ACOUSTICS 1974

The invited lectures presented at
The Eighth International Congress on
Acoustics London 1974

Edited by R W B Stephens

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FOREWORD

This volume contains invited papers given at the Eighth International Congress on Acoustics held at Imperial College, London in July 1974. The contributed papers have appeared in two separate volumes containing single page contributions from over seven hundred delegates.

The main theme of this Eighth Congress was Environmental Acoustics. The opening address and the afternoon invited lectures were related to various aspects of this topic.

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Acoustics 1974

EIGHTH INTERNATIONAL CONGRESS ON ACOUSTICS, LONDON 1974

Public Aspects of Environmental Acoustics

Richard H. Bolt, Bolt, Beranek and Newman
Cambridge, Massachusetts, USA

"We are gathered here ... to participate in ... an International Congress on ... Acoustics. ...This field has a nucleus of two parts: physical acoustics and bio-acoustics. The activity of the nucleus is basic research. On the one side is physical research in the mechanisms of sound generation, transmission and reception, and in the behaviour of matter in the presence of vibratory forces. On the other side is psychological and physiological research in the perception of sound, in the transmission of acoustic information through the nervous system, and in the behavioural response of individuals to the sounds around them. This dual nucleus feeds the applications of acoustics in four general areas: 1) audio communications, 2) musical arts and entertainment, 3) health, comfort and safety, and 4) techniques for science and industry. ...These four areas of application, in turn, are linked collaboratively with many other fields of science and engineering. These include physics and chemistry, radio, telephone, and electrical engineering ... music, architecture and structural engineering, medicine, public health, psychology, physiology. ..We should not infer that the field of acoustics is unique in possessing so complicated a structure, for many fields of technology can similarly be described by a basic nucleus, a limited number of primary functions and a multiplicity of connections with other fields. But ... acoustics is among the pioneers in understanding and pursuing an integrated approach to a total problem of man and his environment. ...This point of view is given international recognition as we meet here today, as we share our knowledge at this Congress."

Now let me pause to make some remarks about the words you have just heard. They are quotations from a speech that was given many years ago. I have read only a few passages selected out of the speech, but the passages are unchanged and are quoted in their original order. The speech was given in the Netherlands on June 16, 1953. I had the honor to present it as the Opening Lecture at the First International Congress on Acoustics.

For today's opening of the Eighth International Congress, I have chosen to read those quotations because they lead so directly to the theme I wish to discuss. Those quotations, backed by all the other presentations given at the First Congress, clearly illustrate the difference between the past twenty-one years of acoustics and the next twenty-one years as I foresee them.

Those words of 1953 introduce the field of acoustics as it has been conducted almost exclusively during the years since then. Those words of 1953 almost totally ignore the activities that I believe will occupy a large and important part of acoustics work in the future. In other words, the quotations direct our attention to a pair of quite different processes: acoustical continuity and acoustical discontinuity.

I do not mean to suggest that we shall cease doing what we have done in the past and will start doing something that we have never done before. Quite to the contrary, I shall argue that we must continue doing what we have done, but must add to it a large amount of work that we have only just begun to undertake. The result, I believe, will be a substantial increase in the total amount of acoustics work, including the work of acoustical societies and of the International Commission on Acoustics.

Now I must start to convert these abstract thoughts into concrete explanations. First, as you may already have noticed, I am using the word, acoustics, interchangeably with three different meanings: the phenomena of sound and its effects, the body of knowledge concerning the phenomena, and the profession of acoustics including its institutions and us, its practitioners.

When I use the words, acoustical continuity and discontinuity, I do not mean them as applied to a sound wave itself — although a sonic boom is a discontinuity of great relevance to this subject. I am applying the words to the body of knowledge, and to the professional activities that must expand and greatly increase the dissemination of relevant knowledge in the years ahead.

The continuity to which I refer is seen in the extraordinary accumulation of basic scientific information in physical acoustics and bio-acoustics, resulting from basic research activity that has continued and flourished in directions set more than two decades ago. Continuity is seen also in the areas of acoustics applications. In the area of audio communications, for example, continuing research in speech processing is leading to practical improvements in telephone service. Again, research in the early and late reflections of sound in rooms is leading to improvement of acoustics in music halls.

Let me use these same two examples of applications to introduce my meaning of acoustical discontinuity. In both cases the scientists did research in clearly defined problems, to gain knowledge directly applicable to clearly recognized practical applications. Further, and of special importance, the practical applications would be achieved through established institutions and mechanisms. For example, the telephone company that invested in the research would recover the costs through revenues from the improved telephone. Again, a combination of revenues from concert tickets and donations from music patrons, channelled through a concert hall manager or architect, would pay for the acoustical consulting work that justified the room acoustics research in the first place.

These examples describe what I shall call private mechanisms operating internally within a set of institutions that share an interest in acoustics research and application. The key words are "private" and "internal". In particular, the major decisions are made privately, within the institutions involved, and are made in accordance with private value judgements. That is, persons responsible to the institutions themselves make the choices about the benefits and costs of applying the acoustics knowledge.

The key words that have the opposite meanings are "public" and "external". These words apply, for example, to most problems of noise from highways. The highway, let us say, was constructed and paid for by a public agency. The highway benefits the users of automobiles, trucks, and buses on the highway. But the noise from these vehicles goes out to homes nearby, where the noise may cause annoyance, interference with conversation and sleep, and complaints. The people who live there are paying some of the "costs" of the highway, and yet they might be people who never use the highway or benefit from it in any way.

I am of course talking about externalities, to use the technical term of economics, which means costs and benefits that do not figure directly in the market mechanism. And also, in the language of economics, I am talking about public sector as against private sector transactions. However, in my remarks here today I shall deliberately avoid restricting myself to the rigorous technical definitions of any one discipline, in order to convey as clearly and widely as possible what I mean by the acoustical discontinuity between the past and the future of acoustics.

What I mean, in brief, is this: Whereas in the past we have for the most part approached public aspects of acoustics haltingly and fearfully, we shall in the future have to approach them vigorously and with properly developed confidence. Whereas in the past we have devoted most of our attention to what I am calling private, internal aspects of acoustics, we shall in the future need to devote the same level of effort and importance to the public, external aspects.

These two aspects, the public and the private, differ from each other in fundamental ways. The record of the past twenty one years, and in fact a much longer historical record of achievement in acoustics, amply demonstrates that we who practice this profession understand well the private, internal aspects. We know how to make productive judgements about scientific questions that merit basic research. We know how to disseminate the resulting information to our colleagues. We know how to apply the information, and how to work effectively with others who apply it. We know about the process by which benefits and costs of potential applications are assessed, and we can contribute usefully to the making of choices and decisions.

For these reasons I shall say no more about the private aspects. I shall spend the rest of my time here exploring some of the public aspects and suggesting some ways in which we might take them into account. I shall restrict my examples to aspects of environmental noise, even though, as my title suggests, public aspects are found also in environmental music, speech, warning signals, and sounds of nature.

One public aspect, to which I have already alluded, is the propensity of environmental noise to spread itself out over large areas, without respect for private property lines. In contrast, the improved quality of speech sounds stays inside the telephone system, and the acoustical properties of the music hall stay inside the hall. But noise from highway vehicles entirely disregards the boundaries of private homes and gardens, and thereby becomes a problem to be solved in the public domain.

We find some exceptions, some cases in which widespread noise is controlled through a private effort. Several years ago a manufacturer of outboard motors for boats invested in research and engineering to produce a quieter motor. Noise from such motors had been annoying people living in homes around the lakes on which the boats were running. The quieter motors produced significantly less annoyance. This improvement in the noise environment resulted from private actions in which the costs of making the less noisy motor were recovered in the price of the motor, which gained a competitive advantage through its quieter performance. Unlike this example, most problems in environmental noise require public mechanisms to solve them, partly because the noise spreads out beyond the private domains of the people who own the motors or whatever other kind of privately owned and used noise maker may be involved.

A single source of environmental noise can affect a very large number of people. A highway operated by a single agency is, in a sense, a single source of noise even though it might stretch a hundred miles or more. It is a single source insofar as the single agency must take the responsibility for doing something about the adverse impact of the noise. It is a single source also insofar as it radiates substantially the same kind of noise, statistically, along its entire length.

Because large numbers of people receive the highway noise, the impact of this single source is a statistical spread of different reactions. For example, the number of people who complain about the noise can range from one percent of the population in one community near the highway to as much as ten percent in another community. The variability in reactions results to a considerable extent from the differences in the attitudes of the individuals and in the social and economic attributes of the community. Social psychological research in recent years has produced important information from which we can predict rather well how a particular person will react to noise, if first we obtain certain data about the person by means of a questionnaire survey.

In principle, then, we could estimate in advance how much noise exposure each person could accept without feeling too much annoyed. Unfortunately we cannot design the highway traffic in such a way as to adjust the noise at each home. We cannot choose a different set of criteria and regulations for each member of the public. We must choose only one set.

When I say that we must choose, I do not mean that we, the acousticians, must make the choice. I mean that we, the public, must do so. This comment brings us to another public aspect of environmental noise. The aspect relates to the nature of public decisions and how they are made. In principle, they are collective decisions that represent, directly or indirectly, the collective needs and desires of the people. The decisions are made through political mechanisms, of one sort or another, that speak for many different interests and constituencies.

This complex process of making public decisions is itself a part of the endeavour of environmental noise control. We may not like to think so; we may prefer to think that we the noise control experts produce the noise control. But from the public point of view, all that we can produce are some analyses and some alternative technologies. And for each alternative we can perhaps calculate the benefits and costs. But the public, through its decision making mechanisms, produces the choices, the decisions as to which alternative they will buy and support.

The acoustics profession is not alone in this ambiguous situation. Many other professions also contribute parts of solutions to environmental noise problems. As a result, the quality of the final solution depends very much on how effectively these several different kinds of contributors understand each other and communicate with each. Let us take a few moments to look at these relationships. We shall start by examining some traditional habits.

Each profession puts its own part truths to work and sees only dimly, if at all, that the problem it seeks to solve does not in fact become solved without benefit of part truths from other professions as well. The myopia infects us all, engineers, scientists, physicians, lawyers, public administrators, economists, and the rest. Each of us defines the problem too narrowly, and therefore fails to see what a full and practical solution really means.

Consider the problem of environmental noise, a public problem that millions of people feel in such forms as annoyance, sleeplessness, impaired hearing, intrusion of privacy, and economic loss. Only when those persons no longer feel the problem, only when they believe that the undesired effects of the noise have gone away, does the problem become truly solved from a practical point of view.

Each profession's part truth may provide a partial solution: the engineer's new piece of noise control technology, the scientists discovery of a stimulus-response correlation, the physician's clinic for monitoring hearing thresholds, the lawyer's new form of legislation, the public administrator's enforcement of a code, the economist's proposed system of noise taxation. Each of the partial solutions may be a necessary one, but none by itself is sufficient to get rid of the problem as felt by the public.

How can the various professions combine their partial solutions more effectively? The starting point is mutual understanding built on mutual knowledge. Each professional practitioner possesses specialized knowledge, the kind of knowledge required to solve the technical problems of the particular profession. Not many people acquire specialized knowledge in more than one professional field. However, a person can gain a certain level of comprehension in many different fields besides his own. Let me call this kind of comprehension interpretive understanding.

A person who possesses interpretive understanding in a field is able to recognize when the solution of a problem may require specialized knowledge from that field, even though he himself is not able to supply it. Interpretive understanding in a field equips a person to communicate effectively with specialists in that field, and to understand how technical contributions from that field relate to those from his own field.

As my opening quotations indicated, the idea of interpretive understanding is not new to us in acoustics. We have had a long history of interdisciplinary communication and collaboration. What is new, as we learn to work more effectively with public aspects, is the wide range of professions involved. In the past we have collaborated mainly with other branches of science and engineering, the professions that underlie technology. Now we must broaden our range of interpretive understanding to include professions that underlie governance, the process of governing.

Clearly one such field is political science, and other fields are the law in many of its specialties, public administration, and public accounting. In addition, such fields of learning as sociology, anthropology, history, and philosophy offer insights into the evolution of social arrangements and their governance.

As we in acoustics apply our specialized knowledge to parts of the problem of environmental noise, we would do well to acquire interpretive understanding of several of the other professions, including ones related both to governance and to technology. Practitioners in those professions, in turn, would do well to acquire interpretive understanding in the acoustics of environmental noise. To acquire these new understandings will be more difficult for the busy, senior persons than for students, and we may hope that professional education in the future will give more attention to learning about related professions. I believe that the resulting benefits to the professions as well as to the public will amply repay the added effort required in education and continuing study.

Many government decisions, especially at lower levels of government, are made with little if any of the specialized professional advice that could make the decisions more effective. Even advice in science, which has gained considerable prominence in several countries through science advisory offices, often falls short of providing the valuable service that it could.

A major reason for the shortcoming is that professional technical advice tends to be given in series instead of in parallel. If each of several advisors offers his judgements separately, one after another, the advice that comes first can lead to decisions that reduce the range of options available to benefit from the advice that comes later. Or the later advice might force the public decision maker to reverse an earlier choice. For example, a piece of noise control technology might be adopted by a government agency, and then the technology might have to be abandoned because later advice from a public health specialist showed that it was not safe, or because later advice from an economist showed that the technology incurred undesired costs.

Working together at the same time, in parallel, becomes possible when specialists from many professions share a common pool of interpretive understanding. Then the professional group itself can find appropriate technical accommodations, instead of having the compromises made by less knowledgeable persons in the traditional, series arrangement.

I am now participating in a pilot experiment of this sort. We have put together an unofficial group called An Intersociety Liaison Committee on the Environment. The group is made up of persons from about twenty different professional societies, including the Acoustical Society of America, which I represent. The other societies cover many of the fields that I named earlier: several branches of science and engineering, medicine and public health, law, accounting, public administration, and so on.

This Intersociety Committee, called AISLE for short, has held two major workshops during the past three years. In the first one, about one hundred persons drawn from the participating societies spent several days together, learning to communicate and to discuss each others' ideas and approaches to the solution of environmental problems. In the second workshop, AISLE members from most of the same societies joined with members of the elected legislature of one of our largest states. Three days of intensive discussion and collaboration led directly to the drafting of some 30 new pieces of legislation, each of which had benifitted from professional advice and technical information discussed openly by persons from all the professions, communicating in parallel.

We are now planning to enlarge this experiment through workshops held with other government organizations. The first results are sufficiently promising to suggest that similar experiments be held in other countries. In fact, the International Commission on Acoustics may want to consider holding some activities jointly with international bodies representing several other professions relevant to technology and governance aspects of the environment.

Next I introduce a third level of comprehension, which I shall call basic literacy. This is a level that is achievable by all persons who have acquired a basic foundation of education. Basic literacy should be our first goal in promoting public understanding of environmental noise and its effects.

The most important public aspect of environmental acoustics is the public itself. The quality of the environment depends ultimately on public choices based on public understanding. The choices may show up through formal voting by individual persons or through informal action by community groups. In either case, the people's perception of the potential benefits and likely costs of a proposed action against noise will determine the effectiveness of the action.

The public learns about noise by reading about it, talking about it, and thinking about it. Let me mention some of the things that we in acoustics have given to the public to read about, talk about, and think about. To save time I shall mention only a small sample of the terminology we use and I shall name only the initials, the letters by which we usually refer to the terms. We have a list of L's: L_1, L_{10}, L_{50}, L_{90}, L_A, L_B, L_C, L_{eq}, L_{dn}, and so on. We have a list of N's: NC, NC-40, NEF, NIPTS, NITTS, NL, NNI, NPL, NR, and more. Of course we have an alphabetical list: AI, BC, CNR, dBA, EPNdB, f, GMF, Hz, ICA-8 ... All these terms and many more like them mean something to us in acoustics. But how much do they mean to the public? We may need to cope with these details and complications in order to solve our technical problems. But does the public need to cope with them in order to acquire a basic literacy in matters of noise?

If our profusion of technical concepts and scales and terms confuses even some of us who are specialists in this field, how much more the profusion of jargon confuses the public. As a result, the public concludes that the subject is too complicated to learn, and so they do not acquire even the basic literacy they need in order to exercise their judgements as citizens. I believe that the need for technical simplification is perhaps the public aspect in most urgent need of attention.

Of course some of the needed simplification has already been taking place during the past few years, in part through the urging of government agencies that have been given new responsibilities for environmental noise control. Especially relevant are the advances made toward simplifying the representations of the frequency spectrum and the time pattern of noise exposure.

The A-weighted form of sound level has emerged as the most widely applicable way to take the frequencies into account. This single measure, which we can read directly on a sound level meter, provides a reasonable approximation of human response to all three major categories of effects: hearing loss induced by noise, interference with speech communication, and psychological reactions of annoyance and complaint. Admittedly we do not understand scientifically why this single quantity should work as well as it does, especially because the A-weighting curve came originally from attempts to approximate the equal-loudness response of humans at a particular loudness level, 40 phons. We know that loudness differs, by definition, from hearing loss, speech interference, and annoyance.

As science and engineering specialists in noise, we must continue to study these differences and to seek ever more accurate correlations between physical attributes of noise exposure and the resulting psychological and physiological reactions of humans. We must continue to use several different scales and methods of analysis, including spectral analysis with the aid of band filters. But as professional persons concerned also with the public interest, we welcome the kind of simplification that the dBA sould level offers, especially in helping the public to acquire basic literacy concerning noise.

Representing the time pattern of noise exposure involves some questions that are not yet well resolved. Most of the exposure measures now in use include one or more separate terms describing the time pattern. However, several recent studies appear to be converging on the use of a single quantity to account for the time pattern as well as the spectrum. This single quantity is obtained by taking the energy average of the noise, instead of a decibel average, using the A-weighted sound level in the process, and then expressing the result in decibels. The result is called L_{eq}, the energy equivalent noise level. Averaging the energy, instead of the decibels, gives added weight to the strong peaks of noise, and thereby incorporates some information about the time variations in the noise pattern. Empirically this quantity, and a variation of it, the Day-Night sould level L_{dn}, that gives added emphasis to noises that occur at night, appears to correlate quite well with community responses over a wide range of exposure.

Yet still we should ask, in the public interest, whether the scales we use are as simple as they could be for serving basic literacy.

An example of a simple scale is the Mohs scale used to measure the hardness of rocks and gems. The hardness of gypsum, a material commonly used in acoustic tile, is 2 on the Mohs scale. The gem, topaz, represents a hardness of 8.

A familiar environmental scale is the Beaufort scale used for measuring the strength of wind. A beaufort force number of 2 means a "slight breeze" blowing at speeds of 4 to 6 knots. Beaufort number 5 means a "strong breeze" of 17 to 21 knots, and Beaufort 8 means a "fresh gale" at 34 to 40 knots. Sea-going people around the world find the Beaufort scale practical and easy to use.

Another environmental example is the Richter scale, which describes the magnitude of an earthquake. As many people who live in earthquake regions know, quakes of Richter magnitude 2 are commonplace and safe, whereas quakes of magnitude 8 or more are rare and catastrophic. The Richter magnitude is defined as the logarithm of the amplitude measured on a standard seismograph located at a standard distance from the epicenter of the earthquake.

The Richter scale measures the magnitude of the quake itself. A related scale of earthquake intensity measures the amount of shaking at any particular distance from the center of the quake. When the intensity is II, some people will feel the shaking; it is felt by everyone and it moves heavy furniture when the intensity is V; and the motion damages buildings severely when the intensity is VIII.

These simple scales for earthquakes bear some resemblance to our scales for noise. We determine the magnitude of a noise source by measuring the noise with a standard meter placed at a standard distance from the source. Again, we measure the intensity or level of the noise at any particular position relative to the source, and we use the resulting number in correlating the noise with its effects at that position. Also, of course, we use a logarithmic scale.

I have mentioned only a few of the simple scales that the public can use in developing and applying some basic literacy about everyday experiences. I could have mentioned many more such scales. People every day make good use of thermometers, as in ovens or outside the back door, without having to become specialists in the physics of thermodynamics.

Let me describe a scale that seemed to show up almost automatically on my note pad while I was preparing to talk with you today. It is called the Noise Potential scale. The numbers run from one to ten.

A Noise Potential of 2 means the kind of noise environment you experience in the wilderness, when the wind is hardly blowing at all. A Noise Potential of 5 is typical of a quiet suburban residential area near a large city. Down in the heart of the same city, where road traffic is heavy, the Noist Potential reading is 8.

My note pad also shows that a Noise Potential of 2 permits complete intelligibility of relaxed conversation between talkers located as far as 20 meters apart. Where the Noise Potential is 5, a survey will show that 10 to 20 percent of the residents are annoyed, even though the community as a whole shows little or no voluntary, adverse reation. People who work regularly in an environment where the Noise Potential is 8 show an increase of 10 to 15 percent in the incidence of a hearing handicap.

One thing that always interests people is how they are getting along compared with other people. What percent of the people have more, or less, of what they have in the way of money or education or vacation time — or noise. My note pad anticipated this question. In the USA, about one-third of the people live where the Noise Potential is less than 5, and another third live where the Noise Potential is more than 6. Again, if a person lives where noise from airports and major highways seems to predominate and cause most of his trouble with noise, then he shares that kind of residential environment with about 10% of the people in the USA.

This scale measures exactly what its name says it does. The numbers on the scale, which come directly from physical measurements on an acoustic environment, relate to the potential of the sound in that environment to be judged as noise because it is unwanted. Precisely how the scale numbers relate to the potential depends on the particular category of effect, such as annoyance, speech interference, or damage risk, and also depends on the particular circumstances involved in the use of the scale. In one use, we might want to know the potential for speech interference on Sunday mornings. Then we should determine, by suitable measurements, the average value of the Noise Potential on Sunday mornings. In judging the quality of a residential neighbourhood, we might want to know the Noise Potential averaged for an entire year. In each case we must specify the circumstances.

Now let me put my note pad aside and return to my theme. My purpose here is not to propose a new scale. My purpose is to discuss public aspects of environmental acoustics. My perception is that some of these public aspects are impeding the improvement and control of our acoustic environments.

In particular, public problems do not become well solved without knowledgeable participation by substantial numbers, if not a majority, of the people. But the people cannot participate effectively if they do not know something about the problems to be solved.

Why does the general public today know so little about the causes, effects, and controls of environmental noise? Mainly, I believe, because the public's attempts to participate are thwarted by the technical complexity and jargon. The complexity, in turn, results in a

MATRIX OF TASKS AND PARTICIPANTS IN
CONTROLLING ENVIRONMENTAL NOISE

TASKS / PARTICIPANTS	Defining the problem in operational terms	Developing the information needed for solutions	Delivering the information to the problem solvers
acoustics profession with Specialized Knowledge			
other professions with Interpretive Understanding			
general public with Basic Literacy			

NOTE: This particular matrix of three rows and three columns is a special case of a general abstraction, a pattern of relations among tasks and team members in any kind of problem-solving game. Other applications of the matrix may call for other numbers of rows and columns, depending on the endeavor involved and the amount of detail desired. The matrix will be useful to the extent that it elucidates the relations and serves to guide the planning and managing of the interrelated efforts required to solve the problems.