6
1999	262	917	1886	3.8%	#5
2002	276	1015	2004	4.1%	#3

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Signal Processing In Acoustics Timeline

600BC • Pythagoras relates tones to lengths of strings.

250BC • Water clocks allow processes to be timed.

1738 •••• Wave equation derived by Bernoilli.

1822 •••• Harmonic analysis formalized by Fourier.

1874 •••• Phonautograph, by A.G. Bell and C. Blake, visualizes speech signals using etchings.

1876 •••• Koenig Analyser visualizes harmonic components of a signal in real time using flames.

1894 •••• Henrici-Coradi Harmonic Analyzer computes harmonic components of a graph using a mechanical integrator.

Periodogram formulated by Schuster.

1900 •••• Teleharmonium developed by Cahill for public distribution of music.

1927 •••• Yule-Walker equations relate autocorrelation to auto-regressive representation of signals.

1928 •••• Theremin music synthesizer (as heard in the Star Trek theme song) is developed, followed by the popular Hammond organ a few years later.

1930 •••• Weiner-Khintchine theorem relates autocorrelation to power spectral representation of signals.

1955 •••• Music synthesizer and recording system developed by Olsen and Belar.

1958 •••• Digital simulation of concert hall frequency response by Schroeder.

1960 •••• DIMUS underwater sonar implements array beamforming in real time.

1963 •••• First Associate Editor for Signal Processing in Acoustics appointed for JASA.

1965 •••• FFT popularized by Cooley and Tukey.

1969 •••• Books on computer music appear.

Signal Processing In Acoustics Timeline

1971 ••••	Computer-assisted psychoacoustic measurement techniques developed by Levitt.
1979 ••••	Speech coding optimized for psychoacoustic model by Schroeder, Atal, and Hall.
1987 ••••	Wave guide synthesis formulated for physical modeling of musical instruments by Smith.
1991 ••••	First use of wavelet transforms for analysis and synthesis of music by Kronland-Martinet.
1994 ••••	ASA Interdisciplinary Technical Group on Signal Processing in Acoustics meets.
2000 ••••	ASA Technical Committee on Signal Processing in Acoustics formed.

Past and Present Chairs of the Technical Committee on Signal Processing in Acoustics

1994-95	James M. Bartram
1995-98	David I. Havelock
1998-03	James V. Candy
2003-	Charles F. Gaumond

Recipients of Interdisciplinary Silver Medals

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Underwater Acoustics, Acoustical Oceanography and Signal Processing in Acoustics

2003 - Arthur B. Baggeroer - For applications of model-based signal processing to underwater acoustics and for contributions to Arctic acoustics.

Chapter 14

Speech Communication

Diane Kewley-Port, Chapter Editor
History Lecture, Peter Ladefoged

Participants in the Speech Communication history lectures presented in 1998 are (from left to right): Hiroya Fujisaki, James Flanagan, Peter Ladefoged, Patricia Kuhl (Meeting Chair), Gunnar Fant, Victoria Fromkin, Robert Porter (presenting for Ludmilla Chistovitch), Katherine Harris, Alvin Liberman and Kenneth Stevens. Photo taken by Peter Jusczyk.

Speech Communication

Introduction

The Speech Communication Technical Committee encourages participation from scientists engaged in research related to the production, transmission, and perception of spoken language. Speech Communication has had a prominent role in the Society since its founding in 1929 when Harvey Fletcher, author of *Speech and Hearing*, became the first president. At that time, speech intelligibility and speech transmission were frequent topics of research. However, the interdisciplinary nature of investigations of spoken language brought many other topics into the Society from its inception, for example speech production, studies of respiration, vocal fold vibration and speech articulation. Soon speech production studies also included acoustic models of articulation, as well as spectral analysis devices and algorithms for speech. Advances in these areas stimulated Society members to investigate speech synthesis and automatic speech recognition. In addition, research on the acoustic cues for speech perception, including theoretical work on perception in adults and infants, has been actively pursued. More recently speech research has expanded into the areas of second language acquisition and perception by hearing-impaired listeners.

Today our Speech Communication members come from many different disciplines, including at least physics, speech and hearing sciences, experimental psychology, linguistics, electrical engineering, and digital signal processing. We have five associate editors of the *Journal* to cover the needed expertise for reviewing in speech production, speech perception and speech processing. In June, 1998 at the Seattle meeting of the Society, we celebrated our history in a special session, "Speech Communication: A Half-Century of Speech Research." Presentations were made by nine pioneers in the area, Gunnar Fant, Kenneth Stevens, James Flanagan, Alvin Liberman, Ludmilla Chistovitch, Katherine Harris, Peter Ladefoged, Victoria Fromkin and Hiroya Fujisaki. Their stimulating lectures are captured on video tape available from the Society. The chapter in this historical volume was written by Peter Ladefoged and provides an excellent overview of 75 years of research in Speech Communication.

Diane Kewley-Port, Chair
Technical Committee on Speech Commutation

The Study of Speech Communication in the Acoustical Society of America

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The study of speech has been an important part of the work of the Society from its earliest days. At that time there were two groups involved, the communication engineers, mainly from Bell Telephone Laboratories, who were concerned with speech intelligibility and speech compression, and the academics, who thought of themselves as speech scientists, and whose background was in language teaching, speech pathology and singing. The two groups had more similar interests than might be expected. Bell Labs had a long-standing interest in speech problems, particularly in helping the deaf and speech impaired. The founder of the Bell Telephone Company, Alexander Graham Bell (1847–1922) was the son of Alexander Melville Bell (1819–1905), who taught elocution in Edinburgh and London. Both father and son were concerned with teaching the deaf to talk.

The first President of the Society was Harvey Fletcher (1884–1981), the Physics Research Director of Bell Labs. He published his great work, *Speech and Hearing* in 1929, the same year as the first meeting of the Society. This meeting was held in the auditorium of Bell Telephone Laboratories in New York, and included a Symposium on Speech. G. Oscar Russell, who gave the first paper in this symposium, almost certainly provided a lively, and perhaps even flamboyant, performance. The written version, which was published in the *Journal* (Russell 1929), is his first person report. It notes that there was laughter and a great deal of interaction between the author and his audience.

G. Oscar Russell (1890-1962) was an Assistant Professor of Spanish who went on to become Director of the Phonetics Laboratory in the Department of Speech at Ohio State University. Shortly before the first meeting of the Society he had published "The Vowel: its physiological mechanism as shown by x-ray," (Russell 1928), a groundbreaking work. His paper recapitulates the book's thesis, which is that the IPA characterization of vowels in terms of the highest point of the tongue is wrong, being based, as Russell puts it, on "imaginary and highly fantastic vocal cavity diagrams," whereas his own study, using an x-ray technique "now finally perfected after years of exasperating experimentation" (Russell 1929) involved over 3,000 x-rays and 400 subjects. (He did not, in those days, have to have his research approved by an Institutional Review Board.)

The first issue of the *Journal* contained three other papers on speech. Vern Knudsen (1893-1974), a later President of the Society, discussed the hearing of speech in auditoriums (Knudsen 1929-30). He used an articulation index to assess the effect of three variables: (1) loudness—speech needs to be at 50 - 70 dB as recorded in the center of room; (2) reverberation—speech reception is dependent on the number of people in the room, in that "hearing would be acceptable when more than 300 persons were in the room, but with a small audience the hearing would be altogether intolerable"; and (3) noise —nicely quantified, showing, rather obviously, that the less the better. He also analyzed the speech errors, providing a confusion matrix showing that, for example, /t/ was heard as /k/ 16 times whereas /k/ was heard as /t/ only 10 times.

The other speech papers in the first issue were by Norman R. French and Walter Koenig, Jr., who reported on the frequency of occurrence of speech sounds in spoken English, providing charts of the number of occurrences of vowels, initial and final consonants in 80,000 words recorded in telephone conversations (French and Koenig 1929-30), and by John C. Steinberg, who discussed the effects of distortions such as variation in signal level and filtering on the recognition of speech sounds (Steinberg 1929-30)

All this was in the first year of the Society. But there was comparatively little speech work reported in the next few years. Harvey Fletcher gave a paper on characteristic resonances of vowels, and Don Lewis (Iowa), Paul Farnsworth (Stanford) and John Black (Ohio) also studied this topic. The concept of 'vowel resonances' (formants) had been known at least since Helmholtz (1863), and Ellis, in his 1897 translation of Helmholtz, had reported that Alexander Graham Bell had determined the first two resonances (formants) of each of his father's nine cardinal vowels. But there were no good analytic techniques available to allow much further progress.

The next important speech paper did not appear until 1939, when Homer Dudley presented the world with the Vocoder (Dudley 1939), a system in which speech was analyzed into component parts consisting of the pitch (fundamental frequency of the voice), the noise (where no fundamental frequency could be detected) and the intensities of the speech in a set of band-pass filters. He showed how speech could be re-made from low frequency control signals representing these component parts. Important as this was from the engineering point of view, what fascinated the world more was the offspring from this work, the Voder. This was a machine, demonstrated at the 1939 New York World Fair and on radio, that allowed a highly trained, skilled operator to create (rather than re-make) speech by operating the controls manually. To everyone's delight the machine could say things such as "Good evening, radio audience" in a way that sounded at least reminiscent of human speech. Dudley's schematic is shown in Fig.1.

The public had to wait till after World War II before the next great advances in speech communication were revealed. During the war, Ralph K. Potter had led a Bell Labs research team that developed the sound spectrograph. This invention, which literally changed the way we looked at speech, was announced by Potter (1945) in *Science*, and then described in detail in a set of papers in the *Journal* in the following year (Potter 1946, Steinberg & French, 1946, Koenig, Dunn & Lacy 1946, Dudley & Gruenz 1946, Kopp & Green 1946). These papers included not only an account of the spectrograph itself, an instrument that took three or four minutes to produce a display of a 2.5 seconds utterance, but also a description of a device, shown in Fig. 2, that produced real-time pictures on a phosphorescent screen. This research was part of an effort to produce a form of speech that could be read by the deaf and others after suitable training, an accomplishment that was later found to be too difficult for most people to acquire with the available instrumentation. Shortly after the development of the spectrograph the influential book, *Visible Speech,* was published (Potter, Kopp and Green, 1947). According to Harriet Green, this

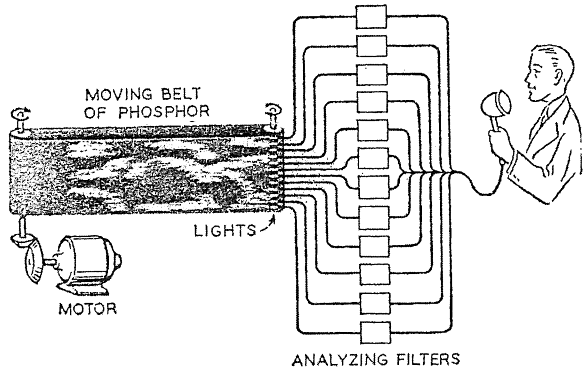

Figure 1. The Voder, a manually operated 10 channel vocoder demonstrated at the New York Worlds Fair, 1939 (Dudley 1939, redrawn figure in Klatt 1987).

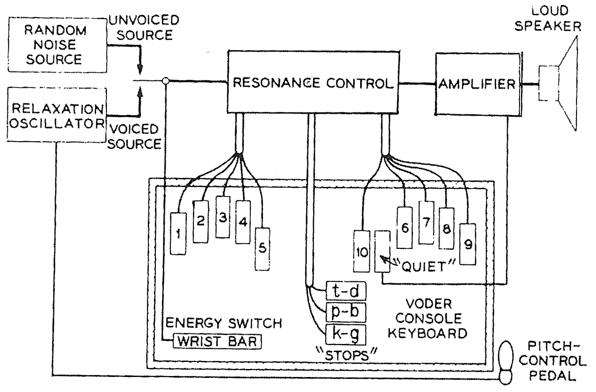

Figure 2. Diagram of the Visible Speech Translator (Dudley & Gruenz 1946).

book was "written by Kopp and Green with his [Potter's] ever present supervision."

Phonetic aspects of speech research blossomed in the fifties and sixties. While still at Bell Labs, Gordon Peterson and colleagues produced a number of studies of vowels, notably Peterson and Barney (1952), which remained the standard account of American English vowels for many years. Peterson left Bell Labs in 1953 to join the faculty at the University of Michigan, where he later founded the Communication Sciences Laboratory. He and his colleagues (notably Ilse Lehiste) published several accounts of the acoustic characteristics of speech (e.g. Lehiste and Peterson 1961).

Bell Labs remained a major influence within the field of speech communication, but, in addition to Michigan, other universities and research labs were also becoming well-known. Martin Joos, a linguist at the University of Wisconsin, published a monograph on the formant structure of vowels (Joos 1948), and Irwin Pollack and colleagues at the Air Force Cambridge Research Center conducted research on speech intelligibility. In 1950 the Harvard Psycho-Acoustic Laboratory under the direction of S.S. Stevens joined with M.I.T to sponsor a Conference on Speech Communication (Stevens 1950), which included contributions from many well-known researchers such as Norbert Wiener (MIT), Paul Menzerath (Bonn), Martin Joos (Wisconsin), John Lotz (Columbia), Ira Hirsh (Harvard), George Miller (Harvard), Jean Dreyfus-Graf (Geneva), H.K. Dunn (Bell Labs), Franklin Cooper (Haskins), and a young Ken Stevens (MIT). Since that time the Speech Communication Group (to use its current name) at MIT has made many contributions to our knowledge of the acoustics of speech. Kenneth Stevens and his students have described the acoustics of speech sounds in far more detail than anyone has ever done before, culminating in a book by Stevens (1998) that is the most complete survey of the field since Fant's *Acoustic Theory of Speech Production* (Fant 1960).

Shortly after the 1950 MIT Conference on Speech Communication, Haskins Laboratories began its rise to become a major institution in speech research. The Laboratories' prominence in the speech field was initially due to its research using synthesized speech in perceptual experiments. Franklin Cooper, an optical engineer at Haskins, was one of the people influenced by Potter, Kopp and Green (1947). From his study of their book *Visible Speech*, he realized that it would be possible to construct an instrument for converting sound spectrograms and their stylized representations into synthesized speech. This device, which he called the Pattern Playback, led to new insights into the nature of speech. The most well known early theory from Haskins was the Motor Theory of Speech Perception, in which the gestures of a speaker are regarded as the objects of the listener's perception (Liberman, et al. 1967, Liberman & Mattingly, 1985). In this view speech production and perception are innately linked so that a single part of the brain is responsible for both perception and production of speech. At much the same time as the motor theory was being pursued, Harris (1970) and others at Haskins were investigating articulatory movements using EMG and other physiological techniques. Haskins has continued as a leading research institute, with more recent work being concerned with the theory of Articulatory Phonology (Browman and Goldstein 1986, 1992). In this theory the plan of an utterance is formatted as a gestural score that provides the input to a physically based model of speech production —the task dynamic model. (Saltzman 1991). Research on speech perception, recognition, production, and synthesis, and their relationship to reading, language disabilities, cognition, and related topics continues at Haskins Laboratories through to the present time.

The Haskins Pattern Playback dominated early research using synthetic speech in the United States. Meanwhile, in Europe, Walter Lawrence had also been influenced by *Visible Speech*, but instead of trying to reproduce spectrographic patterns he realized that it would be possible to construct a parametric speech synthesizer. (Lawrence, 1953). Also in Europe at about the same time, Gunnar Fant constructed a more restricted formant synthesizer which he later developed to synthesize natural connected speech (Fant et al. 1961). But in the United States research using parametric speech synthesizers was not so prominent. There were terminal analog speech synthesizers, but they were limited in scope, usually suitable only for work on vowels. It was not until the work of Dennis Klatt at MIT that parametric speech synthesis really blossomed. The Klattalk system (Klatt 1980, 1982), with its large array of parameters, soon became the standard way of synthesizing speech in parametric terms. Those who were present will never forget one of the last Acoustical Society meetings that Dennis Klatt attended. He came in and said "I can't talk very well, so I'll just let the machine do the talking." He then played the first completely intelligible synthesized speech paper presented to the Society. Dennis Klatt died in 1988 following a long battle with cancer.

Shortly before his death Klatt published a history of research on speech synthesis through the mid-1980's (Klatt, 1987). Throughout most of this period the main aim was to use synthesis as a tool for finding out more about the acoustics of speech. For the last 20 years or so, the emphasis has been on devising Text-To-Speech (TTS) systems. There had been earlier attempts to generate speech from text, the outstanding example being the set of rules devised by Holmes, Mattingly & Shearme (1964), but it was not until computers became more common that commercially viable systems were developed. There is still no TTS system that can read a novel in a satisfying way, but naturally sounding sentences can be produced by many systems. However, instead of building utterances from the component parameters, most of these systems rely on concatenating small segments of prerecorded speech. The problem has become an engineering task, involving the best way of searching through an enormous corpus of snippets of recorded speech in order to find the match most similar to the part of the text to be synthesized. These systems are less interesting to those concerned with learning more about the acoustics of speech.

The obverse of speech synthesis, automatic speech recognition, also had its start before the widespread use of computers. Members of Bell Labs had constructed a system that used the changes in the first and second formants to distinguish digits (Davis, Biddulph & Balashek, 1953). At the same time Fry and Denes (1953, 1957) constructed a more general system in which speech was fed into an acoustic recognizer that compares "the changing spectrum of the speech wave with certain reference patterns and indicates the occurrence of the phoneme whose reference pattern best matches that of the incoming wave," using, in addition, linguistic information about the sequential probabilities of different phonemes. This kind of approach, a combination of linguistic phonetic knowledge and acoustic data, mainly based on spectrographic analysis, continued for many years. In 1971 the US government, through ARPA (later DARPA, the Defense Advanced Research Project Agency) funded Carnegie Mellon University (CMU), Stanford Research Institute (SRI), MIT's Lincoln Laboratory, Systems Development Corporation (SDC), and Bolt, Beranek, and Newman (BBN), asking them to compete in producing a speech recognition system. ARPA required all the SUR (Speech Understanding Research) systems to use a wide range of sources of knowledge, involving not only acoustics and phonetics but also syntax and semantics. ARPA's objective was to obtain a speech understanding system, not just a system that could correctly identify the words in a spoken message. The system had to answer correctly spoken commands such as "List all Soviet submarines in the Pacific fleet." (example from the SDC protocol). At the end of the five year funding period Carnegie Mellon's Harpy system (Lowerre, 1976) was the most successful, achieving a 5 percent error rate on a 1,000 word vocabulary used in continuous speech.

The ARPA SUR project showed that speech understanding systems were viable—provided that they were restricted to using a given vocabulary in a defined context. Such systems are now common in tasks like making airline reservations in which the context can be constrained. The user's options are limited to answering questions such as: "Which airport do you want to depart from?" "Where do you want to go to?" But before they got to their present stage another change in technology occurred. Speech recognition systems began relying on Hidden Markov Modeling (Baker 1975, Jelinek, 1985) and neural network techniques (Elman and Zipser 1988). These techniques involve training the system by inputting large quantities of known speech, allowing desired responses to stimuli to be reinforced and unwanted ones to be given a lower probability. As a result of the training, the likelihood of a given input corresponding to a given meaningful unit is assessed. Like current speech synthesis systems, instead of relying on basic principles of acoustic phonetics for distinguishing sounds, speech recognition systems now rely more on computer science techniques than on information provided by phoneticians and linguists.

As well as the goal oriented work on text to speech synthesis and automatic speech recognition, basic research on speech science has continued. As a consequence of expanded interest in human communication in the academic community, we now know a great deal about how the sounds of the world's languages differ from one another, and how foreign language learners can be helped to acquire a native accent. Explanations are now available for many historical sound changes. Much has been learned about how individual voices differ, and how emotions are expressed. The mode of vibration of the vocal folds has been defined more rigorously, although we still need to know more about pathological and atypical voice qualities. The limits of speech perception are now better defined, and the child's acquisition of speech is better understood. A lengthy essay could be written about each of these topics, and it would be invidious to single out some of them rather than others.

Finally, it is interesting to look back and see how speech research has changed in the Acoustical Society. In the early days many different aspects of speech were investigated. This was followed in the 40's and 50's by an emphasis on engineering aspects of speech communication. During the 60's and 70's there was a change in emphasis in the speech topics discussed in the Society. The number of engineers publishing or presenting papers on speech transmission at meetings of the Society began to decrease, and the number of papers concerned with a more general view of speech began to increase. Prior to 1964 "Phonetics" was not part of the subject index in the 5 year index of the *Journal.* In 1964–1968, the first five year period in which it was recognized as a topic, there were 12 papers on phonetics, as compared with 27 papers on speech transmission. In the next five year period this ratio was reversed: there were 27 papers on phonetics and 11 papers on speech transmission. The indexes for later five year periods combine papers published in the Journal and papers presented at meetings. In 1974–1978 there were 621 papers on phonetics and 90 papers on speech transmission. These figures reflect another fact. A considerable proportion of the publications were simply abstracts of papers presented at meetings. Members of the Speech Communication section of the Society seem to regard the meetings as good places to discuss their work, but often publish the final papers in the more specialized journals devoted to different aspects of speech. In 1987 this prompted the Editor of the *Journa*l to note that "speech communication… coverage [in the *Journal*] has recently been minimal and needs expansion." (Martin 1987).

In the 50's the bulk of speech research was commercially sponsored by the telephone industry. During the 60's and 70's engineers began to regard the Institute of Electrical and Electronics Engineers (IEEE) as a more suitable home, whereas speech scientists and phoneticians who might have been presenting papers at the Linguistic Society of America (LSA) or the American Speech and Hearing Association (ASHA) found the meetings of the Acoustical Society more interesting. This trend continued through the 80's and 90's and now meetings of the Society have a very large and very variegated Speech Communication group. The study of speech is of necessity an interdisciplinary pursuit, and the Acoustical Society is clearly the most popular meeting place for scientists working in this field.

[Editorial note: In addition to the work noted in this report, it should be pointed out that a group that has been the most productive and influential in advancing our knowledge of phonetics was led (over a period of four decades) by Peter Ladefoged at UCLA. As well as producing books containing detailed articulatory and acoustic descriptions of sounds in a wide range of languages (cf. Ladefoged and Maddieson, 1996), Peter Ladefoged trained a generation of teachers and researchers in phonetics from around the world.]

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Speech Communication Timeline

1929	H. Fletcher, Bell Labs, was first president of the ASA.
	H. Fletcher published *Speech and Hearing* (New York: Van Nostrand-Reinhold).
1929-30	G. Oscar Russell published x-rays of human vowel production.
1937-40	D.W. Farnsworth, high-speed motion pictures of vocal fold vibrations at Bell Labs.
1939	H. Dudley invented Voder, first electrical speech synthesizer.
1941	T. Chiba and M. Kajiyama published *The Vowel* - Its Nature and Structure (Tokyo: Tokyo-Kaiseikan).
1946	W. Koenig, J. Dunn, L. Lacy and R. Potter, spectrograph at Bell Labs.
1947	R.K. Pottter, G.A. Kopp, and H.C. Green published *Visible Speech* (New York, D. Van Nostrand).
1952	G. Peterson and H. Barney, acoustic analysis of vowels.
1955	G.A. Miller and P.E. Nicely, perceptual confusions in consonant perception.
1957	P. Fabre, electroglottography.
1958	J. van den Berg, myoelastic-aerodynamic theory of voice production.
1959	M.H. Draper, P. Ladefoged, and D. Whitteridge, EMG recordings of respiratory muscles during speech.
1960	G. Fant published *Acoustic Theory of Speech Production* (The Hague: Mouton).
1961	D. Kimura, application of dichotic listening to study speech perception.
	A. Liberman, F. Cooper, K. Harris, & P. MacNeilage, the motor theory of speech perception at Haskins Laboratories.
1964	L. Lisker and A. Abramson, cross-language study of VOT.
1965	J. Flanagan published *Speech Analysis, Synthesis and Perception* (New York: Academic Press).
1967	P. Ladefoged published *Three Areas of Experimental Phonetics* (London: Oxford Univ. Press).
1968	M. Sawashima and H. Hirose, fiberscoptic study of laryngeal activity in speech.
	B. Atal and M. Schroeder, linear prediction of speech.

Speech Communication Timeline

1970-90 T. Hixon, G. van der Giert, P. Schönle, J. Perkell, development of magnetometer systems to track articulatory movements.

1971 •••• P. Eimas, E.R. Siqueland, P. Jusczyk, and J. Vigorito, speech perception in infants.

1972 •••• K. Stevens, the quantal nature of speech.

K. Ishizaka and J.L. Flanagan, two-mass model of the vocal folds.

1973-76 T.J. Hixon, M. Goldman, and J. Mead, statics and dynamics of the chest wall in speech.

1975 •••• J. Baker, Hidden Markov Models for speech recognition.

1976 •••• H. McGurk and J. MacDonald, audiotory-visual speech perception, the "McGurk effect."

1977 •••• R. Harshman, P. Ladefoged, and L. Goldstein, factor analysis of tongue shapes.

1978 •••• L. Rabiner and R. Schafer published *Digital Processing of Speech Signals* (Englewood Cliffs: Prentice Hall).

1979 •••• L.A. Chistovich and V.V. Lublinskaya, center of gravity in vowel spectra.

1980 •••• B. Delgutte, speech coding in auditory nerve.

1980-90 D. Klatt, software speech synthesizers, leading to DECtalk text-to-speech system.

1984 •••• J.F. Werker and R.C. Tees, cross-linguistic infant speech perception.

1986 •••• S. Furui, dynamic features for speech recognition.

M. Rokkaku, K. Hashimoto, S. Imaizumi, and S. Kiritani, application of MRI to study the vocal tract during speech.

1987 •••• J. Elman and D. Zipser, neural networks for speech recognition.

1988 •••• I. Titze, vocal fold vibration models.

1990 •••• H. Hermansky, perceptual processing (PLP) for speech recognition.

1993 •••• C. Darwin, simultaneous perception of vowels.

1995 •••• R. Shannon, simulating perception of persons with cochlear implants.

Past and Present Chairs of the Technical Committee on Speech Communication

1960-61	Arthur S. House
1961-62	Caldwell P. Smith
1962-63	Alvin M. Liberman
1963-65	Katherine S. Harris
1965-68	Peter B. Denes
1968-70	James M. Pickett
1970-73	Douglas L. Hogan
1973-75	Michael H.L. Hecker
1975-78	Noriko Umeda
1978-80	Jared J. Wolf
1980-83	Edward P. Neuburg
1983-89	Robert J. Porter, Jr.
1989-95	Sigfrid D. Soli
1995-98	Terrance M. Nearey
1998-01	Emily A. Tobey
2001-	Diane Kewley-Port

Recipients of the Silver Medal in Speech Communication

1975 - Franklin S. Cooper - For his theoretical, practical, and literary contributions to the understanding of speech production, perception, and processing.

1980 - Gunnar Fant - For his scientific work in providing coherence and theoretical underpinnings to the complex human activity of speech production and for his qualities of leadership that have helped to bring this field to its present level.

1983 - Kenneth N. Stevens - For his contributions to our understanding of the production acoustic-phonetic properties, and the perception of speech and how we may join speech and technology in useful ways.

1987 - Dennis H. Klatt - For fundamental and applied contributions to the synthesis and recognition of speech.

1991 - Arthur S. House - For contributions to the understanding of speech production, perception, and recognition.

1994 - Peter Ladefoged - For advancing the theory of acoustic phonetics and phonology using acoustic field data from many of the world's languages.

1997 - Patricia K. Kuhl - For contributions to the understanding of innate and learned aspects of speech perception and production.

Recipients of the Raymond H. Stetson Scholarship in Phonetics and Speech Science

This scholarship, which was established in 1998, honors the memory of Professor Raymond H. Stetson, a pioneer investigator in phonetics and speech science. Its purpose is to facilitate the research efforts of promising graduate students and postgraduates.

1999 - Roger W. Steeve
2000 - Elizabeth K. Johnson
2001 - Jeffery A. Jones
2002 - Meena Agarwal
2003 - Cynthia G. Clopper

Chapter 15

Structural Acoustics and Vibration

Courtney B. Burroughs, Chapter Editor
History Lecture, David Feit, Murray Strasberg & Eric E. Ungar

Structural Acoustics & Vibration

Introduction

Most acoustic phenomenon start with vibrating systems. The focus of structural acoustics in the Acoustical Society of America (ASA) is in the generation and transmission of vibrations and the interaction of vibrations with the surrounding acoustic media, which includes acoustic radiation and the effects of fluid loading on vibrations. Although most of the activities in structural acoustics in ASA in the last 25 years have focused on the radiation and scattering from elastic bodies in response to US Navy interests (and funding), structural acoustics is an integral part of many of the disciplines within ASA, such as acoustics of musical instruments, building acoustics and environmental noise. With recent changes in the interests of the US Navy, one of the principal funding agents of research in structural acoustics, structural acoustics is facing new challenges. However, with rapid increases in computational power for numerical modeling and new structural materials, we look forward to a bright future of new and innovative designs in which the vibration responses of structures and their interaction with surrounding media may be customized to enhance acoustic environments.

Courtney B. Burroughs, Chair
Technical Committee on Structural
Acoustics & Vibration

History of the Structural Acoustics and Vibration Technical Committee

David Feit, Carderock Division Naval Surface Warfare Center
& Courtney B. Burroughs, Pennsylvania State University

The Structural Acoustics and Vibration Technical Committee (SAVTC) started life in the Acoustical Society of America (ASA) as the Shock and Vibration Technical Committee, where the focus was on vibrations of structural members in response to oscillating sources and shock, and acoustic radiation from vibrating structural elements, with early applications in the design of microphones and loudspeakers and in noise control in building structures. Research in structural acoustics and vibration began with classical structural vibration and wave propagation in structures of simple shapes in which closed-form solutions were available. These solution enhanced the basic understanding of behavior of vibration and acoustic radiation which underpinned the development of analyses and measurement methods applicable to more complex and realistic structure/acoustic systems.

Administrative History

Prior to 1960, there were in existence a number of technical committees, however, it was not until the spring meeting of 1960, held in Providence, RI, that the technical committee structure and its relationship to the Technical Council became formalized. The primary purpose of technical committees in those early years was the organization of the special symposia at meetings of the society. K.W. Johnson was appointed as Chair of the committee in the years 1957-1960 by the Executive Council (EC), while the first formally elected Chair of the Shock and Vibration committee was Fred Mintz, whose term of office extended from 1960 to 1961.

During the first decade of its existence, the committee raised funds to establish the Trent-Crede Medal. This medal is presented to individuals who have made outstanding contributions to the science of mechanical vibration and shock. It was first presented to Carl Vigness in 1969. Since then, the Trent-Crede medal has been presented eleven times.

The percentage of society members who have chosen Structural Acoustics and Vibration as their primary interest has ranged from a low of 5% in 1972 to a high close to 7%. From the beginning of the *Journal of the Acoustical Society of America* (JASA) papers appeared on Shock and Vibration. In general these papers considered sound transmission through building partitions, loudspeakers and vibration of simple structures, such are strings (in musical instruments) and rods. The percentage of the papers published in JASA on vibration of, scattering by and radiation from structures increased to become 10 to 15% after 1950, then decreased to around 7% after 1970 where it remains. The decrease is partly due to the shift in classifications from structural acoustics to building acoustics, transducers and musical instruments. The current 7% of JASA papers in structural acoustics and vibration is nearly equal to the percentage of members indicating their primary interest as structural acoustics and vibration. In ASA meetings, the number of technical sessions sponsored by Structural Acoustics and Vibration average about 8% of the total number of technical sessions, which is consistent with the number of ASA members who specify their first interest as Structural Acoustics and Vibration.

Achievements in Shock and Vibration During the first 25 Years of the Society

During the 1930's much of the vibration related work was motivated by the practical requirements of architectural acoustics and the development of telephony motivated work. An early paper appearing in the JASA of 1931 by Paul Sabine entitled "Weight as a Determining Factor in Sound Transmission" deals with the transmission of sound by a partition or septum, and approximates the partition as a rigid piston elastically constrained and damped at its edges only. A year later a paper by R. C. Colwell and J. K. Stewart discusses the mathematical theory of membrane and plate vibrations and comments that experimental evidence for the some modes of such structures were obtained.

R.B. Lindsay and collaborators, building on earlier work in the 1920's by W. Mason, wrote a number of papers dealing with the filtering of waves by the periodic loading of one-dimensional solid structures. These studies were theoretical, and included experimental verification of the phenomena. W. Mason was also a significant contributor to the field of structural vibrations, even though he is probably thought to be more closely associated with Physical Acoustics. It should be understood that many of the investigators cited in this history could equally well be referred to in the histories of the other technical committees.

In 1933 F. A. Firestone introduced a new analogy between electrical circuits and mechanical systems, in which he stated that, "Since more is known of electrical circuits than of certain kinds of mechanical systems, it is often more valuable to discuss a mechanical system in terms of its electrical analogue." These notions proved invaluable to a whole generation of the early acousticians, many of which were trained as physicists or electrical engineers. In more recent years many structural acousticians come to acoustics with more of a background in engineering mechanics, and such analogies are less useful to them. Later in the same decade, W. E. Kock published a paper that treated the vibrating strings of the piano as an electrical transmission line.

H. A. Leedy published a JASA paper in 1940 entitled "Noise and Vibration Isolation" in which he discussed the selection of the appropriate stiffness of the resilient mount where the base is not completely immovable. This work is one more example where the subject matter could equally well be considered to come under the purview of a number of different technical committees.

W. T. Thomson, well known for his textbook "Theory of Vibrations and its Applications" was an early contributor to JASA where he published a paper dealing with the effects of rotatory and lateral inertia on the flexural vibrations of beams.

The work discussed previously treated vibrating systems in the absence of any reaction loading from the ambient environment. During and after World War II, because of naval interest in the problems of acoustic signature control, investigators began to turn their attention to problems involving fluid-structure interaction. One of the first significant contributions dealing with fluid-structure interaction problems was that by Melvin Lax entitled "The Effect of Radiation on the Vibrations of a Circular Diaphragm" which appeared in the JASA of July, 1944, and based on work pursued at the Massachusetts Institute of Technology (MIT). This paper included the effects of radiation loading on the vibrations of a circular plate. The plate motion generates a "mass loading," lowering the plate's resonance frequencies, and the radiation of acoustic energy gives rise to an increased damping of the plate motion.

Following on to this work, shortly thereafter in 1945, were theoretical and experimental investigations carried out respectively by R. D. Fay and W.J. Finney of the Acoustics Laboratory at MIT of the interactions between an elastic plate and the sound field of the surrounding fluid. In both of these cases, the Navy Department's Bureau of Ships was cited as the sponsoring agency.

Structural acoustics research was also being conducted just down the road at Harvard University's Acoustics Laboratory under the direction of F. V. Hunt. There Miguel Junger began his studies of scattering and radiation from thin cylindrical and spherical shells where the fluid loading has a significant effect on the structural vibrations. After obtaining his doctorate from Harvard University, he and Preston Smith in 1954 formed Cambridge Acoustical Associates as a small consulting firm. It was here where a number of the fundamental notions of structural acoustics were spawned, developed and finally collected in the monograph entitled "Sound, Structures and their Interaction" by M. C. Junger and D. Feit, first published in 1972.

It was also in this same period that, as a spin-off the MIT Acoustics Laboratory, Bolt, Beranek, and Newman Inc. (BBN) established itself in Cambridge, MA in 1948. There, under the sponsorship of NASA and the Air Force, BBN scientists Richard Lyon, Gideon Maidanik, and Preston Smith developed the principles of Statistical Energy Analysis (SEA). Today this is probably the most preferred and widely used approach to the understanding of the vibrational response and acoustic radiation of complex structural systems. Other notable scientists and engineers who passed through the doors of BBN and contributed significantly to the field of structural acoustics and vibrations were Ira Dyer, Ed Kerwin, Donald Ross, Eric Ungar, K. L. Chandiramani, Manfred Heckl, and Sean Ffowcs-Williams.

With these four institutions in its midst, Cambridge, MA can be considered as the birthplace and spawning grounds of most of the early developments of structural acoustics and vibrations during the first 25 years of the Society's existence. Of the twelve awardees of the Trent-Crede Medal since it was first presented in 1961, seven have been affiliated and/or conducted their research while employed at one or more of the four organizations sited in Cambridge.

Achievements in Structural Acoustics and Vibrations During the Last 50 Years

Statistical Energy Analysis (SEA), already mentioned in earlier paragraphs, had its beginnings in the early 1960's. This approach to problems of high frequency vibrations and radiation is one of the most significant products arising from research and publications of those of the Society who have indicated Structural Acoustics and Vibration as their primary area of interest. The first paper to introduce this approach, authored by Dick Lyon and Gideon Maidanik, was "Power Flow Between Linearly Coupled Oscillators," published in 1962 in JASA. Since then many others such as Preston Smith, Eric Ungar, Jerry Manning and Rich De Jong have made substantial contributions to this technology. Software utilizing SEA is now used widely in the automotive and aerospace industries.

The understanding of vibrations and radiation from complex systems was also enhanced in the 1960's by E. Skudrzyk, and Cremer, Heckl and Ungar. E. Skudrzyk presented the Mean-Value Theory in JASA papers and in his book, *Simple and Complex Vibratory Systems*, published in 1968. In the book, *Structure-Borne Sound*, originally by published in German in 1966 by L. Cremer and M. Heckl, and translated and into English and expanded by E.E. Ungar, wave propagation in and radiation from individual and coupled structural elements, as well as mechanisms of damping, were treated.

During the last fifty years or so significant advances have been made in our understanding of the radiation, scattering, and response of fluid-loaded elastic plates. Contributors to this area whose work was published in JASA in 1967 include G. Maidanik and E. Kerwin, and D. Feit. David Crighton and Dorothy Iness made notable contributions in this area as well, although their papers on this subject were published outside the US.

In the late 1960's M. Junger and D. Feit used the Sommerfeld-Watson transformation to derive a creeping wave analysis for the scattering and radiation of acoustic waves by thin elastic cylindrical shells. This provided a new insight into the mechanisms of high frequency scattering and radiation that was not available from the modal series solution to the problem. Previous applications of this transformation were to acoustic scattering and radiation by solid elastic and spherical bodies. Other leading researchers in this area were H. Uberall, G. Gaunaurd, and P. Marston. Presentations of the latter work, where elasticity theory was used to describe the response of the solid medium, were usually made under the auspices of the Physical Acoustics technical committee.

Another area that was developed and pursued by structural acousticians was that of near and farfield acoustic holography. This experimental approach uses pressure measurements made in the near field of a vibrating object, and back propagates the information to determine its source distribution on the vibrating surface. This work was pioneered at the Pennsylvania State University (PSU) by Eugene Skudrzyk, an ASA Gold Medal recipient, and implemented by Jay Maynard and Earl Williams. In 1999 Earl Williams published a book on the subject entitled "Fourier Acoustics, Sound Radiation and Nearfield Acoustic Holography," based partially on his experiences at PSU, and his current laboratory at the Naval Research Laboratory (NRL). This work at NRL by Williams has been recently recognized as one of its most innovative technologies of the past 75 years.

In the 1980's, Christian Soize developed the fuzzy structure theory to predict the mid-frequency dynamic response of a master structure coupled to a large number of complex secondary subsystems. The structural and geometric details of the latter are not well defined and therefore labeled as fuzzy.

In addition to statistical models, developed from analytic models in the 1960's, computer technology in the 1960's permitted the development and employment of numerical models for the predictions of vibrations [Finite Element Models (FEMs)] and acoustic radiation [Boundary Element Models (BEMs)] from complex structure/acoustic systems. Under NASA sponsorship, the development of the FEM NASTRAN model was started in the 1960's. NASTRAN codes are now commercially available, albeit at considerable expense. However, research continues on improving accuracy and reducing computational efforts. Refinement of element definitions, automatic mesh generation, and user interfacing continue to be the subject of research and development. Also, in the 1960's, the foundation of BEMs, based on the Kirchhoff-Helmholtz integral equation, was developed by Chertock, Schenck and Copley, among others. Recent efforts inclue improving accuracy and reducing computational efforts, along with addressing computational difficulties associated with BEMs, such as singularites, uniqueness of solutions, and discontinuities in vibrations models by FEMs. Also, compatibility between BEM and FEM meshing continue to receive attention. BEM codes are now available commercially. With improvements in numerical models, the analyses of complex structure/acoustic systems are becoming more feasible in the development of designs for reducing vibration and noise.

There is no doubt that the science of structural acoustics and vibrations has progressed greatly over the last 50 years, but certainly there remain still many unanswered questions to be pursued by future generations. This history is far from exhaustive and therefore may have omitted topics and the work of some individuals who have made significant contributions in structural acoustics and vibrations. We apologize to the many structural acoustic practitioners whose names and work we have failed to mention in this brief overview of the history of structural acoustics and vibrations in the ASA.

Structural Acoustics and Vibration Timeline

1929 ••••	Founding of the Acoustical Society of America.
1935-45	Higher-order beam / plate / shell theories.
1944-50	Scattering from elastic structures.
1958 ••••	Finite element modeling.
1960 ••••	Establishment of Shock and Vibration Technical Committee.
1962 ••••	Statistical energy analysis.
1968-72	Nearfield acoustical holography.
1970 ••••	Boundary element modeling. Trent-Crede Award established.
1985-95	Active control of sound and vibration theories and applications.
1986 ••••	Committee re-named Technical Committee on Structural Acoustics and Vibration.
2004 ••••	TC/SA&V celebrates Society's 75th Anniversary.

Past and Present Chairs of the Technical Committee on Structural Acoustics and Vibration

1960-62	Fred Mintz
1962-65	Seymour Edelman
1965-66	Irwin Vigness
1966-69	Dwight C. Kennard
1969-72	Raymond R. Bouche
1972-75	Alan O. Sykes
1975-79	Eric E. Ungar
1979-81	Francis Kirschner
1981-85	Wayne T. Reader
1985-91	Sabih I. Hayek
1991-97	David Feit
1997-00	Jerry H. Ginsberg
2000-03	Scott D. Sommerfeldt
2003-	Courtney B. Burroughs

Recipients of the Trent-Crede Medal

1969 - Carl I. Vigness (posthumously) - For outstanding contributions to the understanding of the phenomena of mechanical shock and vibration, and through this understanding, the development of methods of measurement, simulation, and testing.

1971 - Raymond D. Mindlin - For his creative and definitive analyses of the vibration of isotropic and crystalline plates, for his classic monograph on the dynamics of package cushioning, and for his dedication as teacher and thesis advisor, especially in the field of vibration.

1973 - Elias Klein - For his contributions to the fields of shock and vibration as a scientist and administrator, and particularly for his leadership in organizing and establishing the Shock and Vibration Information Center, thus providing an important forum for information exchange in these fields.

1975 - J. P. Den Hartog - For his contributions to the field of shock and vibration as a practicing engineer, author, and teacher. His contributions have transformed vibration control from a pragmatic art to an applied science.

1978 - Stephen H. Crandall - For his contributions to education, research, and professional development in vibrations, especially those aspects of random vibration associated with component and structural failure.

1980 - John C. Snowdon - For his multifaceted activities in the field of mechanical vibrations and shock, as an outstanding teacher and lecturer, author, and researcher.

1983 - Eric E. Ungar - For his important contributions to our understanding of vibrations in complex structures, the effects of structural damping, and the propagation of structure-borne sound.

1987 - Miguel C. Junger - For pioneering contributions to the theory of the interaction of vibrating structures and associated sound fields.

1991 - Gideon Maidanik - For his profound impact on structural acoustic analyses and measurements in the application of the concepts of structural wave numbers and statistical energy analysis.

1996 - Preston W. Smith, Jr. - For pioneering contributions to Statistical Energy Analysis and structural—acoustical interaction.

1999 - David Feit - For contributions to high frequency noise radiation from submerged structures and to the vibration of fuzzy structures.

2003 - Sabih I. Hayek - For contributions to the understanding of sound interaction with submerged structures.

Chapter 16

Underwater Acoustics

Peter H. Dahl, Chapter Editor
History Lecture, Ralph R. Goodman

Underwater Acoustics

Introduction

The Technical Committee on Underwater Acoustics is responsible for representing and fostering underwater acoustics within the Acoustical Society of America. It is concerned with sound wave phenomena in the underwater medium and in the seabed, including the interaction of sound with the ocean seabed, and sea surface boundaries.

The field of Underwater Acoustics must necessarily encompass many disciplines, including physics, oceanography, geology, hydrodynamics, and signal processing. The field is also somewhat unique from others represented in the Society owing to its strong ties with the basic and applied research associated with naval defense.

Prof. Goodman's chapter, "A Brief History of Underwater Acoustics," shows how the thread of the history our field weaves through two world wars and the Cold War of the 20th century. Yet, history and science can be a difficult mix. The historian Paul Forman wrote that "For scientists history is not the field upon which they wrestle for truth, but principally their field of celebration and self congratulation..."[1] In contrast, Einstein remarked that "Nearly all historians of science are philologists and do not comprehend what physicists are aiming at, how they thought and wrestled with their problems..."[2] The foregoing statements help us place this chapter —and indeed all chapters in this volume—in the proper context.

Prof. Goodman's chapter brings us into the 1980s and the end of the Cold War, which drove post-WWII research funding and direction in underwater acoustics. Yet, even with the ending of this era, the underwater acoustic research community has maintained its reputation as being one of the most vibrant and productive communities in the Society. For example, during the past 20 years, 10 to 20 percent of the papers in any given issue of the *Journal* pertain to underwater sound. The added milestones help to bring this story of underwater acoustics research to the beginning of the new century, whereas the considerable progress made in this century will require more time to evaluate with the right perspective.

As members of the Underwater Acoustics Technical Committee, we are proud of our multi-disciplined heritage, knowing that it has served us well and will continue to do so as new discoveries are made in the world of underwater sound that will help us to explore, utilize and understand the oceans.

1. Stephen G. Brush, "Scientists as Historians," Osiris, 1995, 10:215-231, p. 226.
2. Ibid., p. 226.

Peter H. Dahl, Chair
Technical Committee on Underwater Acoustics

A Brief History of Underwater Acoustics

Ralph R. Goodman, The University of Southern Mississippi

The history of underwater acoustics was the subject of a review at the Eightieth Meeting of the Society in November 1970, chaired by Professor F.V. Hunt, and later published as a series of papers in JASA [1]. Also there was a special session at the 142nd Meeting of the ASA in Fort Lauderdale, FL, [2] that the writer was privileged to organize and chair. Several texts also cover some of the history. This chapter is partially based on these earlier works, Someday, hopefully soon, a complete history of underwater acoustics will be written. There is so much to be told.

Introduction and Background

The science and application of underwater acoustics had its beginnings at the start of the Twentieth Century. Although there were earlier anecdotal reports of some of the acoustical properties of the sea, quantitative experiments were not possible without the invention and development of instruments that could both produce and measure sound amplitudes and accurately measure time. These came at the beginning of the century and are based on the remarkable tools of transduction that the Nineteenth Century gave us. The measurement of the speed of sound by Collodon in Lac Lemon, Switzerland in 1826 [3] is sometimes referred to as the first quantitative underwater sound experiment. However, its purpose was not to understand propagation, but to obtain a value for sound speed with sufficient accuracy so that the adiabatic compressibility of fresh water could be determined [4].

The development of underwater acoustics in the Twentieth Century was closely related to, and for the most part, driven by the significant world events of the time, e.g. two world wars and the ensuing cold war. No other field of acoustics was so affected by these events or had such importance in their outcome.

At the beginning of the century the two primary concerns were age-old maritime problems of collisions at sea and running aground. Although there were some primitive applications of underwater signals, the loss of the *Titanic* in1912 brought before the public the need for a warning system. Acoustic collision avoidance devices were developed, but were soon replaced by radio telemetry. Within three years two other threats arose: the introduction of submarines and the use of underwater mines. For most nations at that time the use of submarines in their fleets was exploratory, and they had not yet been given a place in their orders of battle. Germany, however, had, at the onset of World War I, 38 so-called U-Boats in its fleet, and from their ability to remain undetected while submerged, were considered an important augmentation to their "High Seas Fleet" that was significantly outnumbered by the British "Grand Fleet" (by a ratio of about 2 to 1). In 1917 Germany changed its strategy and began a U-Boat campaign on the high seas. In the remaining two years of the war U-Boats were responsible for the sinking of nearly ten million tons of shipping. They severely crippled the allied supply lines. Contact mines were suspended on cables and were undetectable except by acoustical devices. They too took their toll of ships. Total loss to mines by Germany and Allied forces was146 war vessels (including 40 submarines), 267 auxiliaries, and 586 merchant ships. The effectiveness of mines in naval warfare was indisputable.

The German successes made the future role of submarines abundantly clear to all maritime nations. Those that maintained significant sea power began programs to improve their submarine fleet. Programs were also begun to improve their antisubmarine capabilities. But, with the end of hostilities, the terms of the Armistice, the Treaty of Versailles (that forbade Germany from possessing a submarine fleet) and the "War to End All Wars" mentality that prevailed, there was no urgency to develop new technologies for submarine and antisubmarine uses. Still it was obvious that there was an essential need for the use of sound. It was the only means of detecting submerged submarines. Also, it was the only "eyes" that a submarine had when it was totally submerged. Nations with major naval capabilities continued modest programs to develop acoustic systems, including mines, mine detection sonars, and torpedoes.

In 1939 World War II began and the age-old goal to dominate the seas prevailed. Germany, at the onset of hostilities, already had 57 submarines. Neither side was properly prepared for naval warfare. All out war hastened, not only with the construction of ships, but also the enlistment of large numbers of scientists, engineers, and technicians, unequalled in history, to improve and develop new systems for the detection, identification, tracking, and destruction of submarines and for improvement of submarine operations (submarine warfare). U-Boats again became the important platform aimed at limiting the supply lifeline across the Atlantic. Eventually, the use of aircraft, radar, and ships with improved sonar and weapons limited the effectiveness of U-Boats. Also, acoustically activated mines and acoustic homing torpedoes were developed. With their entrance into the war the United States began a renewed and vigorous effort in underwater research, under the sponsorship of the National Defense Research Council (NDRC) [Fig.1]. This began a collaborative effort among National Labs, other nations, industry, and academia at levels never seen before. (It was the establishment of a research structure that, to some degree, still exists.)

At the end of hostilities the level of effort was reduced. However Stalin's Soviet Union had "imported" the advanced submarine technologies and the construction capability of the defeated Nazi Germany. It developed a fleet of about 400 submarines. The Cold War had begun and this threat to the West kept the need for further developments alive. Most nations stayed active in undersea research. The emergence of communist China in 1949 and the following conflict with North Korea also kept the world's support of defense alive. The United States' losses to mines in the Korean conflict were evidence that the mine threat still existed and led to renewed efforts in mine countermeasures. With the stress that has been placed on the submarine threat it is often overlooked that mines have played an important role in naval warfare for a century and a half. They are difficult to find and

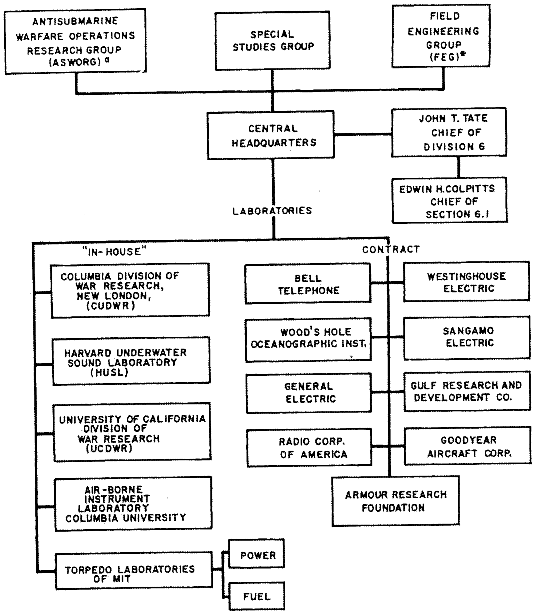

Figure 1. Organization of Division 6, NDRC "Undersea Warfare," 1941-1946.

destroy. Like submarines, the threat of their presence is a major factor in war at sea. The world was again made aware of the effectiveness of mines during the 1991 war in Iraq with the incapacitating damage to two US major ships of war.

Up to the 1950s most research was based on the concept of the conventional diesel submarine. Sonars were expected to cue on radar or visual contact, or, on the radiated noise of a submarine. It was loudest while the submarine was snorkeling. Consequently, sonars were developed to operate at ranges that were compatible with these concepts and to be practical within the range of weapons that were available at the time.

In the 1950's the submarine world was drastically changed with the introduction of nuclear propulsion. Now submarines could remain below the surface for extended periods, only limited by supplies and the endurance of their crews. All the standard cues for alerting were vitiated, except for radiated noise. Vigorous programs were initiated to reduce the radiated noise of submarines. New antisubmarine warfare concepts were needed and required the results of new avenues of research. The concept of submarine warfare literally took on new dimensions. With the capability to launch long-range nuclear missiles while submerged submarines became one of the most important elements in strategic warfare. In the latter half of the Twentieth Century nations were faced with this threat. The conditions under which most of the defense-related work took place were under the shroud of secrecy. Many of the results were not published. In time, some of the work became public.

Two non-military commercial fields that have been important driving forces in underwater acoustics are geophysical prospecting and fishing. In the last 50 years the extraction of oil from the seafloor has become one of the major energy sources, growing to better than 25% of the total. Presently the number of oil platforms in the sea is estimated to be well over a thousand, and many of these are at depths of more than a thousand meters. The drilling for these wells is preceded by elaborate acoustic probing of the seafloor that was developed by the oil industry. The use of sonar for the detection of fish began in the 1930s in England and has expanded to become one of the common tools in the trade. The sonars are relatively short range and their development has depended heavily on military research and development.

Clearly the science of underwater acoustics is inextricably tied to oceanography. Oceanography also had its infancy at about the same time as underwater acoustics. The British research ship *H.M.S. Challenger*, sailed on Christmas Eve in 1872, on a voyage that lasted for over three years and covered a distance of nearly 70,000 miles. That expedition is usually considered to be the start of global systematic studies of the internal processes of the deep seas. It was followed in the latter part of the century by expeditions from other nations. The development of oceanography was (and still is) essential to acoustics. Many of the physical processes, that are important to acoustics, such as internal waves, large scale eddies, and turbulence, have only been studied during the latter half of the last century. Oceanographers study physical and biological processes in order to understand that remarkable engine called the sea. On the other hand the acoustician will ask: how do these processes affect my signals, and how can I overcome them?

From what is described above it is clear that the science of underwater acoustics was driven almost entirely by the need of sonar technology. To use a quote from Professor Ted Hunt: "...for human needs sometimes assert themselves with irresistible insistence without waiting for calm scientific inquiry to run its own well-ordered course" [5, Page1]. It resulted in the development of a large number of sonar systems and led to the introduction of special areas of research and development for both the purpose of improving sonars as well as countering them. There now exist an enormous number of papers and patents on sonar, transduction, target strengths of ships, submarines, mines, etc. (For example, Chester McKinney reported that by 1970 there were 60 specific mine hunting sonars developed since 1940 by the European and U.S. navies alone [6].) Ship self noise quieting, anechoic coatings, arrays and array deployment, signal processing, etc., all play an important part in the application of underwater acoustics. To cover the history of the development of all of the fields of research would take a set of volumes. What follows in this chapter is the history of the physics and basic engineering of underwater sound that was the foundation for the research, development and operation of sonars. Depending on the application (e.g. active or passive systems, submarine or mine detection, seafloor surveys, etc.) each system required its special needs for the understanding of the basics. These can be categorized as propagation, noise, reverberation, and the scattering from the boundaries and from the water volume.

A History of Underwater Acoustics

The Nineteenth Century discoveries of magnetostriction and piezoelectricity, and the subsequent inventions that convert electrical energy to acoustic energy and vice versa, were essential to the development of underwater sound transduction and measurement. The task of applying these tools in the hostile, corrosive, and highly conducting environment of the sea awaited the next century. The well known French physicist, Paul Langevin and the Russian engineer, Constantin Chilowsky, and, independently, the Canadian engineer R.A. Fessenden produced the first functional transmitters that were capable of sending signals of sufficient strength to cause audible echoes from plates (Langevin) and icebergs (Fessenden). Fessenden's source was a moving coil transducer operated at frequencies around a 500 to 1000 Hz. Langevin ultimately developed, with a piezoelectric transducer, a system that detected a submarine at 1500 meters. The listening devices used a simple two earphone (air tube) device that utilized the binaural direction finding capability of the sonar operator [Fig. 2]

Essential to the understanding of underwater sound was the knowledge of the speed of sound in the sea. The German physicist, H. Lichte, recognized the importance of the vertical sound speed structure for the prediction of sound transmission [7]. His work seems to have been forgotten by the rest of the world, at least for the years following World War I. For the newly emerging use of sound to determine the depths of the sea the speed of sound in the sea was essential. The depth dependence of sound speed was obtained by measuring depth with wire and the travel time of an echo from the seafloor. (It was a tedious and dangerous undertaking to deploy and retrieve thousands of meters of wire, keeping it vertical during the measurement.) As early as 1924, in the United States, N.H. Heck and J.H. Service published tables on the dependence of sound speed on temperature salinity and pressure. [8] During the course of the next fifty years measurements, both in the laboratory and in the sea, improved the accuracy to an error of about 0.1 meters per second. Today, with perhaps the exception of those who are interested in the determination of a more accurate equation of state, the published values are sufficient for underwater acoustics. To the lowest orders of magnitude the sound speed (C) can be approximated by [9]. $C = 1449 + 4.6T + 1.34\,(S-35) + 0.016\,D$, (meters per second), where T is the temperature in degrees Celsius, S is the salinity in parts per thousand and D is the depth in meters. For example, near Bermuda in the summer typical values of sound speed would be 1560 m/s at the surface and about 1540 m/s at a depth of 200 meters.

For the reader to have a better appreciation of what follows, it is worth standing back from the history for a moment to see the fundamental importance of this equation. In the upper ocean the temperature is largely determined by solar heating, wind induced mixing, and, in some areas, by large moving water masses such as the Gulf Stream or large eddies. Vertical temperature gradients are generally orders of magnitude larger than those in the horizontal. Summer conditions, with strong solar heating and a warm atmosphere, give rise to sound speeds that are higher near the surface and decrease with depth owing to the thermocline. Winter conditions, with cooling of the surface and more energetic mixing reverses the temperature gradient in the thermocline.

Using the simple consequence of Snell's Law, waves seek a direction toward lower speed, it can be shown, from the sound speed equation above, that sound waves will bend downward under summer-like conditions and do the opposite in winter. Also, again, from Snell's Law, the vertical gradients cause significant refraction for rays propagating near the horizontal while rays propagating near the vertical will be nearly unaffected. In deep water the pressure term(represented by Depth in the equation) becomes dominant as temperature becomes nearly constant with depth. Here upward refraction occurs. Lichte [7] predicted this, but overestimated the amount of upward refraction by not having accurate tables for density and compressibility.)

Bathymetry, Charting and Probing the Depths of the Seafloor

The electro-acoustic projectors of Paul Langevin and R.A. Fessenden generated signals of sufficient strength to produce echoes from the seafloor. Thus the acoustic depth sounder was born. Systems that produced continuous recordings from ships navigating the seas produced revolutionary pictures of the seafloor structure. Before this development the only measurements made in the deep sea were by lowering a wire line from the deck of a ship, a tedious and dangerous method. By the 1920s depth had been measured at about 15,000 sites over the world's oceans and few of these were in the deepest regions of the sea. The comparative ease, rapidity, and safety of acoustic depth sounding made it an immediate success. An example of the revelation of the seafloor structure is shown

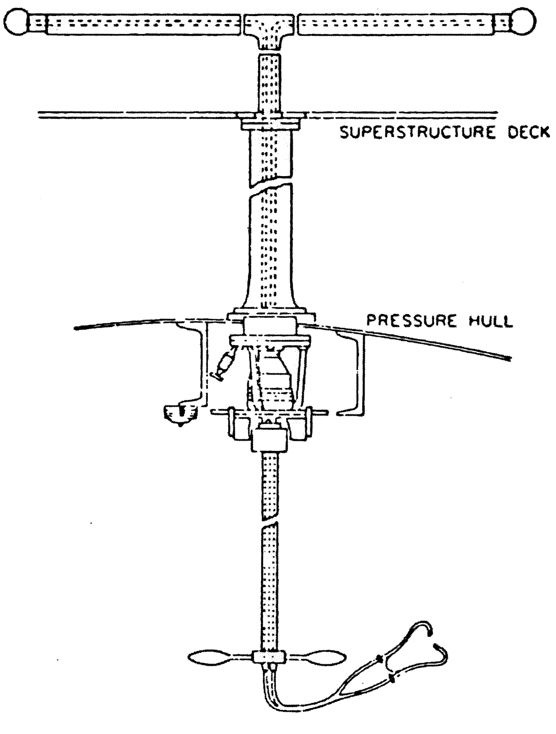

Figure 2. The Binaural sound receiver system as it was installed on a US submarine.

in Figure 3. The measurements were taken in the mid 1920s from the converted German gunboat, the 200-foot *Meteor*. She made several transits of the south Atlantic. Subsequent improvements in continuous depth sounding and its extensive use in surveys ultimately led to the remarkable maps of the seafloor [Fig. 4] created by Bruce Heezen and Mary Thorpe of the Lamont-Doherty Geological Observatory, Columbia University. These maps adorn the walls of many oceanographers' offices. The discovery of the Mid-Atlantic Ridge and its extension throughout the other oceans was essential to the development of the theory of seafloor spreading and, ultimately, to a verification of the hypotheses of continental drift and plate tectonics. (Perhaps this is the most important contribution that acoustics has made to the earth sciences.) The acoustic charting of the main large-scale features of the seafloor is about complete. Current techniques that are mounted use multi-beam arrays that mounted on the hull that map out a width on the order of a kilometer giving a better picture of the details of the seafloor and a much better coverage rate.

Geologists were also interested in the structure of the seafloor and needed sufficiently high levels of sound to penetrate the bottom. This led to the development of new high-energy low frequency sound sources. Explosives, high pressure bursts of gas (air-guns), and high voltage discharges (sparkers) have all been used, with the air-gun now being the most popular. Today the oil industry uses arrays of air guns, towed astern of ships, to direct high

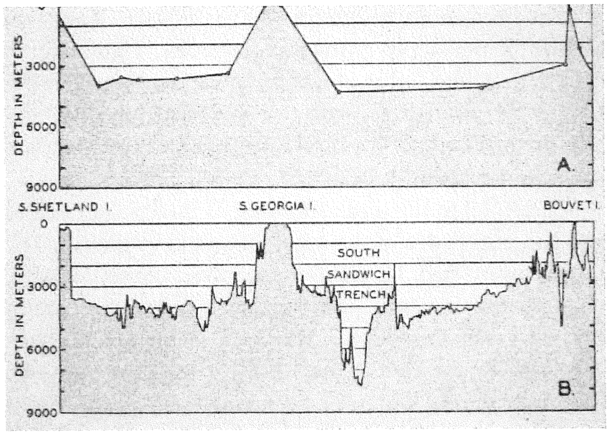

Figure 3. A comparison of the bathymetry along a deep sea track. A. From wire measurements and B. from the echo sounder aboard the German ship METEOR circa 1925.

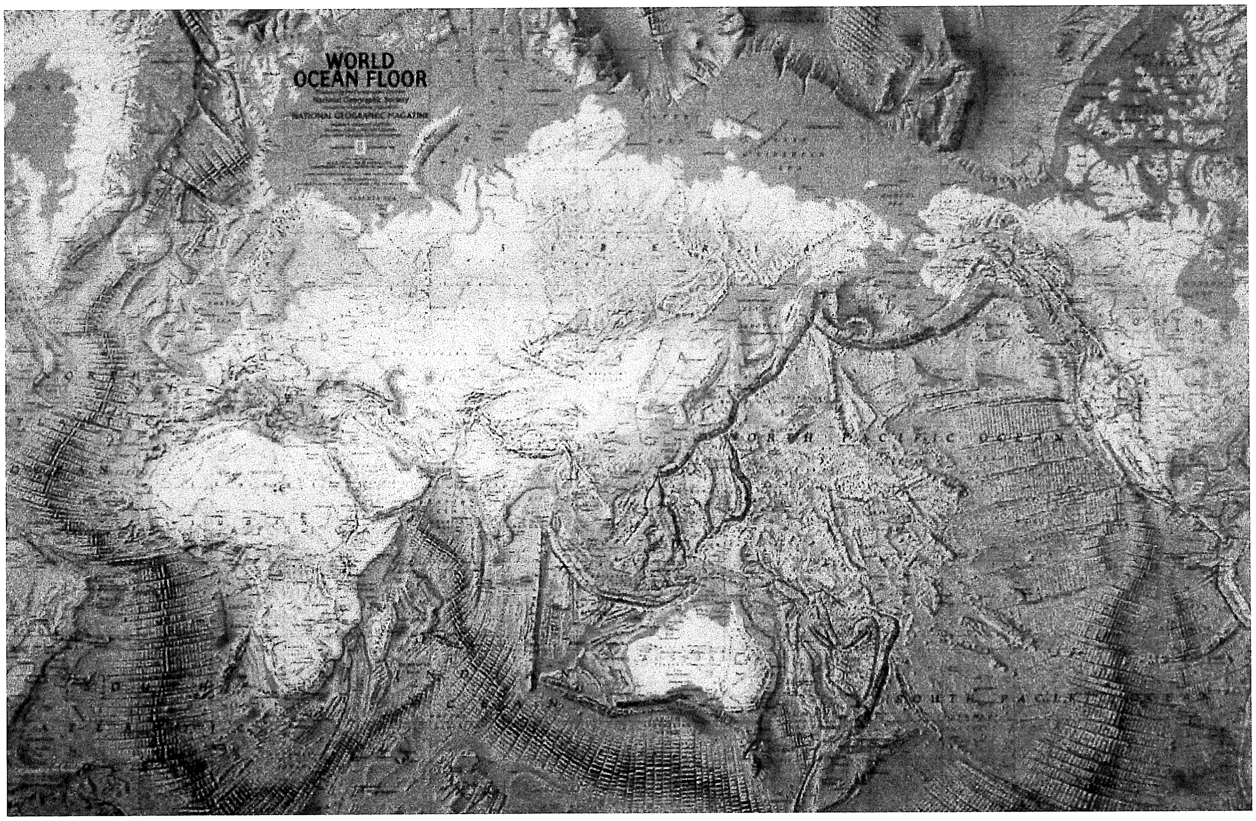

Figure 4. The "Heezen Chart," compiled from all the available bathymetric data at the time. The major features are accurate and some of the detail was left to the geologists imagination. Heezen died of a heart attack aboard the NR1 while he was charting the local details of the seafloor.

intensity signals deep into the sea floor. The signals are received on several long strings of hydrophones that are also towed behind the same ship.

Underwater Detection

There are two methods of acoustic detection of a submarine: (1) to listen to the sounds made by the submarine or (2) to transmit a signal and listen for the echo. (These are referred to as passive and active, respectively.) At first, both methods used listening devices that were connected to the operators' ears. [Fig. 2]. Range was a key problem for passive systems.

Based on the results from the war and from later trials both the United States and England chose active high frequency systems as the future path since passive systems at that time were severely limited by both the ships radiated noise and the self noise of arrays. That decision determined much of the direction of research and development well into the 1950s. Research in underwater acoustics during the period between wars was limited due to the low national level of interest. The US program was put under the direction of Harvey Hayes, the Superintendent of the Sound Division at the newly created Naval Research Laboratory. Although the program was limited by funds, there were significant advances in the development of transduction materials. During at-sea trials enormous variability in sonar performance was observed and became the subject of what might be called trial and error experiments. In 1937, on joint experiments with The Woods Hole Oceanographic Institution, acoustics trials were augmented with temperature/depth measurements. Sonar performance was correlated with the calculated ray refraction that was obtained from the sound speed/temperature profiles. The well-known "Afternoon Effect," in which the performance of sonar detections diminished in some regions of the world in the afternoon, was finally understood to be due to the downward refraction caused by the solar heating of the upper water column. This direct connection of underwater sound to the dynamic conditions of the sea was essentially a rebirth of some of the earlier observations of Lichte and Langevin. It became clear that sound speed structure needed to be known for the prediction of sonar performance. A method of measuring the vertical temperature profile from a naval vessel underway was provided by the invention by A. F. Spilhaus of a deployable "fish" called a bathythermograph [Fig. 5]. This purely mechanical device became an essential item on every naval anti-submarine warfare vessel. To sum up the knowledge of underwater sound up to the period before World War II, little was known about what the effects of the ocean environment had on sonar performance. Calibration standards were not yet developed. Elias Klein wrote in the October 1938 issue of JASA "At present there is no accepted standard for acoustics in liquids" [10]. A perusal of the *Journal of the Acoustical Society*, from its beginning to 1940, will reveal the lack of publication, due mostly to military restrictions on publication and limited research support. Ray tracing (the geometric optics limit in acoustics) was undoubtedly a common tool, within the limits of what could be done computationally. No open publications, however, can be found except the earlier one by Lichte.

The beginning of World War II was the start of a new and incredibly rapid growth in underwater acoustics. All nations, in response to the emergency, saw the need to maximize the use of technologies that had direct application to modern warfare. In The United States the National Defense Research Council (NDRC) was created for that purpose. It became one of the units under the newly created Office of Scientific Research and Development. Its duties were to recommend and administer projects and research programs that supported warfare. It responded to requests from the military services, and from other nations. It also had the authority to initiate its own requests. One of its divisions was Undersea Warfare [Fig. 1]. The recruitment of scientists and engineers from academia and industrial institutions began. Few had experience in underwater acoustics, let alone familiarity with the sea. The urgency of the task to improve the Navy's capability and the reality of the length of time that it took to introduce new equipment into fleet operations made it clear that the primary objective was to perform research to improve existing systems. The highest priority, therefore, was the study of underwater acoustics at high frequency (tens of kilohertz) over the relatively short range of a few thousand meters.

There were several important factors that led to the success of the war effort. First, the infusion into the field of very capable scientists and engineers from varied disciplines and experience forced a return to the very basic elements of underwater sound. Second, there was support for basic experimentation with specialized equipment and dedicated platforms. Third, oceanography, in support of acoustics, was made an essential part of the program. Fourth, calibration of transducers was identified as essential. (This resulted in the creation of the Underwa-

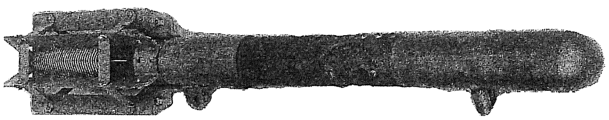

Figure 5. The mechanical bathythermograph. This instrument was lowered, over the side, from a winch with a wire line. The coil at the tail, filled with a fluid, was used to measure temperature. A pressure driven spring system was used to measure depth. A "pen" was used to etch a glass slide, giving a temperature/depth profile. Retrieving the instrument while it passed from the sea to air on a fast moving ship took practice.

ter Sound Reference Laboratory in Orlando Florida that, ultimately, became the nation's center for primary standards in underwater acoustics for the next fifty years.) Fifth, the very close connection with the fleet provided scientists and engineers with fleet assets and also with information on operational concerns. It also provided a path for feedback for improving sonar performance.

For the next five years progress of underwater acoustics was under the wraps of military secrecy throughout the world. The physics of wave propagation was applied to the sea. Ambient noise and scattering from the oceans boundaries were studied. Experimental design and planning imposed new requirements for equipment for deployment from ships and boats. Methods of at-sea research were devised. In order to achieve absolute sound levels, calibration methods were developed. Analog data recording methods were developed and standardized. Protocols for recording experimental data and the logging of the environmental conditions were developed. All of this was done mostly with people who had only laboratory experience. (To quote from Professor Hunt, again, this time on the difficulties that beset Langevin twenty five years earlier: "Troubles continued to intrude, however; the instability of the carbon microphone was not improved by the pressure variations arising from the vertical motion in the water, and there were recurrent electrical breakdowns in the mica transmitter, not to mention the insidious leakage of water which has an uncanny way of finding a path to the interior of seagoing equipment designed by land-based scientists" [5, p. 48]). An incredible number of trials and experiments were performed and analyzed. Submarine target strengths were measured in experiments in which transmission loss was either measured or estimated, giving, for the first time, results that could be compared with theory. At the war's end NDRC issued a Summary Technical Report on the results of all its work. The Sub-Surface Warfare Division produced twenty-two volumes. Four volumes addressed the progress in underwater sound. The one that best summarizes the work that is pertinent here is *The Physics of Sound in the Sea* [11].

Hundreds of temperature profiles were taken and used in ray tracing models of propagation. The mystery of the so-called shadow zones (regions where submarines could not be detected) was solved by plotting rays for each sound speed profile. The plots showed the zones where there was an absence of rays. The plots were then sorted into types, e.g. isothermal, increasing or decreasing sound speed, thermal layers, etc. For each of these types generic ray path diagrams were plotted and put into a "library" to help the sonar operator know the sonar condition once a temperature profile was taken [Fig. 6]. In all of the experiments there was a variation in the level of sound from "ping to ping," but averaging gave a convincing argument that the basic theory was correct. It was known that inhomogeneities in temperature could account for the variation, but no quantitative models were developed. In these comparisons of theory and experiment measured attenuation values were used because the observed attenuation values were significantly higher than those that were calculated for viscous loss. Models of reverberation due to volume and surface scattering were developed and found to account for the basic features. During the studies of volume reverberation the deep-sea scattering layer (known as the DSL) was discovered. In deep water measurements of volume reverberation with 24-kilohertz transducers directed away from the surface the data always showed, during daylight, a uniform decay in time of sound pressure level, followed by a sharp rise and then a drop. At night it was similar, but the time over which the reverberation level was high was broader and not as intense. Ray calculations showed that the depth of this anomalous scattering layer is a few hundred meters during the day and, at night, spread out over a larger region. The DSL was found to exist throughout the oceans. Further studies in the 1950s proved it to be biological. It has been a major area of oceanographic study up to the present.

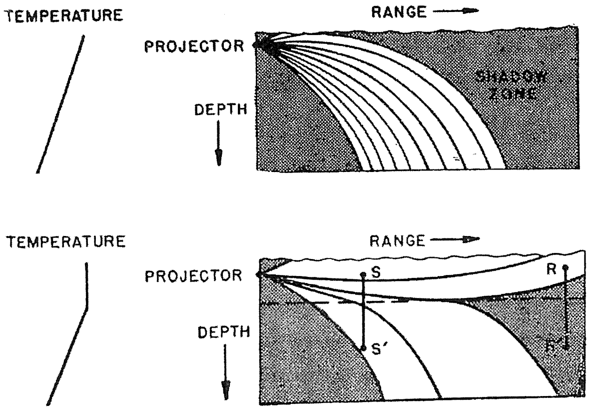

Figure 6. Two "typical simplified ray traces, the first for a negative sound speed gradient, the second for isothermal water above a thermocline. The pressure gradient causes the upward curvature of the rays above the thermocline.

The overall result of the war effort was a significant improvement in naval operations and a better basic physical understanding of underwater acoustics. The experimental equipment and the methods were used for many years afterward; there arose many unanswered scientific questions that led the way into the period after the war.

There were also three studies of low frequency longer-range propagation that had significant importance in the science of underwater acoustics. Two of these appeared in what is now considered a classic monograph by Ewing, Worzel and Pekeris [12] and the other is in an obscure NRL Report by Ide, Post, and Fry [13] that remained classified for a considerable time after the war and, unfortunately, was never published in the open literature. These were the first reported experimental and theoretical results of propagation both in shallow water and deep water.

The experiments, performed in 1943 and 1944, used explosive sources that produced signals with a broad frequency band. Shallow water signals were transmitted to ranges up to about 20 kilometers and deep-water ranges were up to 1600 kilometers with the deep-water sources being detonated at the depth of about 1300 meters, where the sound speed has its minimum value. It was observed that dispersion is present in shallow water but not in deep water. This quickly led to an explanation of the shallow water results being due to wave-guide or modal propagation. Pekeris had, previous to the experiments, developed a complete theory for modal propagation in shallow water with a uniform seafloor of different density and sound speed, based on the earlier work of Lamb and others. It was the communication of the experimental results from Ewing to Pekeris that led to the theory and analysis of Pekeris to be included in this book. The deep water results were satisfactorily explained by the careful ray tracing based on actual vertical sound speed profiles [Fig. 7]. The conclusion was that low frequency propagation along what was called the deep sound channel (DSC) had the possibility of allowing the transmission signals over ranges of tens of thousands of kilometers (that was subsequently observed). Later, the DSC was used to detect the location of downed aircraft by the triangulation of signals received at fixed sensors. For this application the DSC was called the SOFAR channel, signifying "sound fixing and ranging." The DSC was also used to determine the location of missile impacts. The experiment and analyses of Ide et al. were performed in Chesapeake Bay about a year earlier than the Worzel measurements. The conclusion is the same: a modal propagation model is sufficient to explain the shallow water measurements. In 1946 Brekhovskikh independently discovered the DSC. [9, page 119].

At the end of war the NDRC was disbanded and projects were transferred to the Navy. The research at university laboratories at Columbia, Harvard and The University of California were transferred to Navy Laboratories and the newly established federally funded Laboratories at Penn State, University of Texas, Scripps and The University of Washington [Fig. 8]. About 1000 of the 2500 scientists and engineers remained in the programs. Many returned to their prewar careers. The success of the NDRC in advancing the military's technology base demonstrated clearly the need to maintain a civilian presence in defense related research and development. In 1946 the Navy established the Office of Naval Research (ONR) for this purpose. It was given the authority to fund research on projects of general Navy interest. It was able to carry on the NDRC's programs of fundamental studies that were in support of undersea warfare. At that time

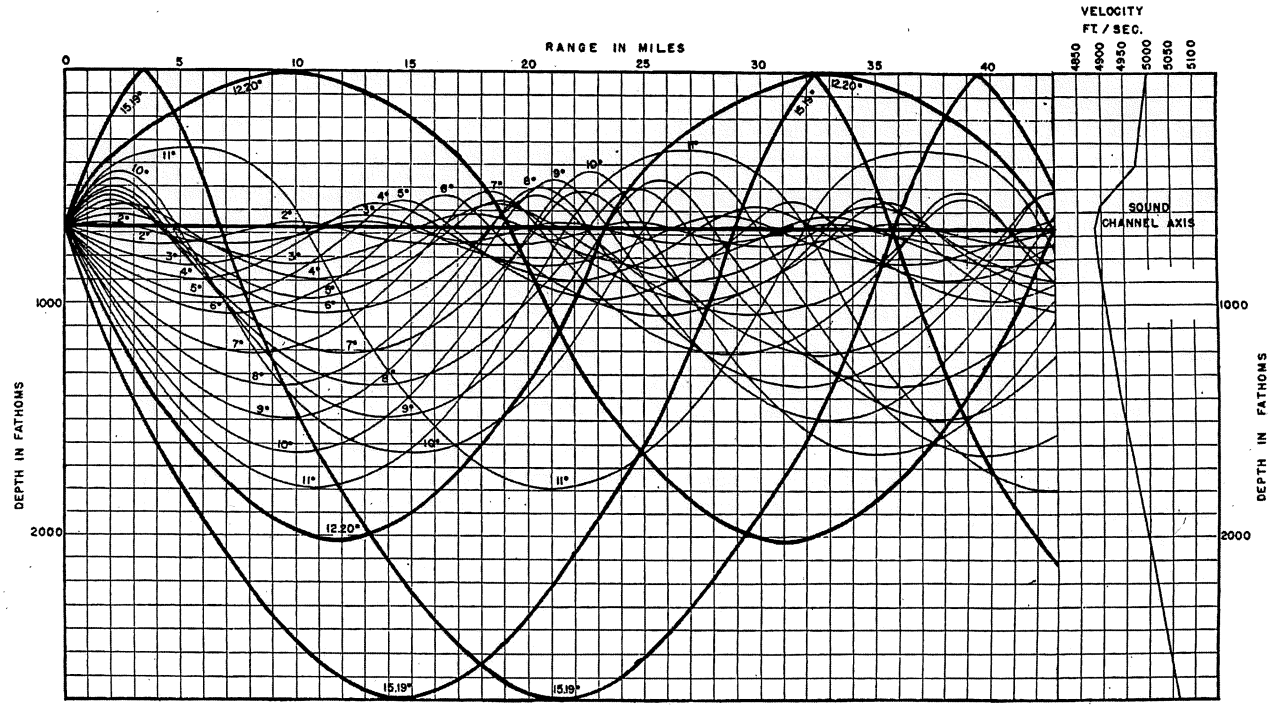

Figure 7. Ray traces in the deep sound channel, from Ref.12. Note the cycle distance of about 30 miles the were later identified as "convergent zone distances." The rays were drawn by hand, using the sound speed profile shown on the right.

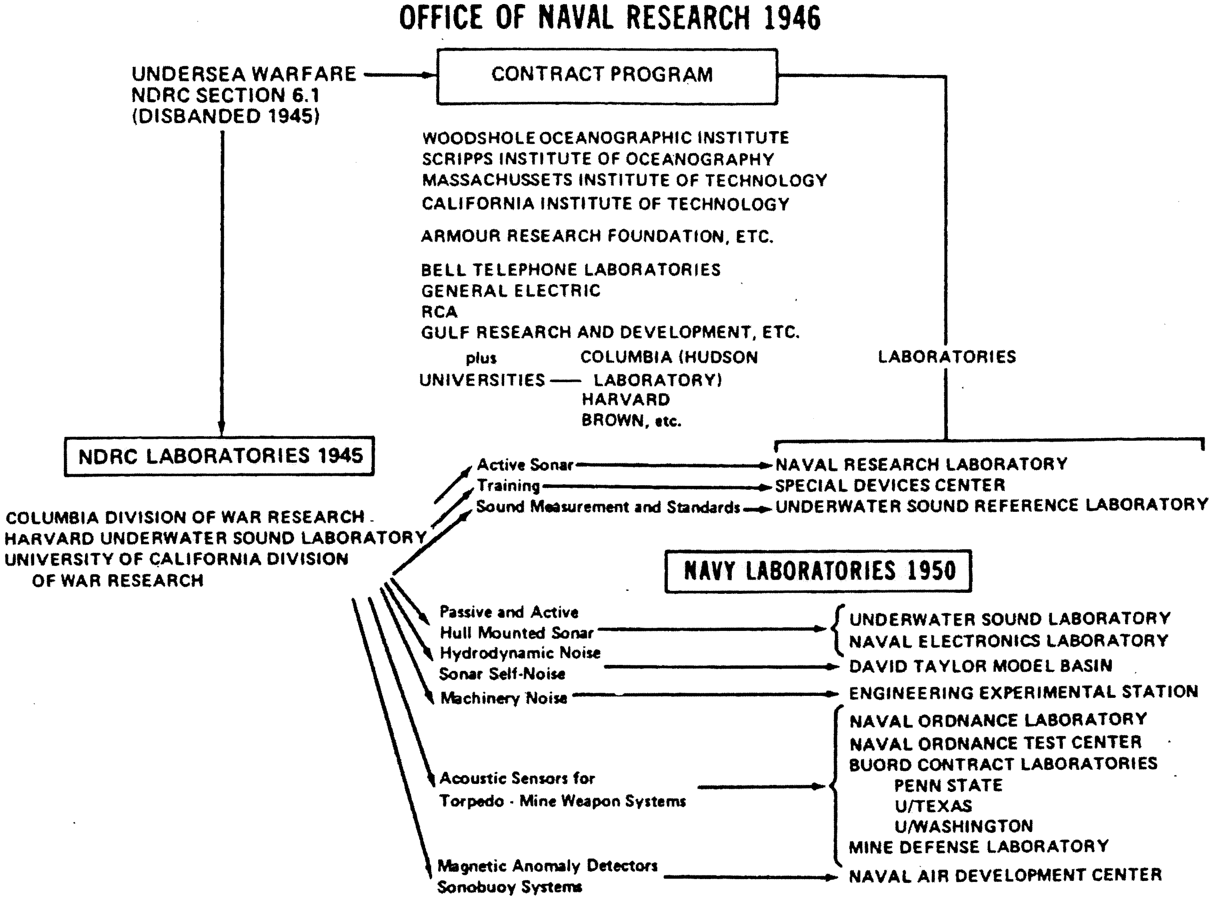

Figure 8. The reorganization of undersea warfare. The transfer from the civilian NDRC to the US Navy and the birth of the Office of Naval Research.

it assumed responsibility to carry out basic and applied undersea acoustic research for the Nation, a role that it has maintained up to the present. Research continued on propagation, reverberation, and ambient noise in support of mine detection, torpedo development and submarine detection. Support was extended to programs at many universities. In the following years much of the previously classified research was published in open journals. A perusal of JASA from 1946 on shows an enormous increase in the rate of publication in underwater acoustics. In the 1950s textbooks specializing in underwater acoustics began to appear. Courses at universities were established and advanced degree programs with specialties in underwater acoustics were developed.

With the exception of the brief Falklands War in 1982, there have been no naval wars in the past half-century. With the haste of war in the past, nations began programs to acquire more effective systems based on what had been learned and on new research and development. These studies evolved into two areas: high frequency (above about three kilohertz) and low frequency (below about one kilohertz). The first was important for mine detection, torpedoes, and ship-borne antisubmarine sonars. The latter was the basis for long-range submarine detection. Ships and submarines were built from the keel up with sonars in their design. Floating listening devices, known as sonobuoys, and long towed arrays became important components of antisubmarine warfare (ASW).

Absorption in Seawater

One of the remaining unexplained observations was the anomalously high absorption. The first measurements of absorption were made in the early 1930s at NRL [14], and extensive measurements were made during the war years in the NDRC projects [11]. The classical theory of absorption due to viscosity was an order of magnitude too low. The anomaly was at first conjectured to be due to sodium chloride, but laboratory tests proved no significant effect. In the laboratory of Professor R.W. Leonard at The University of California, Los Angeles, O.B. Wilson and Leonard measured the decay rate of a resonating glass sphere filled with aqueous solutions [15]. Although the apparatus is not amenable to highly accurate results it was definitely demonstrated that the relaxation frequency of magnesium sulfate is the cause for the high frequency anomaly (even though it is in low concentration in the sea) and also showed that at lower frequencies the ionic relaxation of NaCl was not the cause of attenuation. M. Schulkin and W. Marsh examined thousands of transmission experiments and developed an empirical, frequency dependent, absorption coefficient that was published in 1962 [16]. It was determined that the relaxation frequency of MgSO4 is about 100 kilohertz and varies with temperature, pressure and pH. As the emphasis grew in the Navy to develop very long-range detection the advantage of low frequency was clear—absorption decreases with frequency. In a series of long-range propagation experiments, W.H.Thorpe and coworkers, Mellon, Jones and Browning at the Navy Underwater Sound Laboratory, found that, in the frequency range below 5 kilohertz, attenuation did not follow the extrapolated high frequency curve [17]. At one kilohertz absorption was measured to be about an order of magnitude higher than the value calculated from the empirical equation. Absorption at the lower frequencies is small, about one dB per kilometer at 1500 Hz. It is a very small fraction of loss compared to that due to geometric spreading, which would be typically somewhere between 40 and 60 dB in the first kilometer. It was concluded that the propagation measurements in the Atlantic and Pacific Oceans and the Mediterranean Sea showed an anomalous low frequency loss. Many different physical explanations were proposed. Experiments at sea to sort out and test the theories would have been exceedingly difficult due to the inherent errors caused by the range variability of sound speed, and the persistent temporal variability of the received signal. Once again it was laboratory experimentation that provided the most plausible explanation. At Case Western Reserve University, Professor Ernest Yeager and Fred Fisher, from the Marine Physical Laboratory, using a temperature jump method, discovered that boric acid, at the very small concentration that is found in the sea, exhibits a relaxation frequency near a kilohertz, close to that inferred from at sea measurements [18]. A sample of solution the same as seawater, but without boric acid, did not exhibit a relaxation. At Scripps Institution of Oceanography Fred Fisher and Vernon Simmons made resonance measurements of seawater in a two hundred liter glass sphere over a wide range of frequencies and temperature, confirming the earlier results and improving the accuracy of the empirical absorption equation [19].

High Frequency

High frequency underwater acoustics research mainly has been in support of sonars for mine hunting and torpedo guidance. The objective for mine hunting is to detect and classify (identify) objects in costal environments. The engineering trade offs are range, target resolution for detection and classification, and absorption. Classification of a mine requires that it be sufficiently spatially resolved so that its shape and features can be identified and other objects on the seafloor can be rejected as targets. This requires that the acoustic wavelength be smaller than a mine and its features. Since the size of these objects are about a meter or so, and have features on them that are on the order of a few centimeters applicable frequencies must be from a few kilohertz to hundreds of kilohertz. (The wavelengths of a three kilohertz and hundred kilohertz signals are, respectively 0.5 meters and 1.5 centimeters.) One limitation will be absorption, since it increases significantly as the frequency increases. Range is also determined by the environmental conditions; mainly the sound speed profile and reverberation from the volume, the surface, and the seafloor.

Quantitative measurements of high frequency propagation and reverberation were begun in the war years and have continued since then. One of the causes for the persistent variability of high frequency signals was known to be the spatial and temporal variability of inhomogeneities in the sea, but there were no measurements of smaller scale horizontal thermal variability. Bathythermographs only gave a vertical "snap shot" of the temperature profile. In 1951 Liebermann [20] reported on horizontal temperature fluctuations that were measured continuously on a thermister mounted on a submarine moving at a depth of 30 to 60 meters. Temperature varied randomly, with a maximum amplitude of about 0.1° C. The mean size of the inhomogeneities was approximately 60 cm. Propagation theory had shown, previous to Liebermann's paper, that fluctuations of signals increased with range. Sheehy had reported for measurements at a depth of 50 meters a square root range dependent increase in the coefficient of variation [21]. Using Liebermann's results it was shown that homogeneities of this type did not account for the observed backscattering strengths but could account for the some of the variability in propagation. Several treatises on scattering in random media were written and the subject was covered in several textbooks on underwater acoustics. The principals of scattering were well known. The difficulty is that the environmental parameters were rarely measured to the accuracy necessary for quantitative comparison, In 1957 D. C. Whitmarsh, E. Skudrzyk, and R. J. Urick reported on forward scattering fluctuations and their correlation with measured microstructure [22]. There was reasonable agreement with a propagation model using a turbulent spectrum for the structure of inhomogeneities. R. F. Shvachko, in 1964 also showed agreement between measured variability and that computed from temperature measurement [23]. These two experiments appear to have been the first high frequency transmission experiments to include detailed oceanographic measurements.

Seafloor reverberation is a limiting factor in the search for objects on or in the seafloor. Beginning in1941 systematic measurements were made of seafloor scattering, at 24 kilohertz, from various types of seafloors, (mud, sand, rock, coral, etc.). Seafloor types were placed in categories based on grain size. C. M. McKinney and C. D. Anderson reported on a series of backscattering measurements taken between 1956 to 1960 at 16 locations around the coast of the United States [24]. Over a range of frequencies from 12.5 to 290 kilohertz backscattering strengths were determined as a function of grazing angle. Although each type of sediment seemed to differ in average strength there was wide variation within a type. The results made it clear: there would be no simple "one number" characterization of sea floor reverberation. Ed Hamilton and co-workers at the Naval Electronics Laboratory pioneered in the study of seafloor acoustic properties both *in situ* and in the laboratory [25]. His research still stands out as one of the most accurate and cited works in the field of seafloor acoustics. Since that time high-frequency seafloor acoustics has remained an important field of research. The complexity and variability of the seafloor did not (and still does not) yield to a canonical model. In order to eliminate the uncertainty that is brought about by working from ships with their inherent movement, platforms were mounted on the seafloor. Even under these conditions backscatter showed both scintillations, generally caused by the variability of the small changes of sound speed in the water borne path of the signal [26], and gradual change due to the ever-changing nature of the coastal seafloor, including biological activity. At high frequencies both propagation into and scattering from the seafloor are dependent on roughness, inhomogeneities, debris in the sediment and on the acoustical properties of the sediment. High frequency sound is very rapidly attenuated in the seafloor, so only the first tens if centimeters are important. M. A. Biot introduced a theory of propagation in porous media in 1956 [27]. He used a fluid saturated porous solid as the model. The coupled wave equations for the propagation were derived. The theory predicted a slow wave in addition to two compressional waves. The slow wave has been observed in an ideal laboratory synthesized porous medium. Since then, other theories, also based on models of the structure of sediments, have been introduced. Experimental *in situ* limitations have hindered their evaluation. In recent years there has been a revitalization of high frequency seafloor backscattering research somewhat driven by the application of synthetic aperture sonar for the detection of objects on or below the seafloor.

High frequency scattering from the sea surface has been a subject of research from the early days. The earliest measurements were of backscattering strength. It was, of course realized that scattering would be statistical in nature due to the dynamic nature of the sea surface. Measurements were made with a series of pulses at each angle of incidence and then averaged. Little was known about the theory. In 1953 Carl Eckart published what appears to be the first theory of scattering from a random time varying surface [28]. His objective was to determine from scattering measurements the statistical roughness of the sea surface.

Scattering is clearly associated with the spectral state of the sea surface. A model that approximates the sea surface as having two spectral components, one for long waves and the other for small waves riding on the long waves, (called the composite roughness model) was developed simultaneously in the United States for microwave scattering in wave tanks [29] and in the Soviet Union for acoustic scattering in wave tanks [30]. Several scattering theories are based on this model. With few exceptions, the comparison of theory with measurement has been limited by the measurement of sea surface spectra. A further complicating factor is the presence of bubbles near the sea surface that can dominate scattering at the sea surface and whose sizes and densities are difficult to measure.

The dynamic rough sea temporally spreads a signal in time and broadens the frequency due to Doppler spreading. For a random sea surface there is a random distribution of frequency spreading. When pure ocean swell is present the classical line shifts calculated for a moving periodic surface were observed. For high frequencies, the wavelength is generally smaller than the dimensions of surface roughness, making theoretical models difficult to formulate without the caveats of approximation.

Low Frequency

The shift of emphasis to lower frequencies began in the late 1950s. National programs were initiated to seek methods of detecting submarines at long range. In the United States Navy laboratories, industries, and university underwater research centers participated. Coordinated programs were planned by teams of senior personnel both military and civilian, not unlike that with the NDRC and the Navy during World War II.

The earlier work of Worzel, Ewing, and Pekeris and of Ide, Post, and Fry provided a foundation for what followed. The observation of Worzel et al., that no dispersion was observed in the deep water experiments, coupled with the fact that the frequency content of their explosive signals produce a packet of wavelengths all very small compared to the dimensions of deep water implied that geometric ray theory was sufficient to represent the acoustic field. The results of simple ray tracing diagrams for a sound source at the sound channel axis, described earlier in this chapter, coupled with the computed travel time of the rays that arrive at a receiver located on the channel axis, agreed with the experiment. Contrary to intuition, the first arrivals are those from the rays that traveled the farthest from the axis. The last arrival was the one traveling along the axis. The result is a signal that begins weakly and crescendos to a peak and ends abruptly. [Fig. 9]. The widest excursions are seen to reach the surface at intervals of about 50 kilometers. This remarkable acoustic wave-guide, with only losses due to cylindrical spreading and very low absorption, was of great interest once the need for long-range detection arose. Interest was turned to off axis sources and receivers. Ray paths for sources near the surface showed a convergence of rays at intervals approximately 50 kilometers apart for both the Atlantic and Pacific Oceans, (known as convergent zones), and regions where no rays were present (the same as the "shadow zones" for the high frequency case). Convergent zones were observed out to several hundred kilometers. Because of their military interest, these results were not published until 1961, even though there was clear evidence of their existence in the book by Worzel et al. [12] and in the prediction, much earlier, by Lichte [7]. The results of ray theory and experiment demonstrated that the basic principles were understood. However, over long ranges the ocean does not remain uniform. In long-range experiments there was little chance that there was enough environmental information to allow an accurate comparison of theory and measurement. Since ray theory has inherent limitations; it doesn't treat the shadow zone regions and it runs into trouble at foci (caustics). To treat the problem more accurately, wave theoretical solutions were sought. Normal mode computations were compared to experimental results. The trends in features were in agreement, but large differences between experiment and calculations occurred as well.

Beginning in the late 1950s there was a program in the U.S., called Project Artemis, with the objective of determining what technologies would be required to detect targets actively at ranges on the order of 1000 kilometers in deep water. Even with the good transmission in the sound channel the combination of all the factors affecting detection led to the need for a massive sound source and a large aperture low frequency array. The engineering was exceedingly difficult, leading to a source of massive proportions (50 ft. by 35 ft. and a weight of 150 tons) that was deployed from a center-well 500 meters below a 17,000 ton converted tanker. A large array of hydrophones was placed on Plantagenet Bank off Bermuda with the cable terminating at an offshore rig nearby.

A new underwater acoustic concern that arose with arrays was the need to know the temporal and spatial coherence of low frequency long-range signals. It was found that the required amount and speed of data processing pushed the limits of the computers of the time. Analogous to the high frequency propagation through inhomogeneities the question arose: "What oceanographic processes will limit correlation?" Because of its high level of military importance the project remained classified for many years. It was terminated in 1970 but it raised the issue of coherence over long distances.

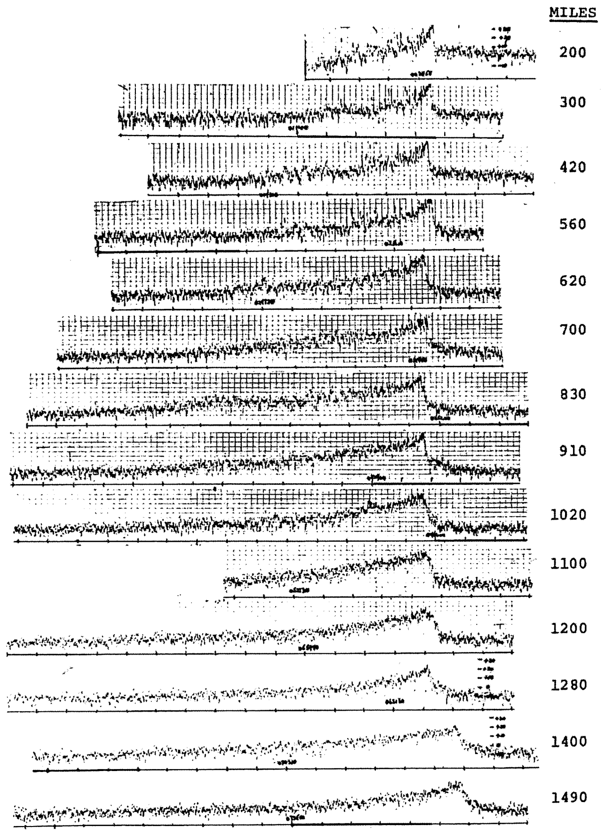

Figure 9. Records of deep-sea explosive signals for a set of ranges. Both source and receiver were at a depth of 4000 ft. First arrivals are from sound that has taken the largest excursion from the channel axis. The last arrival is from the sound traveling along the axis. [60]

To eliminate the motion of ships the ideal measurement configuration for temporal correlation was from fixed sources and receivers. In 1974 George Sanford reported on measurements of amplitude and phase variability of pulsed and continuous signals at 367 hertz, transmitted 1300 kilometers, between Bahamas and Bermuda, using a deep source at 527 meters and two receivers at a depth of 1700 meters, all mounted on the seafloor [31]. The measurements were taken over a period of six months. Temperature profiles were taken at intervals along the transmission path and used to compute ray paths. They showed that there was no interaction with the sea floor, and surface reflection was present only during winter conditions. Correlation times were found to be about six minutes for amplitude and on the order of forty minutes for phase. The power spectra were close to that expected from internal wave interaction and supported the hypothesis based on earlier work by Nichols and Young [32]. No oceanographic measurements were made to confirm the connection. Sanford's measurements, and others, also taken at the same site, and also from other locations around the world demonstrated the value of fixed site experiments. It was abundantly clear that more needed to be known about oceanographic processes. Ships, no longer needed in these experiments as source and receiver platforms, could now serve as environmental data gatherers.

In 1958, Marvin Lasky, at the Office of Naval Research, initiated a program to determine how an array of hydrophones could be towed from a moving ship without the interference from the ship noise and the flow around an array. It was motivated by advances in cable design, in tow hydrodynamics, and the development of low-noise transistors The remarkable success and progress of this program and of follow-on projects produced for the Navy excellent arrays that made detection at ranges hitherto impossible. The question arose: What are the ultimate limits of detection? Since the military objective is to deploy ships and submarines essentially anywhere in the world, there was a need to know something about transmission and coherence, both temporally and spatially, throughout the world.

Coincidently several nations had long-range low-frequency programs which led to both the exchange of results and several joint programs. Clearly it was not feasible to have sufficiently detailed oceanographic measurements to allow for exact comparisons between theory and measurement, but analyses were sufficient to understand the effects of some of the oceanographic processes on acoustic signals. The major ocean currents and the topography of the seafloor were known. Currents meander and occasionally spin off eddies tens to hundreds of kilometers across and with depths of hundreds of meters. Oceanographers did not know their abundance until the 1970s, yet they account for an enormous amount of the dynamic energy of the sea. The meandering of the currents and the presence of large numbers of eddies made accurate computation impossible, but estimates of their effect on propagation could be estimated.

Range dependent solutions did not exist, except in the ray limit, until Allan Pierce introduced, in 1965, a method of connecting modal solutions that assumes each mode conserves energy [33]. A few years later Fred Tappert [34], while working on radar problems at Bell Laboratories, noted that the parabolic approximation that was applied to electromagnetics, introduced by Leontovich and Fok [35], would apply to sound propagation in the sea as well. Under normal oceanographic conditions thermal gradients in the horizontal are orders of magnitude smaller than those in the vertical, and the fractional change in sound speed is small over an acoustic wavelength. That is the condition that allows the parabolic equation to approximate the wave equation. Tappert developed an algorithm using what is called the split step approximation, to obtain numerical solutions, The method was amenable to rapid numerical solutions. It met with considerable success and became so standard that it has been a common piece of numerical digital hardware, used throughout the world. The accuracy of computation depends on the accuracy of the input of sound speed depth and acoustic properties of the sediment. However, it has great value in the solution of generic problems and is highly instructive for determining the effects that are caused by changes in the environmental parameters. The literature is abundant with numerical modeling techniques. [See Ref. 36]

Low frequency scattering theories have the advantage of ignoring scattering from small-scale features (except for resonant scattering from fish bladders or bubbles). Unlike high frequency scattering from the seafloor, scattering is not confined to the surface and to only a few centimeters below it. Low frequency sound penetrates deeper. To have a complete picture requires knowledge of the seafloor substructure and its acoustical properties. The first reported deep water reverberation measurements with explosives and omniderectional continuous wave pulses recorded the temporal decay of the echo, the first being that of the normal incident reflection from directly below the source and receiver, then followed by backscatter progressing outward from an annulus of increasing radius and at decreasing grazing angles. Mackenzie found that his data from sources at 530 and 1030 Hz fit approximately, Lambert's law (from optics) with a coefficient determined from the data [37].

This empirical equation, now referred to as "Lambert's rule," is still used by some to fit reverberation strength data. Little was known about the acoustic parameters or the roughness of the sea bottom. Although there were other models proposed and tested they were empirical and generally confined the parameters of specific geographic locations. In the past thirty years the use of the directionality of towed arrays has provided a method of measuring backscattering over large areas. A large program in the US, during the late 1950s and 60s, called the Marine Geophysical Survey, in support of Navy needs, made an extensive set of broad-band reverberation measurements, resulting in defining areal zones of acoustic properties. Little was gained about the physics of scattering from these surveys.

The air-sea boundary condition, due to the enormous difference in density and compressibility, can be accurately approximated for most cases as a boundary on which the acoustic pressure level vanishes. Thus at any point on the surface the pressure of an arriving signal must be equal and opposite of the scattered or reflected pressure. For low frequency, to a good approximation, the small features of the sea surface roughness can be ignored. Exact solutions for the general problem of a random dynamic ocean surface were intractable, so both mathematical approximations and suitable representations of a random sea surface were made. One approximation is known as the Kirchhoff method. When it is applied to low frequency it is known as the method of small perturbations [9, Chapter 9]. The literature both in journals and in treatises abound.

For backscattering at lower wind speeds the theories adequately agreed with experiments for both backscattering strength and Doppler spreading due to surface motion [9, Chapter 1]. However the back scattering strengths reported by Chapman in 1962 and 1964 [38] are an order of magnitude greater than predicted at higher wind speeds. Other measurements confirmed the "anomalous scattering" result. It was observed later that some high wind speed reverberation measurements did not show a Doppler spread. It was then conjectured that at high wind speeds breaking waves create bubbles below the surface that cause scattering from bubble clouds. Several papers reported on bubble cloud scattering models that gave backscattering strengths of the right magnitude [39, 40]. Using acoustic techniques bubble cloud size and densities have been measured below breaking waves [41, 42, 43]. To date, however, there has been no definitive experiment that included both bubble measurement and low frequency backscattering. Chapman deduced a useful empirical formula for making reverberation estimates but it provides little insight into the physics of scattering.

Shallow Water

In the 1950s the papers of Tolstoy and Clay appeared. Experiments in the shallow water off Long Island were conducted using single frequency transmission. Following the approach of Pekeris [12], normal mode theory was applied to a three-layered model with measured acoustic parameters. They achieved remarkable agreement due both to a very carefully controlled experiment and to the use of accurate acoustic parameters. Tolstoy demonstrated that small deviations from the correct parameters led to significant differences in the calculated field, sufficient to lead to serious errors. With the exception of these papers, a review of the literature indicates a general low level of interest in low frequency shallow water research from the end of World War II to about 1960. Beginning in the1960s there was a renewed interest that has continued to the present.

Urick reported that, up to 1979, there had been four thousand measurements of transmission at low frequency (below 1500 hertz) [44]. A comparison of the dependence of transmission loss on range of these experiments showed enormous differences, even under similar oceanographic conditions. Since most of these tests had inadequate environmental data little insight was gained on the physics of propagation. Based on the results of Pekeris and Tolstoy it was clear that the differences were environmental conditions (depth, sediment type and layering, sound speed profile, etc.), and little could be derived from an experiment without good environmental parameters. Shallow water regions vary in both the structure of the seafloor and oceanographic conditions. Several approximate mathematical models for propagation were developed [9, Chapters 6 and 7]. At short ranges (on the order of the depth) ray methods were found to give satisfactory agreement with measurements. At longer ranges normal mode theory and parabolic equation methods have normally been used. Experiments designed to measure single modes gave good insight on the energy distribution and the effect due to the superposition of modes [45]. By judiciously choosing the depth of the source and the placement of hydrophones on a vertical array, the study of individual modes was possible. Under the conditions that the seafloor was reasonably flat, modes offer a robust and understandable method to interpret propagation. However, as Tolstoy and Clay demonstrated, a faithful representation of the total field requires an accurate set of acoustic parameters of the sediment The parabolic equation methods offered a means of computing acoustic fields in a range dependent environment and has given insight on the effects of sloping seafloors.[36]

Just as in deep water the desire to increase detection drove the use of multi-element sources and receivers (arrays) and signal processing techniques utilizing both spatial and temporal coherence. Spatial coherence was found to be limited by modal interference and by perturbations due to roughness of the boundaries [46]. Temporal variability was clearly due to the dynamic processes at the sea surface and in the water column. In the U. K. David Weston and colleagues had the opportunity to make observations over a number of years at a shallow water site off the Bristol Channel. Their results were reported in a very thorough, lengthy paper [47] that summarizes temporal events from the period of years to seconds. Peter Wille and colleagues at the German Laboratory in Kiel reported, in a series of papers [48] the results of many measurements from an offshore platform in the North Sea. This very fine platform was furnished with environmental measurement equipment that provided the opportunity to correlate acoustic results with ocean and atmospheric processes.

The effect of internal waves on propagation in shallow water has received no less attention than it has in deep water. In addition to the classic internal wave structure, there appears in several areas of the world where at the shelf break another class of internal waves, called solitons, is generated. Research on propagation in the Yellow Sea by Zhou and his group from The Chinese Academy of Sciences, during a several year span, observed that sometimes, under summer conditions, when there existed a warm water layer, very large temporal changes occur in transmission loss, but only over selected frequency bands. In a 1991 paper [49] Zhou and colleagues proposed that the change is due to the presence of soliton wave packets passing between the source and receiver. They presented analytical simulations that match the magnitudes that were observed. Since that time additional analyses have corroborated their results, both for the Yellow Sea and other locations as well. Due to the range variability for these events, parabolic computations show modal conversions at selected frequencies that can account for the loss due to changes in bottom interactions at certain frequencies.

In 1976, Homer Bucker, at the U. S. Naval Undersea Center, proposed a method of locating radiating sound sources in shallow water, now known as "matched field processing" [50] The method matched calculated sound fields for a set of sensor locations, using a normal mode representation, for sound sources located on a grid of positions and matching those with measured values. The method had success and showed promise. It was based on the confidence that enough was known about the environment to make the computation credible and on the fact that computer power was sufficient. This paper led to refinements in the method and is still an area of active research that now includes tracking as well.

Ambient Noise

Ambient noise can be described as that remnant of sound that is present after identifiable sound sources and the inherent self-noise of a measuring system have been removed. It is due to dynamic processes of the sea, to biologic sources, such as marine mammals and snapping shrimp, and, of course, to anthropogenic causes such as ships, geophysical prospecting, and construction. Ambient noise that is received by a hydrophone is the sum of all three and their contributions vary in both time and location.

The study of ambient noise began during World War II. Before that not much attention was given to it since most of the naval interest was on high frequency sonars that were either reverberation or self- noise limited. Had there been an interest it would also have been hampered by the lack of calibrated systems. One significant need for absolute sound levels was the acoustic mine. Thresholds needed to be set so that ambient noise did not trigger them. Under the direction of Vern Knudsen, the director of the San Diego Division of the NDRC, a series of ambient noise measurements were made in coastal waters and harbors from 100 to 50,000 Hz. Knudsen and colleagues published the results in 1948 [51]. In summarizing, the results were presented as a set of curves of noise levels (known as the "Knudsen curves") as a function of frequency for a set of wind speeds from less than one knot to about thirty knots [Fig. 10]. The decreasing slope of the spectrum for each wind speed was constant at about 5 decibels per octave. Even though the results were known to be those in coastal regions the Knudsen curves have been in practical use ever since. A review of the literature reveals that interest in ambient noise waned until the 1960s when it quickly became the second most published field of underwater acoustics, second only to propagation. In the 1950s there were two important contributions to the theory of sound in the sea, one at each end of the spectrum of interest. The first was a paper by Michael Longuet-Higgins [52] on the origin of microseisms due to the nonlinear interaction of ocean waves. It is the result of a second order expansion of the hydrodynamic equations for two waves moving in opposite directions. Although this chapter will be limited to reporting on higher frequencies, this classical paper is worthy of note. The second was a paper by Robert Mellen [53]. The Knudsen curves showed a continuing decrease in ambient noise for all wind speeds. Thus it would be expected that at some frequency the inherent thermal excitation noise would be equal to the Knudsen noise levels, and beyond that it would become the limiting noise floor. Mellen, using the laws of statistical mechanics, calculated the thermal noise floor. He showed that the thermal noise level in decibels increases as the log of frequency and becomes the dominant noise level at 50 kilohertz at very low wind speeds and at about 200 kilohertz at 30 knots.

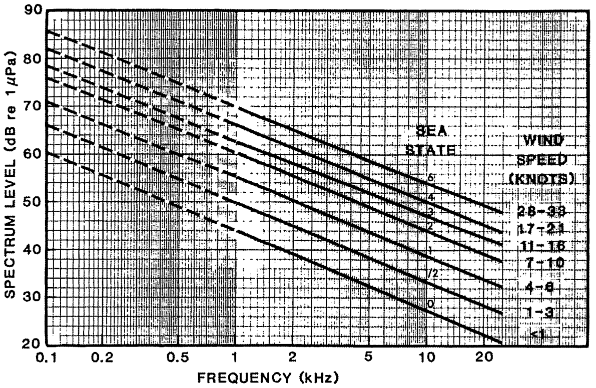

Figure 10. The "Knudsen Curves", compiled from data taken during World War II [51].

The revival of interest in ambient noise beginning in the 1960s was mostly motivated by interest in passive systems at lower frequencies. The very large growth in publication rate led several compilations and reviews of publications. Of particular importance were the papers of Gordon Wenz [54] summarizing the status as of 1961. In these papers Wenz reviews the results of many measurements [Fig. 11], identifying probable causes for noise over the spectrum from 1 to 100 Hz. Methods of measuring, processing, and reporting ambient noise were not standardized at that time, and Wenz's paper provided a standard of reporting that allowed for new measurements to be added to the ever growing data base. The Wenz curves are for average conditions. During the decades of the 1960s and 70s ambient noise studies of the temporal and regional variability and statistics of noise was a major theme. Since shipping noise dominates many of the areas of interest it was important to understand the statistical effects caused by the propagation of noise traveling through the sound channel by many paths and from multiple sources. (In the world of ambient noise the decibel reigns as the unit of choice.) Measurements, of course, are in units of pressure or intensity. Ira Dyer, in two papers, [55] derived the statistical consequences of sound arriving from distant ships, each radiating sets of multipath narrow-band signals. Using distributions based on a model that all arrivals were random, Dyer calculated intensity distributions. By transforming these into a logarithmic scale, standard deviations in decibels were determined. He also demonstrated the inherent skewness in logarithmic distributions. These were the first papers to introduce an analytic basis for the statistics of shipping noise.

The motivation of most low frequency ambient noise studies was for the development and operation of array systems. Their use in specific regions, such as the Mediterranean or North West Pacific where shipping traffic, wind, and propagation conditions were considerably different for both wind noise and ship traffic, led to measurements throughout many parts of the world. Predictions of noise, as functions of azimuth and depth, were needed.

The directionality of shipping noise was, at least in principle, reasonably well understood once normal shipping traffic patterns were known and propagation was sufficiently understood. Ships traveling along coastal routes often showed an increase in sound level. This was named the "megaphone effect." It is due to sound that reflects off the sloping coastal seafloor and propagates in a direction closer to horizontal. Basin wide measurements were made with towed arrays. In addition, fixed sites around the world were utilized. Again, the research stations with long-term fixed systems were invaluable for long-term observations, notably the US station in the Bermuda-Eleuthera area and the UK facility near the Bristol Channel.

The study of vertical directionality of ambient noise required vertical arrays. It was not until the mid-1970s that this technology was available. It was found that at the depth of the sound channel axis at the lower frequencies (near 100 hertz) directionality patterns showed in many cases a broad peak in the horizontal, with a width that is approximately the maximum and minimum angles that cover the propagation of rays in the sound channel. At higher frequencies the pattern is symmetric, with peaks at the angles of the maximum and minimum rays of the sound channel [Fig. 12]. Ronald Wagstaff was the first to publish an explanation of these features [56]. Since ships essentially radiate as dipoles or doublets sound is directed downward over a wide range of angles. Wagstaff postulated that, for ships located on continental slopes, much of the radiated sound is reflected off the slope, each reflection causing the sound to be directed closer to horizontal until it is at or near the angles that keep the sound in the channel. At low enough frequencies the loss of energy per bounce is small so the channel becomes filled with sound. At higher frequencies the loss per bounce is higher so the sound that has made sufficient bounces to propagate along the channel axis is weaker that those that reached the outer limits of the channel with fewer bounces giving rise to the observed two peaks with a minimum on the channel axis.

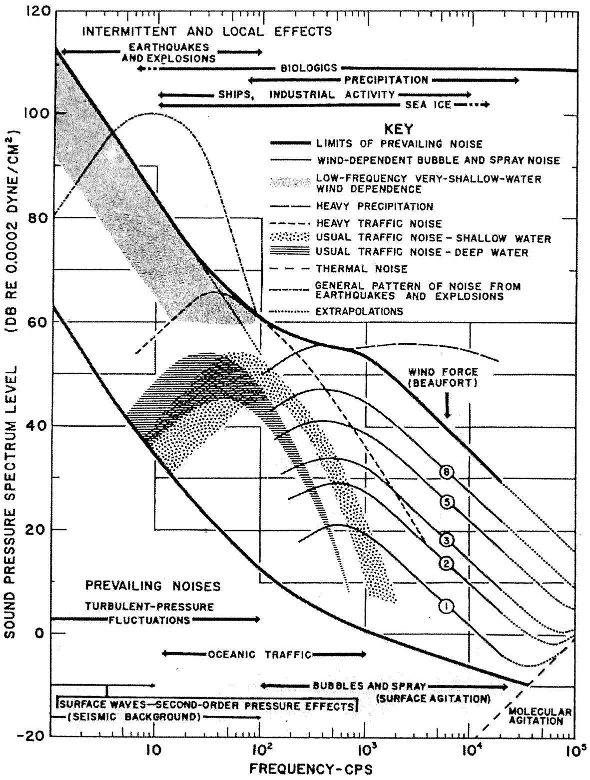

Figure 11. The "Wenz Curves" taken directly from the paper of Wenz [54].

Although the Knudsen and Wenz curves showed the level of sound generated by the surface due to winds the study of the physics of noise was not addressed until much later. For frequencies from about 10 to 500 Hertz shipping dominates most noise measurements in the Northern Hemisphere. A. Wittenborn [57] made measurements in the North Pacific with two hydrophones, one in the sound channel and the other below it. Simple ray tracing showed that the phone below the sound channel only receives noise from a region above it, and the other also receives noise from distant sources, in this case distant shipping. A comparison of the noise levels showed about a twenty-decibel difference over the low frequency band for all wind speeds, but at higher frequencies and at high wind speeds, where surface noise dominates the noise levels converged. He did observe two regimes for wind generated noise, one for low wind speeds and one for wind speed above about 6 m/s, approximately where one would expect the onset of breaking waves. Subsequently, measurements in the Southern Hemisphere [58] and in the North Pacific [59], using vertically directed arrays, also showed two distinct wind speed dependencies. R. Hollet [60] measured, with a vertical array directed upward, the frequency content of the noise of individual breaking waves. Each showed individual signatures rich in frequencies, some as low as 50 hertz. A plausible explanation by William Carey and others is that the number of resonant bubbles produced by breaking waves is sufficient to account for the high frequency sound levels. Carey has proposed that the low frequency radiation is due to the collective oscillation of bubble clouds [61].

SOSUS

The history of underwater acoustics in the United States has another side that does not appear in the literature, and about which a few things can be said. It is the history of the development of a surveillance system known as SOSUS. In 1950, on the recommendation of the National Research Council's Committee on Undersea Warfare, the US Navy initiated a program of research and development aimed at exploiting what was known about long-range propagation in the sound channel for the detection of low frequency signals. The initial objective, since it was before the introduction of nuclear submarines, was the long-range detection of diesel submarines. The program, principally at the Bell Laboratories, with participation from both universities and national laboratories, initiated research and development in all phases of underwater research within the scope of the mission. The ultimate objective was the detection of submarines by arrays mounted on continental slopes with cables terminating at shore bases. The location of each array was a match of strategic importance and environmental conditions. Each deployment was preceded by detailed measurements of propagation and noise. The first of these arrays served both as detection centers and as laboratories for research. The system was designed to send relatively broadband signals in order to obtain a more complete picture of the physics and also of sufficient quality to allow the application of narrow band processing. These fixed systems gave researchers a continuous year's long pictures to work with. The entire program was under the cloak of secrecy until recently when there was a partial release of information. The remarkable accomplishments in underwater acoustics and ocean engineering over the forty years of this program will undoubtedly come to the public someday.

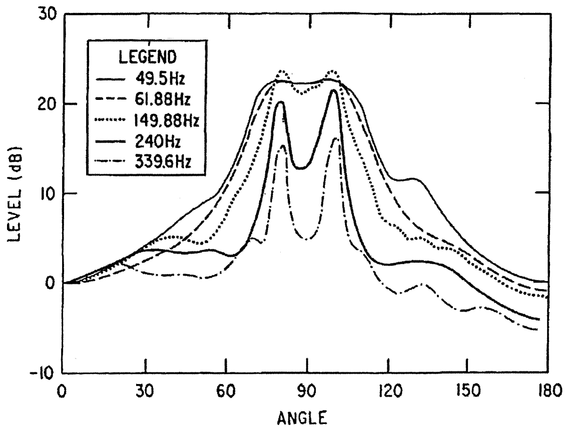

Figure 12. Vertical noise profiles on the sound channel axis, compiled by William Carey [58] from data taken by C. G. Anderson [unpublished].

Summing Up

What is told above is but a sketch of the history of underwater acoustics. Hopefully it conveys the thread of continuity that existed. To go from what was known at the turn of the Twentieth Century to where we are today required the efforts and support of many. The sea is not a compliant laboratory and results presented here were for the most part not easily obtained. Without the external motivations of two world wars and the cold war the field would never have had the manpower and resources to progress as it did. At-sea research is one of the most expensive of the sciences due to the costs of ships, manpower to run them, equipment, scientists, engineers, and technicians to work at sea. Detection of things in the sea is, generally, still a difficult task so there is still research to be done, but, at this time, the pressure of need doesn't seem to be so strong. Perhaps it is time to let the "calm scientific inquiry run its own well-ordered course," to borrow from Hunt's quotation. The brief history that is written here is only a smattering of events of the last century, and the author apologizes for all of the omissions that certainly would be part of some (hopefully) future volume on the subject. The fields covered here, of propagation, scattering, and noise have greatly depended on other fields such as transduction, sonar systems, marine engineering, and signal processing. These are worthy of a study in themselves.

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Underwater Acoustics Timeline

1490 ••••	Leonardo da Vinci observes long-range underwater sound travel by hearing the sound of distant ships.
1826 ••••	First measurement of the speed of sound underwater in Lac Lemon, Switzerland (Colladon and Sturm).
1910-20	Developments in piezoelectric underwater transmitters.
1916 ••••	First use of active underwater sound for anti-submarine warfare by British Navy.
1917-18	U.S. and British navies utilize passive sonar to detect submarines.
1919 ••••	Importance of ocean's vertical sound speed structure discovered (Lichte).
1921 ••••	British Admiralty Research Laboratory established.
1923 ••••	Acoustics Division of U.S. Naval Research Laboratory established.
1937 ••••	Sonar performance correlated with ocean temperature profile by the Woods Hole Oceanographic Institution, launching field of environmental acoustics.
1938 ••••	Emergence of sonar calibration techniques.
1940-50	Establishment and growth of Navy research infrastructure in underwater sound including four major Navy laboratories that were involved in underwater acoustics.
1945 ••••	*Physics of Sound in the Sea* first published.
1946 ••••	Office of Naval Research established.
	Establishment of the University Affiliated Research Centers (ARL-PSU, APL-JHU, APL-UW, ARL-UT, MPL-Scripps).
1948 ••••	Ambient underwater noise correlated with wind speed by Knudsen, refined later by Wenz.
	Discovery of deep-water SOFAR channel in U.S. by Ewing and Worzel, and in Russia by Brekhovskikh.

Underwater Acoustics Timeline

1950's ••	Understanding of sound scattering by turbulence.
	Cavitation threshold for sonars understood (Strasberg and others).
	Developments in towed array technology.
1951 ••••	Discovery and understanding of thermal microstructure effects on sound propagation by Liebermann.
1952 ••••	Theory of high-frequency thermal noise by Mellen.
1953 ••••	Eckart applies Kirchhoff approximation to sea surface scattering.
1954 ••••	The SOund SUrveillance System (SOSUS) is activated to provide deep-water, long-range submarine detection capability.
1955 ••••	Sonar Acoustic Data (SAD) report by Urick and Pryce assimilates and analyzes WWII and post-WWII acoustic data.
1957 ••••	DIMUS: Digital multibeam system for sonars (Anderson).
1956 ••••	Biot derives comprehensive theory of poroelasticity.
1960 ••••	Global acoustics begins with SOFAR propagation from Australia to Bermuda.
	Spectrum of underwater explosive sources understood (Weston, Arans, and others).
1962 ••••	Anomalous scattering from the sea surface due to bubbles identified in field measurements (Chapman, Harris).
1963 ••••	Invention of parametric sonar (Westervelt).
1965 ••••	Adiabatic mode theory introduced (Pierce).
1966 ••••	Composite roughness theory introduced to theory of rough surface scattering.
1970 ••••	In situ acoustic measurements of bubble populations (Medwin).
	Statistical consequence of distant shipping noise understood (Dyer).

Underwater Acoustics Timeline

***1971* ••••**	Effects of fish schools on sound propagation (Weston, Revie, and others).
***1973* ••••**	Tappert introduces the parabolic equation method to ocean acoustics.
	First at-sea measurement of individual Normal Modes (Ferris, Ingenito).
***1976* ••••**	Bucker introduces matched-field processing.
1976-79	Development of theory scintillations from internal waves (Dyson, Munk, Zetler, Ewart, Flatté, and others).
***1980's* ••**	Reduction and consolidation of Navy research infrastructure.
***1985* ••••**	Emergence of the small slope approximation in rough surface scattering (Voronovich).
***1990s* ••**	Bubble-related mechanisms for generation of ocean ambient noise and acoustic scattering are understood.
***1991* ••••**	Importance of solitons in shallow water propagation.
	Emergence of phase conjugation in underwater acoustics.
	Heard Island feasibility test of Acoustic Thermometry of Ocean Climate (ATOC).
***1992* ••••**	Techniques for nonlinear inversion for ocean bottom properties developed.
	Whale tracking with SOSUS array.
1991-93	Critical Sea Test (CST) experimental program resolves sea surface scattering anomaly associated with near-surface bubbles.
***1994* ••••**	Range-dependent Acoustic Model (RAM) parabolic equation adopted as naval standard.
	Experimental demonstration of basin scale acoustic thermometry in the North Pacific Ocean.
***1996* ••••**	First U.S.-China joint experiment in underwater acoustics (Yellow Sea).
***1997* ••••**	Wave number integration used to model propagation in fluid, elastic, and poroelastic media.
	North Pacific Acoustic Laboratory (NPAL) evolves from ATOC.

Underwater Acoustics Timeline

1998 •••• Experimental demonstration of phase conjugation in the ocean.

Arctic Climate Observations Using Underwater Sound (ACOUS).

1999 •••• Emergence of high-frequency sediment acoustics to support acoustic detection of buried mines.

Ocean Acoustics becomes a National Naval Responsibility (NNR) within ONR.

2000 •••• Effects of Sound on the Marine Environment (ESME) initiated, a multi-disciplined program involving mammal biologists, oceanographers, and acousticians.

Emergence of synthetic aperture sonar (SAS) target detection and imaging with AUVs

Past and Present Chairs of the Technical Committee on Underwater Acoustics

1960-61	Chester M. McKinney
1961-63	Robert A. Frosch
1963-66	Warren A. Tyrrell
1966-69	Raymond W. Hasse
1969-72	James E. Barger
1972-75	Burton G. Hurdle
1975-77	Herman Medwin
1977-80	Robert C. Spindel
1980-82	Harry A. DeFerrari
1982-85	William A. Kuperman
1985-88	Arthur B. Baggeroer
1988-91	David L. Bradley
1991-94	Henrik Schmidt
1994-97	Kenneth E. Gilbert
1997-00	George V. Frisk
2000-03	John S. Perkins
2003-	Peter H. Dahl

Recipients of the Pioneers Medal in Underwater Acoustics

1959 - Harvey C. Hayes - For outstanding contributions to the science of underwater acoustics. His farsighted recognition of the challenging technical problems in this branch of acoustics and the potentiality of the application of their solution to the defense needs of the Nation resulted in the first sustained research program in underwater sound. (Abstracted)

1961 - Albert B. Wood - For pioneering leadership in underwater sound; the development of the cathode-ray oscillograph and its adaptation to the study of underwater explosions; his invention of the magneto-strictive depth recorder; and his studies of shallow-water sound transmission. (Abstracted)

1963 - J. Warren Horton - For his pioneering contributions to the knowledge and practice of underwater acoustics as scientist, and teacher, and administrator; and particularly for his painstaking and thorough organization of the science of underwater acoustics and its presentation in the book "Fundamentals of Sonar."

1965 - Frederick V. Hunt - For his pioneering contributions to underwater acoustics as a scientist, innovator, teacher, and administrator; and particularly for his unceasing efforts directed toward greater scientific understanding and more effective exploitation of sound in the sea.

1970 - Harold L. Saxton - For his contributions to both knowledge and practice of underwater acoustics, and particularly for innovative solutions to problems of signal processing and sonar systems and transducers.

1973 - Carl Eckart - For his consummate skill, insight, and clarity in bringing to others the theoretical foundations for understanding the principles of underwater sound and acoustic signal processing, and for his leadership, wise counsel, and kindness in helping others to pursue the unsolved problems of the sea.

1980 - Claude W. Horton, Sr. - For his contributions in underwater acoustics in the field of propagation, reflection, and scattering, signal processing, particularly methods in acoustic data treatment and interpretation, and especially for his contribution as a teacher and friend of scientists.

1982 - Arthur O. Williams, Jr. - For his contribution to the theory of normal mode propagation of sound in the ocean, to the theory of sound radiation from piston sources, and to the education of graduates and undergraduates.

1985 - Fred N. Spiess - For his leadership and insight in applying acoustics to study the ocean and the sea floor, for his many ingenious scientific and engineering contributions; for his introduction of students, scientists, and many others to underwater acoustics.

1988 - Robert J. Urick - For his book "Principles of Underwater Sound" and his many experiments on sound propagation, scattering, reverberation, and ambient noise.

1990 - Ivan Tolstoy - For innovative studies in oceanic, atmospheric and seismic wave propagation.

1993 - Homer P. Bucker - For ground-breaking work integrating signal processing and acoustic modeling.

1995 - William A. Kuperman - For the development and application of models for ocean acoustic propagation and scattering.

2000 - Darrell R. Jackson - For work on acoustic time reversal techniques and scattering from the ocean sea floor and sea surface.

2002 – Frederick D. Tappert (posthumously)- For application of the parabolic equation to underwater acoustic propagation.

Recipients of Interdisciplinary Silver Medals

Silver Medal in Underwater Acoustics and Engineering Acoustics

1992 - Victor C. Anderson - For pioneering underwater sound research in ambient noise and for the invention and engineering development of the delay time compression (DELTIC) correlator and digital multibeam steering (DIMUS) sonar.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Acoustical Oceanography and Underwater Acoustics

1998 - David E. Weston - For seminal work on the physics of explosive sources, scattering, and the horizontal refraction of sound.

Helmholtz-Rayleigh Interdisciplinary Silver Medal in Underwater Acoustics, Acoustical Oceanography and Signal Processing in Acoustics

2001 - Arthur B. Baggeroer - For applications of model-based signal processing to underwater acoustics and for contributions to Arctic acoustics.


ASA at 75

Chapter 17

Acoustics Education and the ASA

Thomas D. Rossing & Uwe J. Hansen

Acoustics Education and the ASA

Thomas D. Rossing, Northern Illinois University &
Uwe J. Hansen, Indiana State University

Acoustics education is as old as the science of sound (acoustics). From the time of the Greeks onward, acousticians have devoted considerable time and effort to teaching others about the science that they love. For example, Pythagoras, the Greek philosopher, taught his students in the 6th century that dividing a string into lengths having simple ratios led to harmonious sounds.

Many fine books present the history of acoustics, and thus the history of acoustics education. Especially noteworthy are Lindsay's *Acoustics* (1973), Hunt's *Origins in Acoustics* (1978), Miller's *Anecdotal History of the Science of Sound* (1935) and Beyer's *Sounds of Our Times* (1999). These four authors were also great teachers of acoustics. In fact, most great practitioners of acoustics have also been great teachers of acoustics.

In this brief historical sketch we will concentrate mainly on acoustics education since the Acoustical Society of America was founded 75 years ago. However, we begin with a brief discussion of the subject up to 1929.

Acoustics Education Up to 1929

It was recognized early that sound travels much slower than light, and that the speed of sound can be measured by rather simple means. Newton apparently measured the speed of sound by rhythmically clapping his hands in a portico in Trinity College at Cambridge, and timing the echoes. (photo 1) The speed he observed, however, did not agree with the speed he calculated (using the isothermal rather than the adiabatic compressibility of air), and so he resorted to what Hunt (1978) calls "a monstrous exhibition of teleological data manipulation," not a good example of acoustics education. Measurement of the speed of sound is still a standard exercise for beginning students of physics.

By 1800, Beyer (1999) points out, it was well established that sound coming from a small source travelled in all directions (spherical waves), but sound could be constrained to travel in tubes in one direction only (plane waves). Reflection and diffraction of sound were also reasonably well understood. Pedagogically, the propagation of sound provided a template for understanding the propagation of light and other electromagnetic waves.

The human voice has long been recognized as an important source of sound. During the 18th century Ernst Chladni (1756-1827) and Thomas Young (1773-1829), among others, explained to their students how the human vocal system works. Young explained that vowel sounds were formed by the glottis and modified by the mouth. Crude talking machines were built by Christian Kratzenstein (1723-1795) and Wolgang von Kempelen (1734-1804). Models of the von Kempelen machine are today used in several science museums to teach how the human voice works. (photo 2).

The modern era of acoustics (and acoustics education) could be said to have begun with John Tyndall (1820-1893), Hermann von Helmholtz (1821-1894) and Lord Rayleigh (1842-1919). Their monumental books *On Sound* (Tyndall, 1867), *On Sensations of Tone* (von Helmholtz, 1862), and *Theory of Sound* (Rayleigh, 1877) still provide valuable resource material for teaching and learning about acoustics. It is significant that the Acoustical Society awards the Helmholtz-Rayleigh Silver Medal to acousticians who have distinguished themselves in more than one area of acoustics.

Tyndall was appointed Professor of National Philosophy at the Royal Institution in London, where his predecessor, Michael Faraday, and others had already established a rich tradition of lecture demonstrations. Tyndall had outstanding talent for developing demonstration experiments to accompany his lectures. His book *On Sound* (1867), is largely derived from these lectures, and includes drawings of his demonstration apparatus, several of which are reprinted in Beyer (1998). Tyndall borrowed a number of ideas from Helmholtz, and in fact Helmholtz had Tyndall's book translated into German.

Helmholtz was trained as a physician, and since he attended medical school on a military scholarship, he served as an army surgeon, but he was given space to set up his own laboratory in physics and physiology. Although primarily remembered for his seminal writing about the ear and hearing, Helmholtz also developed acoustical apparatus that is still used in acoustics education today. Several universities have sets of Helmholtz resonators of

Photo 1. Open corridor at Trinity College, Cambridge where Newton measured the speed of sound.

the type he used for spectral analysis of complex sounds.

The bible of acoustics education was, and still is, Rayleigh's *Theory of Sound*. Rayleigh's interest in acoustics began when, in order to learn German, he read the original German edition of Helmholtz's *On Sensations of Tone*. Although he is mainly remembered for his superb mathematical treatments of acoustics, Rayleigh also carried out important acoustics experiments, and he frequently published notes about simple equipment for acoustics demonstration experiments that are still used in acoustics education.

Several other scientists in the nineteenth century developed acoustical apparatus that is still used in acoustics demonstration experiments today, although we will not try to mention all of them, by any means. At the University of Leiden, Pieter Rijke (1812-1899) placed wire gauze in the lower part of a glass tube in order to generate sound when the gauze is heated. Rijke tubes (sometimes called "hoot" tubes) are widely used in classroom lecture demonstrations today. Karl Rudolph Koenig (1832-1901) was a master of acoustical apparatus, both for research and demonstration experiments. His acoustical apparatus has been described by Miller (1935), by Greenslade (1992) and by Beyer (1999). (photos 3, 4).

In his historical introduction to the reprint edition of Rayleigh's *Theory of Sound*, Lindsay (1945) commented on "a rather stagnant state of acoustics during the first two decades of the twentieth century...academically, acoustics became, by and large, an uninteresting subject." Others might disagree, but there were, in fact, no Rayleighs or Helmholtzes on the scene. The days in which an individual might write papers on speech, hearing, music, vibrations, and sound propagation in solids and fluids were probably passing, and the specialized areas of acoustics were emerging. One such area was electroacoustics, made possible by the invention of the vacuum tube. Another was architectural acoustics, which developed out of the work of Wallace Clement Sabine (1868-1919) at Harvard University. Sabine, a physics professor, was asked to propose changes in the lecture room in the Fogg Art Museum. From his papers, thousands of acoustics students have learned the basics of room acoustics.

Photo 2. David Howard, University of York, with a model of von Kempelen's talking machine.

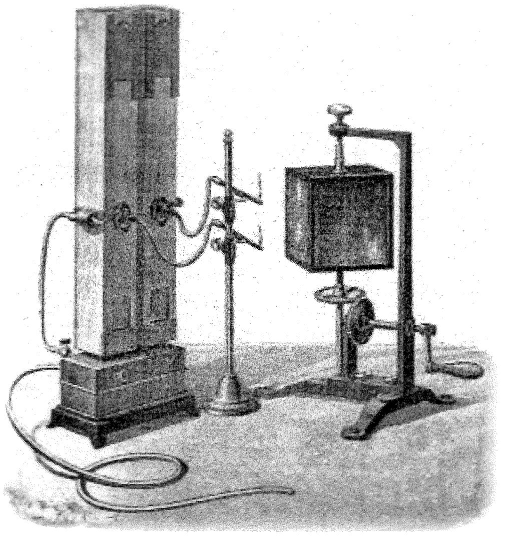

Photo 3. Koenig's manometric flame apparatus. The image of the oscillating flame is seen in the rotating mirror (Beyer 1999).

The Acoustical Society of America

In 1929, the study of sound was still considered to be an important part of the study of physics. Still, Harvey Fletcher (1884-1981) observed that giving papers at meetings of the American Physical Society had become less stimulating because there were so few people there who were interested in what he was doing. Other physicists, such as Floyd Watson (1872-1974) and Vern Knudsen (1893-1974) agreed, and Wallace Waterfall (1890-1974) was urged to convene a group of physicists and engineers working on acoustical problems, which he did at the Bell Telephone Laboratories in New York in1929. The Acous-

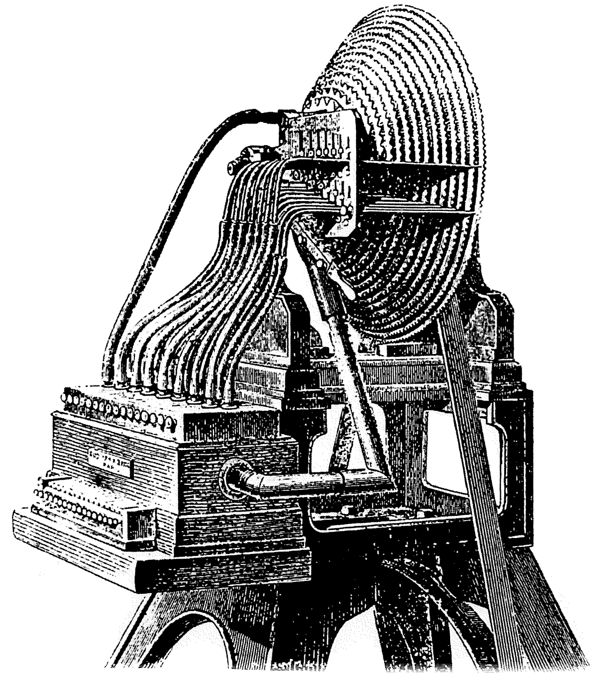

Photo 4. Wave siren (Greenslade, 1992).

tical Society began with Fletcher as president, Knudsen as vice-president, Waterfall as secretary, and Watson with editorial responsibility. (Note that the average lifespan of these 4 ASA officials was 91 years!) From its beginning, the ASA had strong ties with education. The site of the early semiannual meetings alternated between academic institutions and industrial laboratories (Beyer, 1999). (Some of us would still like to see more meetings held at universities in order to encourage participation by students).

Conference on Education in Acoustics, 1964

In 1963, the American Institute of Physics obtained a grant from the National Science Foundation to enable the Acoustical Society to hold a conference to "evaluate the role and significance of the subject matter of acoustics in higher education and to chart the future of education in acoustics." To arrange the conference, ASA president Cyril Harris appointed a steering committee consisting of R. Bruce Lindsay of Brown University (chair), Frederick V. Hunt of Harvard University, and Wayne Rudmose of Tracor Incorporated. John Johnson of Penn State University and Robert Shankland of Case Institute of Technology also joined the committee.

Thirty-six participants from universities, industry, and government were invited to attend this conference, which was held at AIP headquarters in New York, March 12-13, 1964. The principal points addressed were the manpower problem in acoustics and the teaching of acoustics. The proceedings, prepared by Professor Lindsay, include the now-familiar "Lindsay wheel," showing how "the basic theory of mechanical radiation in all material media radiates out into the many fields of applied acoustics."

On the manpower problem in acoustics, Benjamin Bauer addressed the issue from the standpoint of industry, while William Cramer concentrated on manpower problems in various agencies of the U. S. Department of Defense, especially the Navy. Martin Greenspan continued the discussion from the standpoint of government agencies outside the Department of Defense, while Alan Powell addressed the problem from the standpoint of colleges and universities. The speakers seemed to agree that there was a shortage of people adequately trained in acoustics, particularly in electroacoustics, physio- and psycho-acoustics, shock and vibration, and underwater sound. Doctorates in acoustics peaked in 1958, when they reached 3.2% of doctorates in physics.

On the teaching of acoustics, Robert Beyer, who introduced the subject from the standpoint of physics departments, observed that in general physicists tend to look upon acoustics as a tool, a kind of means to an end and not an end in itself, as atomic, nuclear, and solid-state physics are regarded. Cyril Harris commented on some of the problems of acoustics education in engineering departments, including the lack of curricula in acoustical engineering and the lack of room for technical electives in engineering curricula.

It is interesting to note how much the problems of acoustics education discussed in 1964 relate to the problems we face today, and this report deserves to be read by acousticians and educators today.

Committee on Education in Acoustics

The Committee on Education in Acoustics was established in 1964, largely as a result of the Conference on Education and the "need for the Society's conducting a long-range study of the problem." ASA president Cyril Harris appointed a committee of 12 members: Alan Powell (chairman), R. Bruce Lindsay, W. Dewey Neff, John Johnson, C. Paul Boner, Capt. Frank Andrews, Benjamin Bauer, Thomas Northwood, and Douglas Muster.

The Committee on Education in Acoustics has continued as one of the liveliest administrative committees of the Society for nearly 40 years. In addition to studying and discussing the problems of acoustics education, it sponsors sessions on acoustics education at nearly every ASA meeting, reaches out to high school students and teachers, conducts workshops for teachers, helps in administering science fairs and competitions, and recognizes excellence in acoustics education.

Sessions on Acoustics Education

The Committee on Education in Acoustics arranges special sessions on acoustics education at nearly every meeting of the Society. Often these sessions are co-sponsored by one of the technical committees (co-sponsorship by musical acoustics and architectural acoustics appear to have been the most common). These sessions have focussed on a wide range of activities in acoustics education. We mention examples of a few of these.

Laboratory experiments in acoustics. Science is best taught (and learned) by hands-on experience. "I hear, I forget. I see, I remember. I do, I understand." Laboratory instruction has always been an important part of physics teaching, and the teaching of acoustics is certainly no exception. The Committee on Education in Acoustics has arranged several successful sessions at ASA meetings on laboratory experiments in acoustics. For example, a session in Nashville in 1985, chaired by Murray Korman, featured personal computers for laboratory instruction, while a session in Miami in 1987, chaired by Allan Pierce, focussed on project laboratories.

A session in Denver (1993), chaired by Uwe Hansen and Thomas Rossing, and a session in Columbus (1999) dealt with undergraduate laboratory expeiments in acoustics, while a session in Ft. Lauderdale (2001), chaired by Dan Raichel, looked at low-cost laboratory experiments.

Demonstration experiments in acoustics. Demonstration experiments rank next to hands-on laboratory experience as effective ways to learn acoustics and vibrational physics. From the time of Pythagoras, demonstration experiments have been used to demonstrate acoustical phenomena. Faraday and Helmholtz and Rayleigh and Tyndall were famous demonstrators. In more recent times, Captain E. R. Pinkston from the U.S. Naval Academy and his young colleague Larry Crum conducted a full hour of acoustics demonstrations at an ASA meeting at Pennsylvania State University in 1973.

No one will ever forget the demonstration experiments performed by Isadore Rudnick, many of them involving sophisticated apparatus he had designed and even including liquid helium. Fortunately, some of Izzy's demonstration experiments have been recorded on film and videotape.

Sessions on demonstration experiments in acoustics often draw standing-room-only crowds. Old standbys at sessions on demonstration experiments have included Bob Apfel, Anthony Atchley, Larry Crum, Bruce Denardo, Carr Everbach, Uwe Hansen, Robert Keolian, Murray Korman, Tom Rossing, and others. (photos 5, 6)

At the 141st meeting in Chicago (2001), Tom Rossing and Uwe Hansen presented a tutorial lecture on Demonstration Experiments in Acoustics, at which a group of Chicago-area physics teachers joined ASA regulars in doing acoustics demonstration experiments in rapid succession. (photo 7)


Photo 5. Bruce Denardo demonstrates resonances in stepped air column.


Photo 6. Demonstration of acoustic levitation.

Photo 7. Chicago-area physics teachers who participated in demonstration experiments at the ASA meeting in Chicago.

Take-Fives. At these sessions, which have become very popular, participants present short demonstration experiments, videos, or innovative ideas for teaching acoustics. The term "take-fives," borrowed from physics teacher meetings, refers to the 5-minute time limit imposed on the speakers in order to maintain the pace of the session. The popularity of take-five sessions results partly from their spontaneity, and most attendees agree that they return home with new teaching ideas as well as enthusiasm to try them out. The first take-five session was held at the Penn State meeting in 1997, and since then 7 such sessions have been held, including the one at Berlin which included participation by several European colleagues, and the one at Cancun with Latin American contributions. Currently they are scheduled at every second ASA meeting.

ASA Reaches Out to High School Students

Outreach to high school students has become an important activity of the Acoustical Society of America. Special sessions for high school students are now frequently scheduled at ASA meetings. Sometimes they are sessions at which acoustics demonstration experiments of particular interest to high school students are presented (although these sessions are well attended by ASA members as well!). Sometimes they involve hands-on experiments that high school students can perform with advice from ASA members acting as docents.

Since ASA meetings are often held in large cities, it has been particularly effective to invite students from inner city high schools with large numbers of minority students. Special effort has been made to have female and minority members of ASA as docents. Sometimes a pizza lunch is provided by ASA. At some future date, we hope to hear a testimonial from an acoustician whose first contact with acoustics came by visiting such a session at an ASA meeting. [photos 8]

Several years ago, Larry Crum and Tom Rossing led an ASA team which prepared a proposal to the National Science Foundation to develop teaching materials. While that proposal was unsuccessful, the Committee on Education in Acoustics has continued its search for outside funding for outreach activities.

Workshops for Teachers

The Technical Committee on Musical Acoustics (TCMA) has sponsored a series of workshops for high school teachers and for elementary school teachers. Support has come from the Department of Education by way of "Eisenhower" grants as well as from ASA in the form of technical initiatives. These very successful workshops have been organized by Uwe Hansen and other members of TCMA. (photo 9).

Other Activities of the Committee on Education in Acoustics

The Committee arranges to have acoustics professionals serve as judges at regional and national science and engineering fairs. Assistance for regional chapters to conduct poster session competitions is also provided.

Prize for Acoustics Education

Various initiatives through the years to establish a medal or award for acoustics education have been unsuccessful. However in 2002 Thomas Rossing donated money to the ASA Foundation to establish a prize for acoustics education to be awarded annually. The purpose of this award is to recognize an individual each year who has distinguished himself/herself in furthering acoustics education through distinguished teaching, creation of educational materials, textbook writing, and other activities. Each recipient will present a special lecture at an ASA meeting.

Photo 8. Hands-on session.

Photo 9. Science teachers assemble a monochord.

Other Societies Concerned With Acoustics Education

Other professional societies and science teachers societies are also concerned with acoustics education. We will give only a few examples.

American Association of Physics Teachers (AAPT)

AAPT was established in 1930 with the fundamental goal of ensuring the "dissemination of knowledge of physics, particularly by way of teaching." It is one of the member societies (along with ASA) of the American Institute of Physics. Although the study of sound is not as prominent in most physics curricula as it once was, the two AAPT journals (*American Journal of Physics and The Physics Teacher*) carry a disproportionately large number of articles and papers on acoustics partly, no doubt, because it is a popular subject with students.

AAPT meetings regularly feature special sessions on teaching acoustics, and especially demonstration experiments. One particularly successful AAPT program has been the Physics Teaching Resource Agents (PTRA) program, in which experienced teachers help to train new teachers. Two popular PTRA workshop topics have been "Waves and Sound" and "Physics of Music."

AAPT commissions resource letters on various topics intended to guide college physics teachers to some of the most important literature on these topics. These resource letters are published in *American Journal of Physics*, and often a reprint book, based on these letters, is published by AAPT as well. One of the authors (TDR) has published three such resource letters on acoustics topics: MA1: Musical Acoustics (1975), ENC1: Environmental Noise Control (May 1978), and MA2: Musical Acoustics (1987). Each of these was also followed by a reprint book, also published by AAPT.

Audio Engineering Society (AES)

The Audio Engineering Society was founded in 1948 and now has over 12,000 members. Many audio professionals are members of both societies. Of the 100 or more AES sections worldwide, over 35 are student sections which are located on campuses offering studies in audio and sponsored by faculty members who are professional members of the AES. The AES Education Committee guides these students and oversees the Student Delegate Assembly with its elected international student officers. The AES directory, which was first compiled by the Education Committee in 1979 and now is online (http://www.aes.org/education/directory.cfm), lists over 200 schools offering studies in audio, ranging from short courses to graduate degrees.

European Acoustics Association (EAA)

The European Acoustics Association brings together 23 national acoustical societies. Founded in 1992, it publishes *Acta Acustica/Acustica* and it arranges symposia and tutorials, most notably the tri-annual Forum Acusticum. Although it does not have a committee on acoustics education, it includes papers on educational subjects at its symposia and in its journals.

German Acoustical Society (DEGA)

The German Acoustical Society includes a technical committee for the teaching of acoustics (Fachausschuss Lehre der Akustik—FALehre) in its technical committee structure. This committee holds regular sessions at the annual DAGA meeting. At the joint ASA, DEGA, and EAA meeting in Berlin a "take-5" session was co-sponsored by DEGA and ASA. The FALehre has produced a directory of German acoustics education programs with 70 entries. The committee has also produced a web site "Multimedial Education in Acoustics" for the EAA (http://zope.eaa-fenestra.org/MME/index.html) with links to 11 mostly interactive sites.

The Institute of Acoustics (IOA)

The United Kingdom Institute of Acoustics was formed in 1974 through the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society. To meet the needs of professionals seeking to enter the field of acoustics or to update their current knowledge, the Institute has established a one-year part-time postgraduate Diploma in Acoustics and Noise Control. The Diploma is currently offered at several universities and colleges throughout the UK and is also available as a distance learning package. Students take a General Principles of Acoustics module and two of seven optional specialist modules.

Textbooks on sound

At most universities it is customary to designate a primary textbook for a course, supported by one or more "recommended" references. There has been no shortage of good textbooks and reference books in acoustics. Perhaps the most important textbook over the years has been *Vibration and Sound* (1936, 1948) by Philip Morse (1903-1985). The Acoustical Society reprinted this important book in 1981. Some of the topics in this textbook are expanded in *Theoretical Acoustics* by Morse and Ingard (1968). A textbook on acoustics by Allan Pierce (1981) has also been reprinted by ASA (1989). More appropriate for undergraduate courses in acoustics, perhaps, are books by Kinsler, et al. (1950, 1962, 1982), Hall (1980-1981), Blackstock (2000), Stumpf (1980), Raichel (2000), and Rossing and Fletcher (1995).

Acoustics by Beranek (1954), a practical textbook of acoustical concepts and theory that emphasizes electroacoustics, has been reprinted by ASA (1986). *Nonlinear Acoustics* is well presented by Beyer (1974) and Hamilton and Blackstock (1998). Books on acoustics that emphasize vibrations include Cremer, Heckl and Unger (1973) and Junger and Feit (1986).

In speech acoustics, Fant (1960) and Flanagan (1965) have been traditional standards, although books by Pickett 1999), Strong and Plitnik (1983), and David and Denes (1972), and others are popular as well.

Courses in acoustics for students not majoring in science or engineering frequently emphasize musical acoustics, since music has considerable appeal to students. Textbooks for this audience have included Backus (1977), Benade (1976), Campbell and Greated (1987), Rossing, Moore and Wheeler (2002), and Hall (1991).

ASA's Future Role In Acoustics Education

The Acoustical Society of America is the world's leading acoustical society, and therefore is looked to for leadership in acoustics education. It will continue to cooperate in this important endeavour with professional engineering societies, speech and hearing societies, and science teacher societies. An area that ASA should pursue is seeking government, foundation, and industrial support for acoustics education, and especially for development of materials for teaching acoustics in schools. To further this role, the Committee on Acoustics Education has proposed that an ASA Education Officer be appointed as a full-time or part-time position. Presumably the salary would be charged to grants administered by this official.

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Chapter 18

The Role and Future of Standards in Acoustics

Tony F.W. Embleton, Paul D. Schomer, and Susan B. Blaeser

The Role and Future of Standards in Acoustics

Tony F.W. Embleton, Past Standards Director,
Paul D. Schomer, Standards Director, &
Susan B. Blaeser, Standards Manager

The Need for Standards

In acoustics, as in any other technical discipline or indeed in everyday life, standards are essential and implicit in all branches of the subject. Whether writing papers for publication or technical reports, one must use terminology that is standardized so that a reader understands exactly the message of the author. At other times, when measuring or analyzing some property of a sound field or other phenomena, one implicitly relies on instruments to provide the same results (within a predictable experimental error), regardless of which company manufactured them. Instruments can only be relied upon to perform as expected because they have been specified, manufactured, and calibrated according to a commonly accepted set of national or international standards. Yet other standards specify the procedures to be followed in both simple as well as difficult or complicated situations in order to obtain measurements that are as reliable and repeatable as technically possible. (See photo 1.)

Standardization allows for choice because one can easily compare acoustical specifications such as sensitivity or accuracy and other properties such as power consumption, weight, or prices of competing products. One is then able to make informed trade-offs between features important to the user. Standardization is important for safety. To cite an example from acoustics, standards prescribe the tonal quality and sound levels for warning signals.

These simple comments illustrate why a company that does not follow national standards may severely limit its ability to find markets even in its own country. Already one sees examples where countries and companies with products that do not satisfy international standards, or national standards that are compatible with international standards, are finding it difficult to compete in global markets. Cases exist where companies chose to abandon the global marketplace rather than try to meet international standards, then later found the domestic market was too small for financial viability (though it was big enough as an add-on for foreign companies operating globally) and went out of business.

Standards, including acoustical standards, must exist in the modern scientific and commercial world. Many acoustical standards are currently produced in the United States through a recognized relationship, which operates according to a precisely defined and approved set of rules, between the Acoustical Society of America and the American National Standards Institute.

The American National Standards Institute (ANSI)

In the United States the principal non-government voluntary standards organization is ANSI. ANSI coordinates the activities of numerous standards-developing bodies that write and maintain standards in many fields. These bodies may be professional societies, trade associations, or other organizations. The standards that a standards-developing organization produces can be approved as American National Standards if the organization meets the operational procedures and methods required by ANSI for the development of such documents. ANSI also serves as the national body to coordinate the United States position on international standards as they are developed by both the International Organization for Standardization and the International Electrotechnical Commission, ISO and IEC respectively.

The procedures that ANSI requires standards developers to follow include the following main elements:

- representation from a broad range of diverse interests, such as manufacturers, government, consumers or users. No single interest group is allowed to dominate.
- evidence that a substantial consensus exists for the final document that is submitted to ANSI for approval, and that all comments and objections have been considered,

Photo 1. Sound level meter measurements at a flour mill (ANSI S1.4-1983). Instruments need standards so that my decibel is compatible with yours.

- demonstrate that a concerted effort has been made to resolve negative comments and objections, so that the submitted document is the best that can be achieved at the present time,
- an appeals process that is available to persons with unresolved objections.

The Acoustical Society is one such standards developer.

The Acoustical Society of America and Its Standards Secretariat

The Acoustical Society of America (ASA) provides the Standards Secretariat that supports and coordinates the activities of four ANSI-Accredited Standards Committees. The Secretariat provides liaison with ANSI and arranges for production, publication, and marketing of a standard after it is approved by both the appropriate Accredited Standards Committee and by ANSI. The standards produced are not Acoustical Society Standards but are the responsibility of the cognizant Accredited Standards Committee. The Secretariat and the four Committees all operate under guidelines that have been approved by ANSI as compatible with ANSI's own rules for standards development. The four ANSI-Accredited Standards Committees are respectively:

- S1 Acoustics – deals with instruments and procedures for analyzing sounds and monitoring noise exposure,
- S2 Mechanical Vibration and Shock – deals with instruments and procedures for measuring shock and vibration of machines, vibration isolators, and machine condition monitoring,
- S3 Bioacoustics – deals with instruments for measuring hearing, audiometers, hearing aids, speech intelligibility, and the effects of shock and vibration on people, and
- S12 Noise – deals with procedures for measuring noise in the workplace and community, and environmental criteria.

The ASA Committee on Standards (ASACOS) is one of the Society's administrative committees. Its members include one representative from each of the Society's 13 technical committees, as well as the Chairs of the four S Committees, and the Chairs of the US Technical Advisory Groups to various ISO and IEC Technical Committees. ASACOS also includes the ASA Standards Manager, the Vice Chair of ASACOS, and the ASA Standards Director. Other members are the immediate past Standards Director and some officers of ASA. The Standards Director is both Chair of ASACOS and also an officer of ASA. This interlocking administrative structure ensures that the operations of the Standards Secretariat and the four S Committees are compatible not only with ANSI requirements but also with those of the Society. The technical committee representatives provide general technical direction from the broad membership of ASA including suggestions for new standards, and report to their technical committees on the standards activities of the Society. In addition, the Vice Chair of ASACOS is an ex-officio member of the Society's Technical Council.

The Acoustical Society of America has been active in national standards since 1932 when it asked the then American Standards Association to initiate a project to standardize acoustical measurements and terminology. The Acoustical Society was appointed as the sponsor of the new committee, designated Z24. By 1942 the scope was extended to include vibration and by 1957 the work had grown to such an extent that the old Z24 committee was disbanded and replaced by three committees, namely S1 Acoustics, S2 Mechanical Vibration and Shock, and S3 Bioacoustics. These committees were still administered by the United States of America Standards Institute (USASI) now known as ANSI. In 1969 ASA took over administration of these committees. In 1981 a new committee was established: S12 Noise. Thus, the structure that exists today has evolved gradually almost since the founding of the Society, and in response to the evolution of acoustics and the needs of society, as they become apparent. ANSI and ASA have also been evolving at the same time, and all have remained in harmony. This is one of the main reasons for the strength of the current system.

Each of the four S Committees typically consists of 15 to 30 organizational members and about an equal number of individual technical experts. The organizations represented are a balanced mixture of users, general interest organizations, trade associations, manufacturers, and government departments. The individual experts are from the same interest groups, but also include consultants and members of academia. ASACOS nominates the Chair and Vice Chair of each S Committee and also the individual experts, but each S Committee must then ballot and approve its own leadership. In practice, there are about 50 individual experts that serve the four S Committees; with many serving on more than one committee, this provides for adequate technical liaison between adjacent technical areas, and also with other societies.

Draft standards are written and developed into final drafts by Working Groups (WGs) that consist of people interested, and knowledgeable, in the subject of the proposed standard. Procedurally, a WG and its members are advisors to the S Committee that will later ballot and approve the draft standard. Currently there are just over one hundred WGs responsible to the four S Committees. Collectively, the WGs and their four parent S committees are responsible for maintaining and updating about 120 standards in acoustics.

The total number of people involved in ASA's Standards Program is just over 500. Some of 270 of these are members of the Society and over 40% of these are Fellows. The four S Committees meet yearly at the spring meetings of the Society. Many WGs also arrange to meet during ASA meetings, either in the spring or fall. Other WGs find it more convenient to meet at other times and other places, as at meetings of other professional organizations. Some rarely meet but conduct the business of their WG by e-mail, FAX, or conference phone calls.

The Society's standards are sold to individuals (at a discount to Society members), in bulk (at a discount for multiple copies) and by subscription throughout the world. Formats available include paper copy and electronic format via the Society's website.

ASA's Role in International Standards – ISO and IEC

The close relationship between the four S Committees and their international counterparts in the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) is demonstrated in two ways. The S committees serve as the US Technical Advisory Groups (US TAGs) to their counterparts: reviewing, commenting on, and recommending the US vote on international documents as they are developed. ANSI is the US member body in these organizations but the S Committees provide the technical expertise.

The S Committees, serving in their capacity as the US TAGs, also appoint US expert members to serve on ISO or IEC working groups. These experts meet around the world, at their own expense, to participate in the development of international standards. This participation brings the US position into these standards at the earliest opportunity and tries to assure the continued competitiveness of US industry in the world market.

Above and beyond the participation of the S Committees in international work, ASA, acting on behalf of ANSI, provides the International Secretariat for two ISO committees:

- ISO/TC 108 Mechanical vibration and shock– This is the ISO technical committee (parent committee) charged with developing international standards on all aspects of mechanical vibration and shock, including machinery balancing, and
- ISO/TC 108/SC 5 Condition monitoring and diagnostics of machines – This is an interdisciplinary subcommittee focused on all techniques employed in machinery monitoring, diagnostics, and prognostics.

Why Is This a Successful Operation?

In a 1992 survey by the Council of Engineering and Scientific Society Executives (CESSE), the ASA was placed in the top three among 42 national organizations having a standards development program. This external peer evaluation is encouraging, but the high quality of the standards developed under the auspices of ASA and its Standards Secretariat is based upon hard-working and dedicated individuals and upon a number of significant factors such as:

- The present operational structure and relation ship between ANSI and ASA has evolved slowly over more than 70 years in response to the changing needs of society and the developments in science.
- The membership of the Society is a valuable source of expertise. Individuals may serve on standards committees, or are available for advice on a personal ad-hoc basis.
- Many individuals have been involved with standards under the umbrella of ASA for 20 years or more, a few for 40, 50, or even 60 years. These people are implicitly mentors of younger people and pass on their experience and enthusiasm.
- Through the international membership of a professional organization such as ASA, it is natural to develop an empathy with other countries' standards, especially regionally with Canada and Mexico. In the past few years, such cooperation has begun to develop with some countries in South America.
- There is undoubtedly much room for improvement. For example, the time from the formation of a WG to the production and marketing of a standard is often far too long. Steps are currently being taken to improve this process and reduce the time period, initially by modifying the S-Committee and ASA Secretariat procedures to follow some that have been found beneficial by ISO and IEC.

Room for Improvement

Despite the fact that ASA has supported standards activities for more than 70 years, the ASA Standards program remains virtually unknown to many ASA members. Although hundreds of ASA members participate in standards work every year, in some ways the ASA Standards program remains the Society's best kept secret.

The ASA investment in standards work is one of the Society's largest outreach efforts. This work furthers the basic mission of ASA: to increase and diffuse the knowledge of acoustics and promote its practical application. In recent years, ASA Standards has attempted to focus some of its outreach effort within the Society itself. Special sessions at ASA meetings have been organized to introduce the Standards Program and its roles in and outside of ASA. Articles have appeared in JASA and other publications to describe the program.

More recently, ASACOS has appeared as a co-sponsor of many technical sessions. Co-sponsorship reinforces the close technical link between the ASA Standards program and the Technical Committees. The strong ASA support for the development of the classroom acoustics standard shows that experts from many different technical areas can work together through standards to benefit the general public.

Every technical committee is encouraged to consider technical areas where standardization could be of benefit. As technologies mature, even technical areas which have had little historical interest in standards may see a benefit in standardizing such things as terminology, methods of measurement, and specification of equipment.

History and Looking Into the Future

The future of standards activities in acoustics is best considered in the scientific and social context in which it exists, and as a continuum from the past.

The Acoustical Society's interest began in 1932, only three years after the founding of the Society, and from then until the 1960s acoustical standards were mainly driven by the needs of acoustics. Until about 1972 many acoustical standards were the responsibility of the Society. These were approved by the Executive Council on the recommendation of the Standards Advisor to the Executive Council, Laurence Batchelder. The use of sound pressure rather than the then often-used sound intensity as a measure of sound level was standardized. Two of the earliest standards were "Specification for laboratory standard pressure microphones," Z24.3-1949 and "Method for the coupler calibration of earphones," Z24.9-1949, both developed while Leo L. Beranek was Chair of Standards Committee Z24. Standards for measuring instruments followed, and with a broadening and coherent base of knowledge, much progress was made. A milestone was the publication in 1954 of the standard Z24-X-2 that documented for the first time the consensus that quantified that exposure to loud sounds could produce hearing loss.

In 1969 responsibility for most national standards in acoustics coalesced in the Society, and in 1971 it also assumed the responsibility for developing the US position on international standards in acoustics being developed by TC108 of the International Organization for Standardization (ISO). At about the same time, ANSI became the body to approve all national standards. The Executive Council no longer approved the acoustical standards. By 1978 the Executive Council chose a new structure to develop standards under the auspices of the Society. The Society appointed a Standards Director as an officer of the Society, with Henning von Gierke as the first incumbent and a Standards Secretariat with Avril Brenig as the first Standards Manager.

With these broader responsibilities toward acoustical standards, the Society considered the development and maintenance of national acoustical standards to be a program of public service, to be at least partially funded by the Society, with some support from organizations and government agencies, and income derived from the sale of standards. In keeping with the sense of public service, the number of standards produced under the auspices of the Society increased tremendously, from about 30 in the early 1970s to just over 120 today. While much activity continued on the development of standards related to measuring instruments and their calibration and use, there was also a shift in focus to the broader needs of society. There are now standards dealing with many specific noise sources commonly found in the community, procedures for testing the performance of hearing protectors and conducting hearing tests, rating schemes for auditoriums, offices and other public spaces. The most recent example is the very important standard on "Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools", ANSI S12.60-2002. (See photo 2.)

The driving forces acting on standards development are now shifting again. They have become stronger and are more related to trade, economics and politics on a global scale. The political will to act on noise as a social and economic issue arose first in the US with the passage of the Noise Control Act in 1972. This political will largely evaporated during the late 1980s. More recently a strong political will has arisen first in Western Europe and then in Japan. In both places high average population densities mean that more people live closer to more noise sources, which has led to strong public pressure to control and reduce noise. (See photo 3). In Europe the political parties in power, with the support of many major industries for reasons of their economic interest, have recognized the increasing strength of Green Parties in recent elections in several countries and have chosen to act now rather than later. With the current trend towards globalization of trade there is already a noticeable increase in harmonization between national and international standards, especially in recent years. This harmonization will continue, especially for those standards pertaining to purely technological factors such as measurement procedures and specification of instrument performance. An important factor in this process has been the formation of the European Union, that is not only a major trading and economic block but also a significant standards-developing organization. Harmonization will probably occur more slowly, and with greater difficulty in areas where standards impact the differing social and cultural factors of nations, or adversely affect the economic viability of their major industries.

An important consideration for the Society is the fact that it is generally seen as the major force in standards development in acoustics in North America. This reputation causes many people, either as individuals or as representatives of other organizations, to come to the Society's meetings especially to work on its standards. In so doing, this invigorates the meetings and also further enhances the Society's position as the focus of acoustical activity. The broad range of necessary acoustical standards aids the cohesion of the Society by requiring the participation of at least some members from almost every one of its 13 technical committee areas. Thus, the Standards program is a broad, unifying force in our Society. It enhances membership and meetings, and it contributes most positively to the Society's image in the broader technical community and in society in general. The Standards program is our Society's largest instrument for outreach and a main vehicle that supports its basic mission: to increase and diffuse the knowledge of acoustics and promote its practical application.

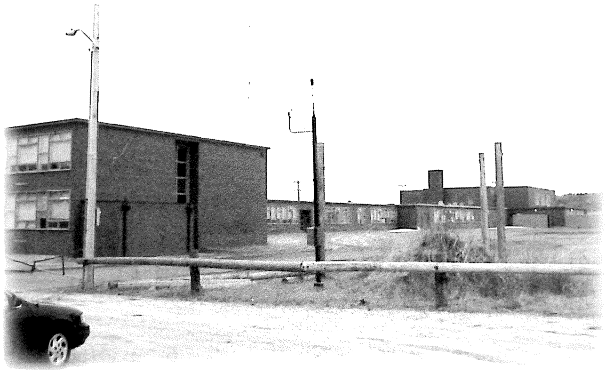


Photo 2. Airport noise monitor near a school. ANSI S12.60-2002 addresses classroom noise from both internal and external noise sources.

Photo 3. Highway noise barrier. ANSI S12.8-1998 was the source document from which the later ISO standard was developed.

Standards in Acoustics Timeline

1932 •••• ASA become sponsor of Committee Z24 Acoustical Measurement and Terminology. Developed many early standards.

1942 •••• Scope of Z24 Committee expanded to include vibration.

1954 •••• Z24-X-2 "The Relations of Hearing Loss to Noise Exposure" published. Provided the basis for future standards.

1957 •••• Z24 split into three committees: S1 Acoustics, S2 Mechanical Vibration and Shock and S3 Bioacoustics.

1962 •••• "The Effects of Shock and Vibration on Man" published through S3. Provided the basis for future standards.

1969 •••• ASA takes over the Secretariats for all three committees from USASI (now ANSI).

1971 •••• ASA takes over the international secretariats of ISO/TC 108 and ISOTC 108/SC1.

1981 •••• New Committee developed from S1 & S3: S12 Noise.

1993 •••• New ISO subcommittee formed with ASA as Secretariat: ISO/TC 108/SC 5.

Major Contributors to Standards

Since the beginning, many of ASA's leaders have also been leaders in the ASA Standards Program. This is demonstrated by the number of the Society's Honorary Fellows and winners of Gold and Silver Medals who have contributed to Standards.

Honorary Fellows

1954 – Vern O. Knudsen
1994 – Leo L. Beranek
1997 – Robert W. Young

Gold Medals

1954 – Wallace Waterfall
1955 – Floyd A. Firestone
1963 – R. Bruce Lindsay
1965 – Hallowell Davis
1967 – Vern O. Knudsen
1969 – Frederick V. Hunt
1975 – Leo L. Beranek
1985 – Laurence Batchelder
1988 – Richard K. Cook
1992 – Ira J. Hirsh
1999 – Henning E. von Gierke
2002 – Tony F.W. Embleton

Silver Medals

Architectural Acoustics

1957 – Vern O. Knudsen
1961 – Leo L. Beranek
1982 – Thomas D. Northwood

Engineering Acoustics

1982 – Per V. Brüel
1981 – Henning E. von Gierke
1984 – William W. Lang
1986 – Tony F.W. Embleton
1988 – William J. Galloway
1992 – George C. Mailing, Jr.
1994 – Kenneth M. Eldred
1999 – Larry H. Royster
2002 – Louis C. Sutherland

Physical Acoustics and Bioresponse to Vibration

1990 – Wesley L. Nyborg

Noise and Architectural Acoustics

2004 – David Lubman

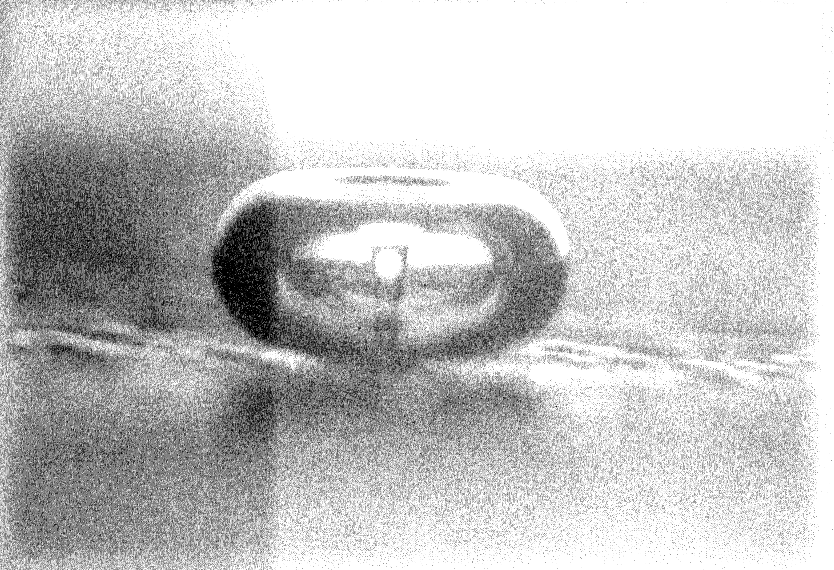
Underwater Acoustics

1965 – Frederick V. Hunt

Afterword

A Vision for the Society's Next 75 Years

William A. Kuperman, President 2004-2005



A cavitation bubble near a surface collapses asymmetrically, producing a high-speed liquid jet. The violent impact of the jet is thought to be the primary cause of cavitation damage. Courtesy of L. A. Crum

A Vision for the Society's Next 75 Years

William A. Kuperman, President 2004-2005

So here we are at the 75th Anniversary of our very remarkable Acoustical Society of America and the obvious question to ask is: where will we be at the 100th? Actually, to be a bit more conservative, I prefer to ask where are we going because my experience is that predictions are most successful at time zero. Since persistence is statistically a reasonable basis for prediction, we should at least examine our trends over the years and problems we are either facing now or will encounter in the near future. Let us take a look at the four central aspects of our Society: our technical areas of interest, journals, meetings and outreach.

Most representative of the technical breadth of the society is our technical committee (TC) structure [see Chapter 3 and the subsequent thirteen chapters on each of the current committees]. At the time of the 25th Anniversary there were a few technical committees and the emphasis was on physical and engineering aspects of acoustics. By the time of the 50th Anniversary in 1979 the technical committee structure, introduced in 1960, had evolved to specifically represent the following areas: Architectural Acoustics, Musical Acoustics, Noise, Psychological and Physiological Acoustics, Speech Communication, Shock and Vibration, Underwater Acoustics and two others with a bit of their own history. Physical Acoustics was originally the Ultrasonics TC; the TC on Audio Engineering and Electroacoustics was shortened in title to Electroacoustics and then subsequently merged with Sonic and Ultrasonic Engineering to form the Engineering Acoustics TC.

Now, at our 75th Anniversary, change Shock and Vibration to Structural Acoustics and Vibration. Further, add Acoustical Oceanography, Signal Processing in Acoustics and as a model for future evolution of TC's, Animal Bioacoustics and Biomedical Ultrasound/Bioresponse to Vibration. The latter originally began as a Technical Specialty Group titled Biological Response to Vibration in 1984, and by 1998 had evolved in its scope to be renamed Biomedical Ultrasound/Bioresponse to Vibration. Our TC structure really represents an Acoustics Renaissance, circa 2003, reaching through physical, biological, physiological, psychological, as well as architectural and engineering sciences with extraordinarily broad applications. To name just a few, from impacting our understanding of baby speech, to developing refrigerators without moving parts, to introducing new medical procedures, ASA members have been at the leading edge of a remarkable number of fields. The extraordinary breadth and diversity of our acousticians suggests that there will be significant changes in the TC structure over the next quarter of a century.

One of the central themes of this evolution is going from acoustical science ("for its own sake") to acoustical science and its applications, with the goals of the latter receiving more and more emphasis. Another example to add to the above evolving diversity is that the intention and emphasis of Acoustical Oceanography is ocean exploration. So an emerging common theme is that our research interests are becoming more and more interdisciplinary. Some fields such as Signal Processing are strictly interdisciplinary in that the signals they study range from music to physiological to geophysical specialties. What we see is a membership gravitating toward multiple interests as evidenced by our members significant participation in other organizations. It is common, for example that members interested in medical acoustics are also active in the Ultrasonics Section of the Institute of Electrical and Electronic Engineers and other organizations, and that members interested in ocean acoustics are also heavily engaged in the American Geophysical Union and similar type organizations. The same is true for almost all the disciplines associated with the technical committees and it is a healthy condition, promoting cross disciplinary approaches to common problems.

The merging of pure and applied acoustics brings up two issues: The future Society involvement of "practitioners," and the potential for some sort of cooperative meetings between ASA and related societies. The latter issue is straightforward and I predict that we will continue to increase our cooperation with societies resulting in joint meetings, such as the past joint meetings of the ASA with the Institute of Noise Control Engineers, cooperative scheduling, and multi-sponsored satellite meetings and workshops. The issue of practitioners, however, demands a Society decision in that it suggests considering greater balance between the interests of academic researchers and practitioners. Our Society will confront this issue in the coming years and it is my hope that the ASA's centennial will see an increase in practitioner participation with a resulting positive two-way enhancement.

We have seen the scientific climate change between the 50th and the 75th anniversaries. There has been a decrease in public support (not just financial) of basic scientific research in the physical sciences, though presumably not in the health sciences (yet). We see a diminishing industrial presence in basic research (e.g., the Bell Lab types) and even in government, and an increasing emphasis on shorter term applied, engineer-to-the-solution approaches. Hence, there is an obvious necessity to increase our outreach activities— not only to bring young people into our science — but also to educate the public so as to encourage their support. We must continue to support our outreach to the press and public through the ASA's *World Wide Press Room*, by funding *Discoveries and Breakthroughs Inside Science* which are produced by the American Institute of Physics for TV broadcast and to K-12 through participation in the *International Science and Engineering Fairs*, the *Physics Olympiad* for high school students and the soon-to-be-released website by the *Online Education Committee.* Since scientific support is cyclic, I suspect that we will help bring back a friendly basic research climate, so that at the 100th we will as likely be in a transition time—either heading toward or away from a basic research climate—as be in positive or negative times. Our diversity will continue to help us weather these climate fluctuations.

Other meeting issues are two-versus–one–per-year and international meetings. I believe that we will continue the two meeting per year schedule because it provides the opportunity and flexibility to meet the demands of the trend implied in the previous paragraph. Further, ASA is holding joint international meetings every three-to-five years. I expect that to continue, but not increase in frequency because over-internationalization may decrease our internal flexibility

The Journal of the Acoustical Society of America (JASA) is THE premier Acoustics journal. We are now at a cross roads—the beginning of the era of Electronic Publishing and a significant part of the next 25 years will involve the Society reaching a financial accommodation with this new paradigm of scientific publication. This is a huge issue because, at least until now, the *Journal* has been a financial positive for the Society. I do not expect (unfortunately, from my point of view) that JASA will be a paper journal at the 100th. Probably, *Acoustics Research Letters Online (ARLO)* will somehow be combined with *JASA*. Now, at our 75th we are launching a new popular acoustics magazine. My feeling is that its survival to the 100th will be dependent on how we deal with the participation of practitioners in the Society.

An important and successful aspect of our outreach efforts is our Standards activity. We must, in the coming years, finally reach a businesslike accommodation for this activity. On the one hand there are important social payoffs such as the recent example of developing classroom acoustics standards which, we should gladly support as part of our social and public responsibility. On the other hand, there are many financial/industrial payoffs for many of the Standards activities that are significantly subsidized by the Society and such activities may be increasingly difficult to justify because of the increasing financial pressures associated with our two mainstays: publications and meetings. We will have to develop a business model for our Standards activities that reflects the dichotomy in the services (and types of client base) that they provide (and service).

In the last few meetings, I have detected a marked increase in student participation that is also reflected in our membership statistics. While this appears to point to a vibrant society for the future, this outcome is not automatic. We must be sensitive to our members' needs, and to provide them with services that are accordingly responsive. In particular, younger members require more immediate care and attention because they have not yet achieved a career history and the associated momentum. Whether it be a more timely publication process, career networking opportunities or response to their specific requests, how the Society meets these challenges will ultimately determine of success of our centennial celebrations.

We have challenges to keep us alert and vibrant and I am optimistic that we will continue to be a healthy Society at our Centennial. We will gladly step up to the registration booth at the 100th and plunk down the $1600 registration fee (BUT—$1250 for early registration, of course), and we will still be arguing about banquets versus buffets, the number of special sessions, etc. HAPPY 75th!

"The Acoustical Society of America is in a state of evolution. We don't know what the form of the Society will be or what the subject matter of the papers and the programs will be at the Hundredth Anniversary Celebration. We wish that we could look in to the crystal ball. There is a crystal ball up here [pointing toward the movie camera], but it is only half a crystal ball, it's a one-way affair, posterity is able to look at us, but we can't look back through that lens and see you on the other side. I wish we could. I know that we would find you as strange and quaint and amusing, in your ways, different from us as you find us as you look at our faces on the screen. However, you are our descendants, you carry on the torch; and with this salute to posterity, I declare this meeting, our Twenty-Fifth Anniversary Celebration, adjourned."

Hallowell Davis
June 1954, New York City

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