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ECHOES

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The mystery of the Taos hum

By Joe H. Mullins and James P. Kelly

Media attention has focused recently on individuals in and around Taos, New Mexico who perceive an irritating low-frequency sound that has come to be known as the "Taos hum." There have been persistent complaints of annoying low-frequency sounds in the U.S.A. and other countries, but the group of "hearers" in Taos has been particularly outspoken. In 1993, they got the attention of the New Mexico congressional delegation, resulting in a request for an investigation.

Many Taos residents feel that the government may somehow be involved in the sound, so the investigation was open and public. One of the authors, Joe Mullins of the University of New Mexico, served as the team coordinator. The team of a dozen investigators included, among others, Rod Whitaker (Los Alamos National Laboratory), Mark Leher (Phillips Air Force Laboratory) and Horace Poteet (Sandia National Laboratories). The second author, James Kelly, a hearing research scientist from the University of New Mexico's Health Sciences Center, joined the team later to provide expertise on human hearing.

Based on interviews with hearers, we determined that any proposed explanation for the hum should take into account its principal attributes. First, the hum is selective. Only a small percentage of Taos residents perceive it. Second, the hum is persistent since most hearers perceive it on a weekly basis. Third, the source of the hum must be widespread since hearers perceive it not only throughout the Taos area, but also we have received letters from all over the country describing a similar phenomenon. Fourth, the hum is invariably described as low in frequency and reminiscent of a distant pump, an idling diesel truck or perhaps someone's high-powered audio bass running amok.

Hearers who are musicians identify the hum as a modulated tone near E flat (41 Hz) and those with some technical background identify it as an amplitude modulated sound with a carrier frequency ranging from 30 to 80 Hz. We decided to supplement these anecdotal descriptions of the hum with psychophysical matching tests using known hearers before we proceeded with our search for the source.

The hum matching tests were made with ten hearers. The equipment was set up in the bedroom of a guest house near the Taos residence of Bob and Catanya Saltzman, two hearers who had been instrumental in getting the investigation started. We built a custom microphone from an 18-inch woofer to serve as an ultra-sensitive, low-frequency sound detector with a relatively flat frequency response (sensitivity of -60 dB sound pressure level from 8 Hz to 80 Hz). The microphone, in its enclosure, weighed more than 150 lbs. The output of this "big ear" was fed to recording and analyzing equipment housed in an RV some distance away.

To keep the tests as simple as possible, we used a modulated sine-wave source and a low-frequency speaker to generate matching sounds. Eight

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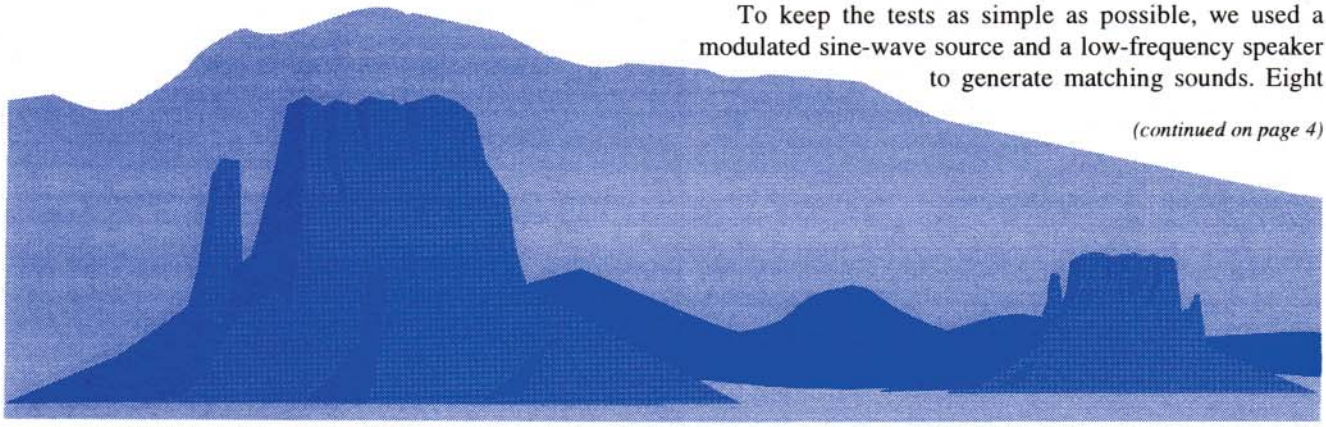

We hear that...

There will be several medals and awards presented during the Plenary Session at the upcoming St. Louis meeting:

- The Pioneers of Underwater Acoustics Medal will be presented to **William A. Kuperman**;
- The Silver Medal in Engineering Acoustics will be awarded to **James E. West**;
- The Wallace Clement Sabine Medal will be conferred upon **A. Harold Marshall**; and
- The von Bekesy Medal will be presented to **Peter Dallos**.

The following new Fellows of the Society were elected at the Washington, D.C. meeting and will be individually recognized at the St. Louis Plenary Session:

Arthur Ballato	**John J. Ohala**
David H. Berman	**Wayne O. Olsen**
Christopher Feuillade	**Jean Piquette**
Roger P. Hamernik	**Joseph Pope**
Uwe J. Hansen	**Stephen I. Roth**
Bruce Hartmann	**Barbara J. Sotirin**
Jorge C. Novarini	**Eric I. Thorsos**

Also at the St. Louis meeting, Mead Killion, Vice President of the American Auditory Society, will present that society's Lifetime Achievement Award to **Edgar Villchur** for his contributions to sound reproduction and to signal processing for the hearing impaired.

Alan Powell has been appointed one of ASA's representatives on the American Institute of Physics' Governing Board. He replaces Patricia Kuhl, Vice President-Elect of ASA, who has resigned from the position due to increasing obligations.

ECHOES

Newsletter of the Acoustical Society of America
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Executive Director's note

Modernizing the ASA, YET maintaining its volunteer spirit

When I was very young, my Brooklyn grandmother would pose the following riddle: "Yesterday your grandfather drove his car across the Brooklyn Bridge, and YET walked!" How was that possible, she would ask. The answer, which we grandchildren knew all too well from constant retelling, was that YET was the name of his dog. The riddle for the Acoustical Society is how to modernize the services provided by the Society, and YET maintain the collegiality and volunteer spirit so unique to our Society.

This question came up often when the "ReCreation" process was begun under President Richard Lyon in 1992. It is continuing under the Long Range Planning Committee chaired by Ilene Busch-Vishniac. Her Committee will host a town meeting in St. Louis, immediately after the plenary session, entitled "Societal growth: How much is enough?" Just like the riddle, these kinds of policy questions can be solved, but they take some careful thinking.

There are many ways that the Society has already addressed the question of modernization. One of the most significant examples is ASA's response to the opportunities in electronic communications, which has happened mainly because of President Robert Apfel's leadership and enthusiasm. These services include electronic submission of abstracts, the availability of the *Journal* on CD ROM, an ASA Home Page on the WWW, and the ASA listserver. (See the article "ASA goes electronic" on p. 5.)

Another important way in which ASA has moved with the times is by enhancing its role in the international arena. ASA will hold its third joint meeting with the Acoustical Society of Japan in Honolulu next year. The Society will also host the International Congress in Acoustics in Seattle in 1998. A joint meeting with the European Acoustics Association will take place in Berlin in 1999. (See article on p. 8.)

ASA is modernizing its *Journal* distribution by providing members with certain options. The editorials in the July and August issues explain the format changes and choices available, which include not only the option to receive the "offprint" section only, but also the option of a CD ROM version of the *Journal*.

Our semi-annual meetings are growing steadily larger, while continuing to make full use of volunteer efforts in their planning and execution. In addition to these meetings, ASA now hosts meetings on individual topics. Examples are the ONR Physical Acoustics Summer School, the International Conference on Issues in Advanced Hearing Aid Research, and the Sabine Centennial.

Within the Society, outreach to members has consisted of a conscious effort toward wider participation and

(Continued on next page)

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Journal to be available on CD ROM

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ASA Home Page up and running

Are you curious about where the next few meetings of the ASA are going to be held? Do you want to read or search electronically through abstracts for the next meeting? Do you want to hear the sounds of whales? Do you need to see a picture of someone on the Executive Council to recognize this person at the next meeting? Or perhaps you want to interest a non-member in acoustics or in the Acoustical Society? If so, tune into the ASA Home Page at http://asa.aip.org/. This Home Page owes its existence to many hours of volunteering by Paul Baxley of ASA's Public Relations Committee and Carr Everbach of the Committee on Education in Acoustics. It will be maintained by the American Institute of Physics (hence the "aip" in the call name). If you have suggestions for improvements or just plain compliments for Paul or Carr, please drop an e-mail note to asa@aip.org.

Listserver provides quick communication to ASA members

ASA Members with e-mail addresses may now receive ASA bulletins almost instantaneously through ASA's new listserver. If you are not receiving these bulletins (the last two were on a correction to the Call for Papers and a message from President Bob Apfel) you may add your name to the listserver.

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Member donations help students and Russian acousticians

Even if you aren't a student any more, you might still remember the time when you were short of cash and struggled to put enough money together to attend an ASA meeting that was important to you. Or perhaps you didn't come simply because you didn't have funding. It was for this reason that ASA set up a student travel fund, the interest from which helps to defray travel costs for some of the students attending our meetings. First priority goes to students presenting papers who plan to travel in a group, such as a car pool. In the past, some enterprising students have even rented a van or two! Other means of travel are also acceptable, and occasionally travel funds are given to overseas students. The ASA travel fund allows students to attend meetings and hear about the latest advances in their field, as well as meet the experts whose papers they have been reading. And at the same time, experienced members can share in the excitement and enthusiasm of students who will carry on their work.

ASA supported 23 students to attend the Washington, D.C. meeting, many of whom would otherwise not have been able to have this experience. This assistance is made possible by ASA members who designate a contribution to the student travel fund on their dues statement. Last year members donated approximately $7700.

Also on last year's dues statement was a one-time request for donations to support acousticians in the Former Soviet Union and Eastern European countries. This specific request raised $13,000, which, when added to the $20,000 donated by the Society itself, helped acousticians in the Commonwealth of Independent States and Eastern European Union with 20 student grants and ASA membership dues for 16 acousticians. Peter Mikhalevsky, who chairs the ASA Committee for Support for the CIS/EU, has expressed his appreciation on behalf of all the acousticians who have been helped by the generosity of ASA members.

(...Taos hum-continued from page 1)

of the ten hearers were able to generate a sound that matched the hum they were perceiving. Hearers matched the same sound to the perceived hum quite reproducibly. Surprisingly, many hearers reported beats between the speaker-generated sound and the hum, implying the physical existence of a second tone.

The results of these tests were both intriguing and puzzling. The carrier frequencies selected by the hearers ranged from 32 Hz to 80 Hz. The modulating frequencies they chose ranged from 0.5 Hz to 2 Hz. All chose amplitude levels near or below the known sensitivity of the ear in this frequency range. But the most striking thing is that hearers could still perceive the hum in the presence of

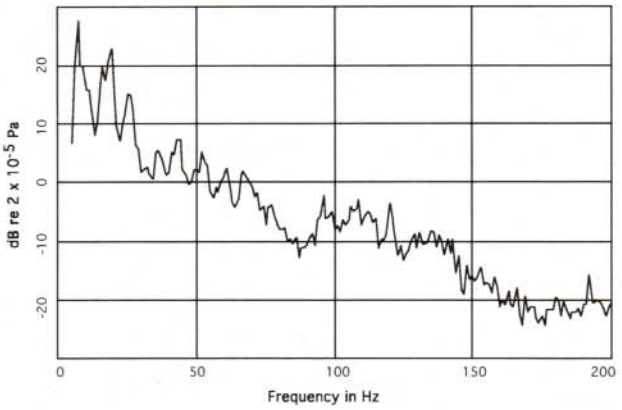

Fig. 1. Background noise in 1/4-Hz bands in a Taos home.

ambient noise with a relatively flat spectrum when the matching signal was turned off. Figure 1 shows a representative sample of the noise background in the Saltzmans' rural home at 7,000 feet above sea level, recorded with our "big ear." The noise amplitude, even when converted to one-third octave bands, is 15 to 20 dB below the accepted threshold for hearing in this frequency range. This suggests that the hearers are not extracting a faint period signal from noise by a mechanism similar to stochastic resonance and perceiving the signal as a hum, although we cannot rule this out.

The Saltzmans' residence and the Taos golf course were selected as sites to conduct acoustic, geodynamic, magnetic and electromagnetic measurements. Additional geophone and magnetometer data were collected at other locations in and around Taos to track down the origin of a strong harmonic component in the 60-Hz power grid around Taos. At first glance this provided a possible source for the hum, but hearers agreed almost universally that the perceived sound was unusually intense at a very remote site near Tres Piedras, where we could find little trace of the 60-Hz magnetic component.

Measurements made with magnetometers in an electromagnetically quiet area did show the Schumann resonances created by sources such as lightning-induced electromagnetic radiation, reverberating in the space between the ionosphere and the earth. The observed frequencies of the Schumann resonances cover the range implicated in the Taos hum, but they appeared to be normal in amplitude and we could find nothing unusual about them.

Taos is a relatively quiet seismic area so it is not surprising that geophone data showed nothing but background noise. One massive event turned out to be a determined gopher restoring a burrow obstructed by placement of the geophone. Our electrostatic field detector recorded many events, but all could be attributed to lightning strikes or movements of people in the vicinity. The electromagnetic data were collected from 20 Hz to 18 gHz, using an assortment of antennas and receivers. Everything that was found could be attributed to 60-Hz power lines, electromagnetic noise, or known radio and TV transmitters.

Since the U.S. Navy ELF stations (short for Extremely Low Frequency) in the Michigan peninsula and in Wisconsin were widely suspected to be sources of the hum, we looked carefully at the 65- to 75-Hz region of the electromagnetic spectrum, the frequency range where ELF signals would be prominent. We could find nothing above the noise. Considering the spread spectrum of this broadcast, its limited antenna length, and the distance from the transmitting site, it is unlikely that the signal would be above the noise level in northern New Mexico.

As a result, we are left with a mystery. There are no known acoustic signals that might account for the hum, nor are there any seismic events that might explain it. There are no unusual lines at suspect frequencies in the electromagnetic spectrum recorded near Taos. In fact, other than the signals generated by the power grid or, in the case of the golf course, a power generator located at the course headquarters, we found no clear lines at all in this spectrum. At a more fundamental level, there is no known mechanism whereby weak electromagnetic signals might even be transduced selectively by the human ear and perceived as sound. Our next step, therefore, was to shift our emphasis from the physical environment to the hearers themselves.

We first wanted to determine what fraction of the people in the Taos region are affected by the hum and to probe the characteristics of their perception. To this end we sent survey forms concerning the hum to 8,000 residents in Taos and Ranchos de Taos and the neighboring communities of Tres Piedras, Questa, Eagle Nest, and Peñasco. These communities represent points to the west, north, east, and south of Taos respectively, on a circular perimeter roughly 40 miles in diameter with Taos at its center.

A total of 1,440 residents in these areas responded to the survey and 161 respondents were classified as hearers.

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(...Taos hum-continued from page 4)

Most of the hearers (72 percent) are between 30 and 59 years of age and there are approximately equal percentages of male (52 percent) and female (47 percent) hearers. The hum is perceived by most hearers (62 percent) between 8:00 p.m. and 9:00 a.m. About 80 percent of the hearers perceive the hum at least one a week and, as shown in Figure 2, a hearer's first experience with the hum usually occurs in the immediate vicinity of Taos. It is noteworthy that 19 percent of the hearers perceive the hum at sites more than 50 miles from Taos.

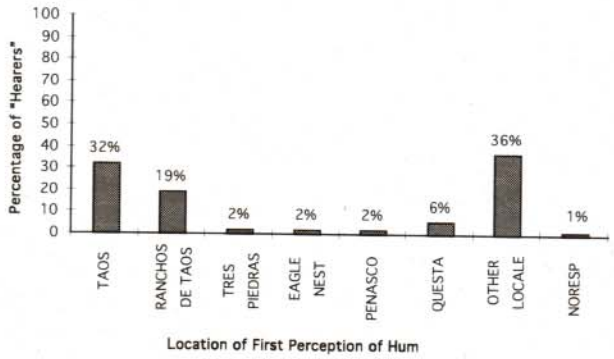


Fig. 2. Location of first hum perception.

If we assume that all hearers responded to the survey, we can estimate that the lower limit of the fractional number of hearers is approximately 2 percent of the population surveyed. If this ratio holds for other populations in remote or quiet rural areas, we would expect that the number of hearers is very substantial in this country.

It has been proposed that the hum might represent some kind of low-frequency tinnitus arising from a disturbance in the cochlea of the inner ear. One problem with such an explanation is that tinnitus itself is not well understood. Most individuals with tinnitus match what they perceive to a tone between 3000 to 6000 Hz, and rarely, if ever, does a tinnitus sufferer match to a tone below 1000 Hz. Why should such a phenomenon skip from regions of the cochlea where the 3000- to 6000-Hz frequencies are represented, over intermediate zones, to the extreme apical end of the cochlea where the lowest sound frequencies are represented? Furthermore, many hearers insist that they can hear beats between their perceived tone and the objective tone generated in matching experiments. Beats have not been demonstrated reliably in matching experiments using subjects with tinnitus.

Our next goal is to compare low-frequency hearing thresholds and other aspects of auditory function in hearers and non-hearers from the Taos region. Informal testing of one hearer provided a tantalizing hint that the sensitivity of hearers in the frequency range from 20 to 100 Hz may be significantly more acute than is implied by some of the widely used sensitivity curves. Therefore, we are currently developing equipment for low-frequency audiometry, as well as equipment to measure distortion product otoacoustic emissions generated by the ear at low frequencies. The measurement of these emissions has become standard clinical practice at frequencies above 1000 Hz, but to date no one has reported success in detecting evoked or spontaneous emissions in the frequency range we are investigating. The problem is that the noise floor for the usual ear-insert microphones is very poor at low frequencies, so we are using electrodynamic elements with considerably lower noise floors.

Despite the absence of definitive results, our interest in finding a source for the elusive Taos hum remains high. The character of the Taoseños and their unique town only add to the flavor of this mystery in acoustics and human hearing.

Joe H. Mullins, Ph.D. former Director of the Systems Analysis Center at AT&T Bell Labs, is currently Professor Emeritus of Mechanical Engineering at the University of New Mexico. After a long career in particle physics and manufacturing engineering, he is now developing acoustical technology for the analysis of low-frequency hearing.

James P. Kelly, Ph.D. is an Associate Professor in the Division of Otolaryngology at the University of New Mexico's Health Sciences Center. His research at the University of New Mexico focusses on the physiology and anatomy of the human inner ear.

Investigators Mullins (left) and Kelly (right) at their experimental setup.

ASA and Marine Mammal Society host workshop

A two-day workshop in marine mammal bioacoustics will be held on December 12 and 13, in Orlando, Florida, immediately preceding the meetings of the Marine Mammal Society. The workshop is intended for individuals with a science background but without specialized training in underwater acoustics or marine mammalogy. Topics will include an introduction to underwater acoustics, responses of marine mammals to disturbances, laws governing marine mammal interactions with humans, and the need for standards. For information about the course call ASA's NY office at (516)576-2360 or e-mail asa@aip.org.

Acoustics in the News

Several articles were written as a result of sessions held at the ASA May/June meeting in Washington, DC. The June 21 issue of the Provo, Utah *Universe* carried an article entitled "First dean of Y engineering remembered in conference" by Alesha Thompson. The article described the life and work of Harvey Fletcher, and the special session honoring him at the ASA meeting. Yet another article about the effects of underwater noise on marine mammals, along with the delay of the ATOC experiment, appeared in the Greenwich, CT *Time*, ("Outcry over acoustic study focuses on sea mammals" by Matt Crenson). Also stemming from the ASA meeting was a discussion of the "speech motor economy" theory, the tendency for speakers to reduce the effort of speaking, proposed by Kenneth de Jong and Elizabeth Zsiga. The article, "IU researchers explain why Brooklyn natives drop the 'r' sound from words," appeared in the Bedford, IN *Times Mail* on June 21. The June 5 edition of *The Dallas Morning News* described the paper by Ellen Haas and Judy Edworthy on auditory warning signals in another piece by Matt Crenson entitled "Acoustical study of alarms takes on a sense of urgency." The article was also featured in *The Des Moines Register* (Iowa) and *The Orlando Sentinel*.

Stephen Benka's article "How Low Can the Violin Go?" in the September issue of *Physics Today* also draws on a special session at the recent ASA meeting, in which violinist Mari Kimura gave "an electrifying performance" to a standing-room only audience. The article discusses the research of Frederick Halgedahl and Roger Hanson, who had discovered and researched the violin's low-tone capabilities, while Ms. Kimura discovered them independently and put them to musical use. In the same issue of *Physics Today*, James P. Wolfe has authored an article, "Acoustic Wavefronts in Crystalline Solids" about newly developed imaging techniques to describe the vibrational wavefronts from point sources, providing insight into the propagation and interference of acoustic waves in solids.

An article in *The Philadelphia Inquirer* about the graduate program in acoustics at Pennsylvania State University features the work of Gerald Lauchle, Gary Koopmann, and their students in controlling the noise from everything from vacuum cleaners to cars. The article entitled "Professor dulls roar of common machines," written by Ralph Vigoda appeared on April 16. Similar articles appeared in *The Detroit Free Press* (4-25), *The Arizona Republic* (4-17), *Mechanical Engineering* (June), and *Compressed Air Magazine* (June). Another piece on noise control, this time in the office environment, appeared in *The Wall Street Journal* on August 21. In "Scientists Study Secrets of a Quiet Office," author Jon Bigness describes the research facilities at the Steelcase Acoustics Lab. He quotes senior engineer Steven Brown as saying that the problem of distraction by the human voice will become worse when, before long, people start talking to their computers.

The June 15 issue of *Nature*, included the article, "Elevation of auditory thresholds by spontaneous cochlear oscillations" by N.L. Powers, R.J. Salvi, J. Wang, V. Spongr, and C.X. Qiu concerning spontaneous otoacoustic emissions (SOAEs). The authors found that the activation of auditory nerve fibers by SOAEs results in "internal biological noise," which interferes with a neuron's ability to respond to sound and creates a kind of hearing loss that is completely different from the loss caused by damage to sensory cells. The article prompted a report by National Public Radio's "All Things Considered," which described SOAEs more generally and interviewed researcher Dennis McFadden.

The September 1 issue of *Science* included three articles on estimating the speed of sound through Jupiter in order to calculate pressure and temperature levels in the planet's hydrogen interior: "Sound and Fury in Jupiter" by R.J. Hemley; "Temperature Measurements of Shock-Compressed Liquid Hydrogen: Implications for the Interior of Jupiter" by W.J. Nellis, M. Ross, and N.C. Holmes; and "Ab Initio Calculation of the Sound Velocity of Dense Hydrogen: Implications for Models of Jupiter" by A. Alavi, M. Parrinello, and D. Frenkel. An earlier issue of *Science* (Aug. 11) featured a study on the use of low-frequency ultrasound to increase the skin's permeability, facilitating the trans-dermal delivery of drugs via skin patch ("Ultrasound-Mediated Transdermal Protein Delivery" by S. Mitragotri, D. Blankschtein, and R. Langer). The study was subsequently reported by *The New York Times* in a piece by Tim Hilchey, "Researchers Are Using Pulses of Ultrasound to Deliver Drugs" (8-15-95), and by *Science News*, "Sounding out a better way to deliver drugs?" by J. Travis (8-12-95).

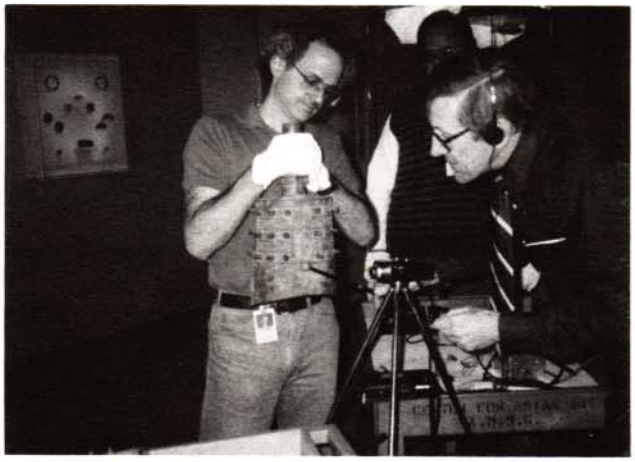
Two recent magazine articles discuss the acoustics of the natural world. "Shhhh...those 'peculiar people' are listening" by A. Richard Immel in the April issue of *Smithsonian*, describes the work of the Nature Sounds Society and other nature recorders, including Emmy Award-winner Gordon Hempton. The article discusses the recording techniques of these dedicated individuals, as well as the endangered subjects of their recordings. In the August issue of *Scientific American*, Peter M. Narins presents an intriguing discussion of how the frequency, amplitude, and temporal patterns of their vocalizations enable frogs to proclaim their territory and call their mates. The article, entitled "Frog Communication," also tells how nature has succeeded in protecting male frogs from their own ear-splitting emissions.

The summer issue of Cornell University's magazine *Engineering* contains the article, "The Shape of a Sound" by John Yaukey. The author reports on the work of Cornell student and scientist Tobin Driscoll, in analyzing the acoustical properties of "virtual drums" to help bridge the gap between these mathematical metaphors and the way they would sound in the real world.

Ancient Chinese bell collection celebrated

Thomas Rossing will be one of the speakers at a symposium celebrating the completion of a three-volume catalog of the ancient Chinese bronzes of the Sackler collection at the Smithsonian Institution. The symposium is scheduled for October 14 at the Freer and Sackler Galleries in Washington D.C.

At the invitation of the Smithsonian, Rossing began his acoustical studies of the ancient bells in 1991. The collection consists of 16 bells in the Sackler Gallery plus additional bells in Princeton and New York. "I was particularly fortunate to be given the opportunity to do hands-on acoustical research on an outstanding set of ancient Chinese bells and to compare their acoustical properties to other ancient and modern bells," said Rossing. He reported that he intends to discuss his acoustical data in a paper at a future ASA meeting.



Tom Rossing testing one of the ancient Chinese bells in the Sackler Collection

Pre-publication offer on violin acoustics

ASA is considering publishing the definitive treatise, "Research Papers in Violin Acoustics: 1975-1993," edited by Carleen Hutchins with associate editor, Virginia Benade. A pre-publication offer at $100 stands until December 1, 1995, after which the two-volume set would cost $120 for ASA and CAS members and $155 for non-members. The introductory essay, "350 years of violin acoustics" relates for the first time the development of the violin to the scientific advances, as well as the musical climate, of each era from the early 15th Century to the present. The set of books contains 120 research papers with an annotated bibliography of over 400 references. It promises to be an essential reference for researchers, violin makers, string makers, wood technologists, string players, musicologists, and every library.

ASA and EAA plan joint meeting in Europe for 1999

The Executive Council of the Acoustical Society of America and the Board of the European Acoustics Association agreed to a joint meeting in Berlin scheduled for March of 1999. The meeting will serve as ASA's Spring Meeting. The city of Berlin and its many attractions, along with the convenience of the meeting site's central location at the Technical University of Berlin should add to its appeal. In addition, the official language for the joint meeting will be English, and we are fortunate that many Berliners speak English quite well. More details will be provided as the date approaches so that members can prepare for this first ASA meeting to be held in Europe.

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